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Foreward

The World Bamboo Organization (WBO) is proud to present the VIII World Bamboo Congress following the VII WBC in New Delhi, India in 2004. After the cancellation of the proposed congress in Brazil in 2007, it has been a challenge for the WBO to organize this congress in Bangkok. The recent global financial meltdown is indeed an important wake-up call for the world economy. It is more than evident today that economic growth and sustainable development is not necessarily the same thing. During the last century and a half, the industrial revolution has witnessed unprecedented material development. However, such material development has come at a significant cost. Even as societies grapple with these challenges, the world today is confronted with another impending catastrophe: the phenomenon of global warming and climate change. As such, this edition of the World Bamboo Congress in Thailand has rightly chosen the theme of "*Bamboo, the Environment and Climate Change*."

It is a privilege for WBO to associate with the people of Thailand in hosting the VIII World Bamboo Congress; importantly also that the event coincides with the 113th Anniversary of Thailand's Royal Forest Department on September 18. This day will also be important to all the bamboo lovers as it also will be declared as "World Bamboo Day"!

Bamboo is so tightly interwoven in the life of the Asian people that it is hard to imagine Asian culture without bamboo. It has now gained acceptance globally in light that it is a versatile plant which holds many promises for the both rich and poor nations. The theme of the congress – "Bamboo, the Environment and Climate Change" is a theme of global relevance as climate change is a immense challenge which needs urgent response and action. It is very encouraging to know that the global community of bamboo experts and researchers are working on the most pressing issue of the time.

The vital issue here is: how can bamboo help us do things differently? Or what can we do with bamboo that will benefit the environment, our world, and ultimately, our lives? I am sure that this bamboo congress will offer many new perspectives to address this question. It is inspiring to know that the program of this congress includes a plethora of topics covering biology, engineering, architecture, industrial applications and development of community and economy.

As a Foreward to this bamboo congress, I would like to give my perspective on the issue of bamboo within the context of global environmental concerns without excluding the concern for achieving economic development and sustainability. Developing countries that are heavily reliant on agriculture are the most vulnerable to changes in climate. Global actions and responses to address climate change need to be made on the basis of the principles of equity, flexibility, effectiveness and common but differentiated responsibilities. Alternately, environmental policies – particularly strategies for tackling climate change - have to consider the relative

economic conditions of countries and respective capacities of their people. The priority we give to the environment must be balanced with the need of the country to achieve sustainable development.

Considering the alarming rate of deforestation in the world, it is clear that we are compromising the ability of future generations to meet their needs and thereby constrain their possibility to consume timber products. Trees are crucial for the global environment as they absorb carbon dioxide; they are important instruments to minimize global warming and related problems. It is for this reason that it has become important to find an alternative to wood. Here, bamboo has the advantage of growing fast and being a perfect material for a wide application of industrial products. By using fast growing alternative and renewable resources such as bamboo, we can reduce the pressure on tree forests, safeguarding the natural environment and the needs of future generations.

From a social perspective, bamboo is a great source for productive employment especially in rural areas facing unemployment problems. Bamboo can not only generate sustainable livelihood for the rural poor but will also give them a sense of identity and a meaning to their life.

Therefore the potential advantage of bamboo for environmental and economic development cannot be understated. However, to realize the potential of bamboo, interventions are needed, particularly in the field of forestry and land use, industry, technology and finance.

I am confident that this VIII World Bamboo Congress, attended by delegates and participants from more than 30 countries, will generate many new ideas that will stimulate economic development through bamboo for the sake of the environment and livelihood development.

I am also thankful to the sponsors of this Congress, particularly the National Bamboo Mission of India, the Government of Nagaland, India, Building Materials and Technology Promotion Council (BMTPC), The Japan Foundation, Japan Bamboo Society, Bamboo Society of Australia, ASEAN Secretariat, the Royal Forest Department of Thailand, Kasesart University Bangkok, UNIDO, FAO, TCEB, and Royal Thai Airways, for their support to this Congress.

Finally, I would like to thank Ms. Susanne Lucas, Organizing Chair Person of this Congress, Mr. Harsh Adhyapak, Event Co-Ordinator, Professor Dr. Walter Liese , Mr. M. Rajaretnam of ASEAN, and Mr. Smit Boonsermsuk of RFD Thailand and my colleagues at CBTC for their continued commitment and support in organizing this historic event in Bangkok, Thailand.

(KAMESH SALAM)

President, WBO

VOLUME 1

Inaugural Session

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Human Flying and Bamboo Fiber, from the Aviation Pioneer to Contemporary Design

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Paris, August 2009

Abstract

History tends to forget, but if man reached the sky, it was with the help of bamboo. From the legend of kite-flying people to the reality of man using kites to fly (Baden Powell, Cody, Hargrave).

Bamboo fiber is the material early adopted by the aviation pioneers: on the first airship (Renard and Krebs, Severo, Santos Dumont), on the first glider (Chanute, Lilienthal), on the trial of airplane (Ader, Ferber), on the first flying airplane (Whitehead, Santos Dumont), on the first airplane mass-produced (Santos-Dumont), on airplane panels (de Leon), on the first hand glider (Wills, Miller), and, on contemporary design (Abadie).

Introduction

« Or you make it strong and you are too heavy, or you make it light and you are too breakable. »
said Captain Ferdinand Ferber, one of aviation's pioneers. To resolve that crucial dilemma, on his way to build an airplane of the early days of the last century, he was using extensively bamboo. Light and strong, easy to manage with hand tools, the iron vegetable has been the favorite material for many reseachers and adventurers trying to explore a new environment in a way to see humans fly.

From the early lighter-than-air dirigible airships, to the first human gliding, then the first airplane flying, to modern design, bamboo fiber is the best material to be used through elaborate knowledge. Today, does bamboo have any chance to supplant the spruce, the expensive traditional light aviation material ? Indeed, there is an opportunity to explore the use of bamboo fiber as a contemporary material for light aircraft.

The 10 lessons from history.

1 - Bamboo kite legend, is this the first evidence of a human flying ?

- In China :

There is documentary evidence for the early emergence of the kite in China, historical analysts concede that China may get credit due to the fact that its history was well preserved in both written and artistic records.

Early kites in these Asian cultures (China, Indonesia, and the South Sea islands) relied on the use of natural materials: Bamboo or similarly strong reed-like branches for framing structure; thin strands of vine or braided fibers for flying/tethering line; leaves, braided reeds and similar fibrous sheets, or in the case of China - woven cloth and later paper, were commonly used for sail material.

The Chinese Daoist writer Ge Hong (284–364 AD) wrote that kite vehicles with frames made of wood from the jujube tree had ox-leather straps "fastened to returning blades" that could allow the device to soar high into the air. As a form of execution, the notoriously cruel Emperor Wenxuan of Northern Qi (r. 550–559) had members of the rival Yuan and Tuoba clans attached to kites and launched from the top of the Tower of the Golden Phoenix in the capital, Ye, China, as test pilots; Yuan Huangtou (d. 559) glided for a while and survived the landing, but he was executed shortly after.

In 549, king Wu Liang prisonner of general Heou-King sent messages by kite to his followers.

During Marco Polo's China travels of 1282, he reported seeing manned kites. Chinese shipping merchants would tie someone (usually a miscreant) to a huge frame (kite) held by eight strings and having launched the kite with the man into the wind, they would determine whether the voyage would be a prosperous one or not. Polo also explained how the men would pull on the rope attached to the eight strings to lift the kite higher. If the kite flew straight up, it was a good omen for the voyage; if the kite failed to rise, merchants were reportedly wary about loading cargo onto that ship.

- In Japan :

The beginning of kites in Japan date around the 9th century. According to a legend, the warrior Tame Tomo built an immense kite on which he lashed his son and allows him to escape from an island exile.

2 - Bamboo kite and the reality of human flying

- BADEN POWELL (1857-1941) Great Britain, one of the "fathers of manned flight".

June 27, 1894, an officer of Baden Powell flew till 30 meters high on a kite train call Levitor. The model has been officially presented to the London Arts Society in 1898 for the success of the renowned of Baden Powell.

- *Lawrence HARGRAVE (1850-1915) Great Britain, one of the "fathers of manned flight".*

Living in Australia, he developped the idea of the kite box and flew with a train of them on November 12, 1894. This was one of many stages in Hargraves' quest for a stable lifting device which could then be used as a means of aerial transportation. Hargraves is considered by many to be one of the significant "fathers of manned flight". As an aeronautic researcher, this man is the bridge between pioneers like Octave CHANUTE, Captain BADEN POWELL, Alexander GRAHAM BELL and the spiritual mentor of Alberto SANTOS DUMONT.

- *Samuel CODY (1867-1913) USA, the first man crossing the ?Channel pull by a bamboo kite.*

In 1898, Samuel CODY, the flamboyant Wild West showman, began to share his son's fascination with kites and the two of them competed to make the largest kites capable of flying at ever increasing heights. After a great deal of experimentation, financed by his popular show, Cody patented his first kite in 1901. Cody uses trains of kites and elaborate basket systems to develop reliable systems for lifting observers into the air. It was a winged variation of Lawrence Hargrave's double-cell box kite below.

3 - Bamboo dirigible airships structure during the 19th century.

- *Charles RENARD and Arthur KREBS, the first fully controlled free-flight with the La France (1884) France*

In 1884, Charles Renard and Arthur C. Krebs, inventors and military officers in the French Army Corps of Engineers, built an elongated balloon, *La France*, which was a vast improvement over earlier models. *La France* was the first airship that could return to its starting point in a light wind. It was 165 feet (50.3 meters) long, its maximum diameter was 27 feet (8.2 meters), and it had a capacity of 66,000 cubic feet (1,869 cubic meters). Like the Tissandiers' airship, an electric, battery-powered motor propelled *La France*, but this one produced 7.5 horsepower (5.6 kilowatts). This motor was later replaced with one that produced 8.5 horsepower (6.3 kilowatts). A long and slender car consisting of a silk-covered bamboo framework lined with canvas hung below the balloon. The car, which was 108 feet long (33 meters), 4.5 feet (1.4 meters) wide, and 6 feet (1.8 meters) deep, housed the lightweight batteries and the motor. The motor drove a four-bladed wooden tractor propeller that was 23 feet (7 meters) in diameter but which could be inclined upwards when landing to avoid damage to the blades. Renard also provided a rudder and elevator, ballonnets, a sliding weight to compensate for any shift in the center of gravity, and a heavy guide rope to assist in landing.

The first flight of *La France* took place on August 9, 1884. Renard and Krebs landed successfully at the parade ground where they had begun—a flight of only 5 miles (8 kilometers) and 23 minutes but one where they had been in control throughout. During 1884 and 1885, *La France* made seven flights. Although her batteries limited her flying range, she demonstrated that controlled flight was possible if the airship had a sufficiently powerful lightweight motor.

- *Augusto SEVERO and bamboo dirigible airships Bartholomeo de Gusmao and La Pax (Brazil)*

In Brazil, during the armed revolt of 1893 against the government of Floriano Peixoto; Augusto Severo, a member of the House of Representatives, proposed to contribute an airship -- “seeing indistinctly the possibility of the job of the balloon in the fight against the rebels”. On this pretense, Severo travelled to Paris in 1893 to

order the construction and to follow the manufacture of the airship *Bartholomeu de Gusmão*, by the well-known firm of Lachambre & Machuron, responsible for the construction of several of the Santos-Dumont balloons.

The *Bartholomeu de Gusmão* was 60 meters in length and the car measured 52 meters; the structure built of bamboo. Severo intended to make it of aluminum, but the material was not available in the Ministry of the War and Severo did not make use of resources for aquiring it.

On February 14th, 1894, the airship carried out its first ascension. However, during the stability tests of the device, the gondola broke, damaging the airship framework. At the same time, the Civil War followed its course. Floriano Peixoto bought, in Europe, a new squadron, composed of used warships, as a way to possibly stop the fighting quickly. In March of 1894, the squadron was ready to confront the rebel naval forces by bursting into the Bay of Guanabara. The rebels decided then to prevent a decisive battle and retreated to the open the sea. The imminent danger to Rio de Janeiro was removed and thus began the decline of the revolt. The movement ended, and the government was no longer interested in Severo's invention, therefore the *Bartholomeu de Gusmão* did not receive the repairs necessary and was abandoned. Later on, in France, he built airship La Pax with a full bamboo structure. Unfortunatly, the airship crashed in the middle of Paris during the first flight.

- *Alberto SANTOS DUMONT and bamboo dirigible airships*

Since his No. 1 model in 1898, Alberto SANTOS DUMONT built forty dirigible airships mostly in Paris where he was living. « However, it was his N°6 of 1901 that brought Santos-Dumont real fame. It had the shape of an elongated ellipsoid and was 100 feet long by 20 feet thick with cone shaped ends… Suspended from the envelope was the bamboo bridge. In it he won the 100.000 francs prize offered by M. Deutsch de la Meurthe, a wealthy memeber of Aeroclub, for a flight of about 11.3 km from Parc de St Cloud, around Eiffel tower and back. » (Hidalgo-Lopez)

Another peak of his lighter-than-air aviation career was the No. 9 dirigible, nicknamed “Baladeuse” which means as much as “the promenader”. Built to demonstrate the possibilities of urban travel, Santos-Dumont often used it to "drop in" on unsuspecting friends, powered by only a 3 h.p. motor and a gasbag capacity of a mere 220 cubic meters. It was the first real air-car that was built and with it, Santos-Dumont reached one of his main objectives, to build a small airship that can be used to travel around in town. He indeed used it as such and started the airship from the corner of his street and the Champs Elysees to fly to his favorite restaurant for lunch. And when he returned at his home in the afternoon, his butler would waiting with coffee !

4 - Bamboo between kite and airplane, the gliding…

- *Octave CHANUTE (1832-1910) USA,*

Aviation Pioneer. Born in Paris, France he moved as a child to the United States, where he became known as a pioneer in the transportation arena. He spent most of his life as an engineer in the railroad industry, but later gained international fame for his contributions to the study of aeronautics. He designed and oversaw the construction of many of the first railroads and railroad bridges in the United States as well as the union stockyards in both Chicago and Kansas City. He invented a system that preserved railroad ties and telephone poles by pressure treating them with creosote. In 1889 he retired from his engineering business and revived an

interest in the new study of aviation. He visited with and conferred with aviation pioneers around the world and in 1894 compiled and organized all the data he had collected and published "*Progress in Flying Machines*". This work became recognized as the first written collection on aviation research and became a guidebook for the world's many would-be aviators. Although too old to fly, he worked with many of the world's early aviators, helping invent the "Katydid" glider and the "Chanute- Herring Biplane". He was an active encourager of the work of Orville and Wilbur Wright. He shared advice with the brothers, and visited Kitty Hawk, North Carolina on several occasions during their flight experiments. Wilbur Wright presented the eulogy at the engineer's funeral. The town of Chanute, Kansas is named in his honor as well as the former "Chanute Air Force Base" in Rantoul, Illinois. The decommissioned base is now home to the "Octave Chanute Aerospace Museum" which shares the history of aviation to its many visitors..

- *Otto LILIENTHAL (1841-1896) Germany,*

A German mechanical engineer, Otto Lilienthal (b1848-d1896), began researching aerodynamic effects of wing shapes in the 1870's. In 1889, he published the *'Birdflight as the Basis for Aviation'* book that detailed aerodynamic formulas. The book was the most informative aviation book of the time. From 1891 to 1896, Lilienthal built five gliders that had a single wing (monoplane) and two gliders that had stacked wings (biplane). Lilenthal's wing design was shaped as a true symmetrical curve rather than the parabolic shape of the airfoils today. During his flying career, he managed to complete over 2000 flights. During Lilienthal's first flights, he suspended himself in the glider with only his arms. By 1895, he developed a harness that was used to hang from the glider. In retrospect, with the application of the harness, Lilienthal was the first hang glider pilot. Lilienthal managed to fly for distances of over 800 feet (250 meters) in gliders that were foot launched from man-made hilltops near his home in Gross-Lichterfelde, Germany. On August 8, 1896, Otto Lilienthal crashed his hang glider from an altitude of 50 feet (15.3 meters) after a wind gust ripped apart one of his wings. He died the next day in a Berlin hospital from a broken back. His last words were 'Sacrifices must be made'. Lilienthal's knowledge in aerodynamics would prove beneficial to the Wrights who would later read his book and use the concepts as a beginning point for building their gliders.

5 - Bamboo at the beginning of airplane adventure : trial and error...

- *Clément ADER (1841-1925) France,*

October 9, 1890, the Frenchman Clement Ader flew 50 meters at 20 cm with the Eole, a bat-looking airplane with use of bamboo in the wings. The *Eole* was described as a single engine (steam) tractor monoplane, with a four-bladed bamboo propeller made in the form of bird feathers. The wings were bat-like, with extreme canopied curvature. There was no elevator, no rudder, and no conventional flight controls. Each wing could be swung forward and aft separately by a hand-operated crank, thus changing the position of the center of pressure and consequently the pitch of the airplane. Wings could be flexed up and down by foot pedal; the wing area and chamber could also be changed by crank action. In all, six hand-operated cranks, two foot pedals, and engine controls had to be operated by the pilot in flight.

- *Captain Ferdinand FERBER (1862-1909) France,*

Ferber's experiments in gliding began in 1899 at the Military School at Fountainebleau, with a canvas glider of some 80 square feet of supporting surface, and weighing 65 lbs. Two years later he constructed a larger and more satisfactory machine, with which he made numerous excellent glides. Later, he constructed an apparatus which suspended a plane from a long arm which swung on a tower, in order that experiments might be carried out without risk to the experimenter, and it was not until 1905 that he attempted power-driven free flight. He took up the Voisin design of the biplane for his power-driven flights, and virtually devoted all his energies to the study of aeronautics. His book, « *Aviation, its Dawn and Development* », is a work of scientific value--unlike many of his contemporaries, Ferber brought to the study of the problems of flight a trained mind, and he was concerned equally with the theoretical problems of aeronautics and the practical aspects of the subject. Although he never built a successful plane by himself, he did aid somewhat in the design of the Antoinette. During 1909 he competed at Reims. He won several minor competitions but on 19 September 1909 lost his life in a crash at Boulogne.

Ferber in his airplane of bamboo.

6 - Bamboo use on the first airplane to have ever flown.

- *Gustave WHITEHEAD (1874-1927) USA,*

On August 14, 1901, almost two and one half years before the Wright Brothers flew at Kitty Hawk, Gustave Whitehead lifted his acetylene-powered monoplane into the air at Fairfield, Connecticut, for his first flight. The machine which took him into the air for the first time, his No. 21, included advanced features such as powered landing gear, folding wings and adjustable pitch propellers. He was also the first to land a plane on water !

Of the first flight of the aircraft N. 21, designed and constructed in 1901 in Connecticut by the Bavarian Gustav Weisskops (subsequently Whitehead), only testimonies of dead persons remain, but no photographic documentation in flight. Perhaps this, with other complex and also incredible reasons, can only partially justify

the total absence of this pioneer of aviation from the history of flight. A few years ago, a full-scale replica was flown with success, thus demonstrating that Weisskop's perceptions and his design choices made sense indeed !

Allegedly chased out of Pittsburgh by the police on account of his "dangerous" experiments, Whitehead found employment in Bridgeport, Connecticut in 1900 as a mechanic. His new home had space for a small workshop, and the neighbors (and local law enforcement) must have had more understanding for his inventors' ways. Scientific American, reported in June, 1901, of Whitehead's motorized flying machine. *« While standing on the ground, the two front wheels are connected to the kerosene motor and the rear wheels are used for steering... On either side are large wings or aeroplanes shaped like the wings of a flying fish or bat. The ribs are of steel tubing in No. 22 instead of bamboo as in No. 21 machine and are covered with 450 square feet of the best silk obtainable. In front of the wings and across the body is a steel framework to which is connected the propellers for driving the machine through the air ».*

Two months later, with this motorized "hang glider" - Number 21 - Whitehead completed a flying distance of about 2.5 km at about 10-15 meters altitude. In so doing, he had proof it was possible to start a flight without artificial aids from land and with two motor driven propellers, and to land without damage. Whitehead had recognized that a successful takeoff requires a definite minimum speed; other aviation pioneers were still using catapults for takeoffs.

In spite of the Whitehead's flight, all the pilots of the world and even the last of the schoolboys know that the Wright Brothers were the first to fly a motorized aeroplane and, for this reason, they are considered the very pioneers in the history of aviation.

- *Whitehead / Wright brothers and Smithsonian controversy*

It has been long believed that the Smithsonian refuses to recognize Whitehead due to a deal made with the estate of the Wright Brothers in 1948. This agreement stipulated the Smithsonian would only retain the right to display the famed aircraft "The Flyer" <u>if it did not display any other work belonging to predecessors of the Wrights.</u>

The agreement reads in part: "Neither the Smithsonian Institution or its successors, nor any museum or other agency, bureau or facilities administered for the United States of America by the Smithsonian Institution or its successors shall publish or permit to be displayed a statement or label in connection with or in respect of any aircraft model or design of earlier date than the Wright Airplane of 1903, claiming in effect that such aircraft was capable of carrying a man under its own power in controlled flight."

Some theories even go so far as to say that the Smithsonian has knowingly lost or destroyed the only known photograph of Whitehead in flight. Although there have been attempts to meet with the Smithsonian over this issue in the intervening decades, it has never been resolved to the satisfaction of Whitehead's living supporters who believe his "foreign-born" status contributed to his lack of recognition in his time.

- *Alberto SANTOS DUMONT and XIV bis model with a bamboo body structure.*

After some other less successful projects, like a helicopter, that the engines of that time just couldn't bring into the air, Alberto Santos Dumont then built a strange looking plane that was nicknamed "Canard" or in English "duck". After several tests on Sept 13, 1906, he made <u>the FIRST ever official flight with an heavier-than-air</u>

flying machine, that could lift the ground by its own means, as the Wright brothers flight never had official witnesses and also the plane back then was launched by a catapult.

7 - The bamboo Demoiselle, first airplane mass-produced

- Alberto SANTOS DUMONT and The Demoiselle, Nov. 16, 1907 in Bagatelle.

Once Santos-Dumont had flown a heavier than air machine in Europe, airplanes spread over Europe very fast and a lot of pilots built their own aircrafts. Also Santos-Dumont improved his airplanes and in the end came up with his No. 19 project, called “Demoiselle” (dragonfly or young lady). It was the first prototype of a small and very light monoplane and the birth of the first ever sports-plane. Santos-Dumont never held patents for his inventions ; he saw them as a gift for humanity. In his Nos. 20, 21 and 22, Alberto Santos-Dumont perfected his Demoiselle, and as he offerd the plans free to anyone who was interested the Demoiselle was very often reproduced all over Europe and also in the United States. Some aviation heros, like for example Roland Garros, learned how to fly in a Santos-Dumont Demoiselle.

The No 19. was a small monoplane, 8m long and with a 5m wingspan. The wings were of Japanese silk, covering a bamboo frame. In the rear there were two diamond-shaped frames, that formed the rudder, controlled by piano strings. He added a 20 HP engine with two cylinders, placed between the wings, above the pilot. The plane itself only weighed 56 kilos. It was an extremly light and elegant construction.

The author, Michel Abadie, with the <Demoiselle>

8 – The first airplane with a bamboo panel fuselage

On 1951, the Institute of Science and Technology (Philippines) conducted research about the use of traditional material for aircraft. The study conducted by Antonio J. de Leon with the help of the Philippines Air Force started in 1952. It was about using bamboo-woven mat glued to wood or laminated to another bamboo mat for use as stressskin covering for light aircraft. The result was positive. Its fatigue strength under bending stress was found to be much higher than that of wood, and the bond strength of bamboo to bamboo was comparable to that between bamboo and wood.

The L-14 Maya was a Filipino three-seater experimental general-utility aircraft developed during the 1950's to test the suitability of locally produced materials, such as locally grown woods, or bamboo panels for use in aircraft construction. The XL-14 Maya was a high-wing strut-braced monoplane of locally grown wood construction powered by a Lycoming O-235-2 four-cylinder horizontally-opposed air-cooled engine providing a top speed of 184 kmh and a range of 480 km.

9 - The revolution of hand gliding

On 1948, aeronautical engineer Francis Rogallo invented a self-inflating wing which he patented on March 20, 1951 as the *Flexible Wing*, also known as the *flexwing* and Rogallo wing. Francis Rogallo had first proposed his flexible wing concept to the Langley Research Center in the late 1940s as a simple, inexpensive approach to recreational flying, but the idea was not accepted as a project.

The simplicity of the Rogallo wing, ease of construction, capability of slow flight and its gentle landing characteristics did not go unnoticed by some hang-glider and ultralight glider enthusiasts. The publicity on the Fleep and the Paresev tests sparked interest in independent builders like Barry Palmer and John Dickenson, who separately explored distinct airframes and control systems to be adapted to a Rogallo wing and be flown as a hang glider.

On August 1961, American engineer Barry Palmer developed and flew the first foot-launched Rogallo wing hang glider.

On May 23, 1971, the hang gliding officially became a sport.

Taras Kiceniuk, a Cal Tech student, flew a version of Richard Miller's Bamboo Butterfly, called The Batso. Taras Kiceniuk later wrote, "The Bamboo Butterfly demonstrated [that day] that this design was capable of excellent control in the hands of a skilled pilot-and very limited in aerodynamic performance. The gliders ... showed the opposite face of the coin-acceptable aerodynamic performance and practically no control!"

10 – Open the way for a contemporary design bamboo experimental plane and airship

- *Michel ABADIE and Flyboo (1998) France.*

Ninety years after The Demoiselle, the project FLYBOO (for FLYing bamBOO) is an ultra light aircraft, entirely made of bamboo, proposed by The World of Bamboo, a Paris (France) based organization which promotes bamboo as a renewable resource and material for the future.

In May 1996, The World of Bamboo/Paris received the Henry Ford European Awards for Nature Protection with an bamboo airplane project. By autumn 1996, a small team was working on the project with design projections and display. An innovative shape of four but-jointed wings displayed in diamond shape was decided for structure resistance and aerodynamic advantage.

After research on history, design, and feasability conducted with a school of aeronautics (Estaca / Paris) and an aerodynamic research in the wind tunnel of National Superior School of Aeronautic (SUPAERO Toulouse - France), one of the oldest "Grande Ecole" in aeronautics and space, the shape of the future aircraft was decided.

In May 1997, during the Paris Bourget Airshow, a scale model was presented to the visitors. Five remote control scale models were tested before the decision to go ahead early 1998.

FLYBOO 01 - In June 1998, the real building of FLYBOO 01 began. With a wingspan of 7.70 meters and 5.50 m length, the plane weighed 260 kilos with four wings joined together in a special losange display. The body of the aircraft was built with two bamboo poles (15 kilos each) supported by two laminated rings of 2.20 meters wide (23 kilos each). Covered with bamboo mats specialy woven for the purpose in China, the wings of 4.62 meters length (23 kilos each) were made with a traditional structure in spruce. The 64 horsepower engine and the propeller were located inside the back ring. The pilot and the passenger were positioned under the protection of the first ring.

In September 1998, not yet finished, the prototype was presented for the first time in the main public Paris subway station prior to be on display on the Champs Elysées avenue during the Centenary festival of the French Aero Club. Thousands of enthusiastic visitors (Parisians and foreigners) arrived to discover and support the idea. But the plane was too heavy, not fully made of bamboo and, because of the rings, not easily transportable.

FLYBOO 02 - In October 1998, the decision was made to build a new prototype to be presented at the International Bamboo Conference in Costa-Rica. This was done by a team of seven people working very hard, six days and nights, with the challenge to be ready in time. And, it was done !

In November, the new prototype Flyboo 02 was exhibited in San Jose, Costa Rica.

Fully made of bamboo, with the wings covered by Dacron textile, it was 160 kilos ligther and easier to carry. Unfortunately, during the transportation to the conference hall, a wing was badly damaged making the display incomplete.

FLYBOO 03 – In July 1999, the construction began of the third model of Flyboo with the challenge to be lighter than the SANTOS DUMONT's Demoiselle (70 kilos). Using small bamboo strips (1 cm x 0.5 cm), the new prototype was done with a different body, a kind of laminated ladder. Smaller, with a span of 5.30 meters, Flyboo 03 is lighter than ever = only 30 kilos without the engine (25 kilos or less depending of the type of engine). In August 1999, after one month of work, the Flyboo 03 went out from the hanger to be presented during the European Bamboo Congress in the Netherlands.

The very original shape of the wings - covered by transparent Mylar – highlight the harmony between the bamboo material and the design of the airplane. The use of these natural and resilient materials make the manufacturing quite inexpensive except the time investment to build it. Flyboo 03 is easy to take apart. Very light, the whole plane can board a commercial aircraft on two bags.

Unfortunatly, the builders ran out of money to finance an electrical engine to complete the model.

The main idea of building Flyboo was to conduct a campaign to promote the contemporary use of bamboo in an innovative way. A new way to enhance the idea of bamboo as a strong, light and renewable material for the future. At the end, it was also an acknowledgement of bamboo, as a plant who facilitated the flying of humanity, the ultimate in symbol and potential.

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Bamboo and Climate Change: The Imperative

David E. Sands
President/Chief Architect, BAMBOO LIVING Homes, Resorts and Communities

What if there were a building material which by choosing to use in their buildings people everywhere were actively addressing climate change? There is such a material. It is bamboo.

Bamboo, as perhaps the fastest growing plant on the planet, has a very important role to play in restoring balance to the Earth's climate system.

Currently, the 30 billion tons of carbon dioxide equivalent produced each year by human activity are wreaking havoc on the global environment. Efforts to curb our CO2 emission are essential but much more needs to be done. And soon!

Global efforts are underway to reduce our planetary carbon emissions below 1990 levels. That still leaves a lot of CO2 being put into the atmosphere each year by human activities. Bamboo offers perhaps the quickest way to remove vast amounts of that carbon dioxide from the atmosphere. Build buildings with that bamboo and you have sequestered the carbon for a hundred years. At the same time, you are creating jobs and opportunities for farmers and builders throughout the world. Bamboo buildings are a carbon capture and storage system.

Bamboo plantations will soon become possibly the greatest natural carbon sink. Each acre of bamboo sequesters up to 40 tons of CO2. The bamboo plant eats carbon dioxide. It takes CO2 from the atmosphere and through the process of photosynthesis turns it into sugars. The bamboo plant transforms these sugars into the compounds that make up bamboo fiber. The carbon from the atmosphere is thus locked up in the bamboo fiber itself. When that bamboo fiber is used to construct buildings the carbon in it is sequestered for the 100 year lifetime of the building. A bamboo building has taken out of the atmosphere over 15 tons of carbon dioxide for every 100 square meters of floor area.

Bamboo is only effective for longterm carbon sequestration if the bamboo plant is being regularly harvested and that harvest turned into durable goods or biochar. Left unharvested the sequestration rate of the bamboo plant levels off. By harvesting 20% of the biomass of the plant each year as 3+ year old mature bamboo culms, the high rates of carbon sequestration are maintain for the 50-75 year life of the bamboo plant. Unlike most trees you are not killing the bamboo plant when you harvest. Each year the mat of primitive roots called rhizomes is expanding, sequestering additional carbon for the life of the bamboo plant. Also unlike trees the bamboo plant produces microscopic plant stones that encapsulated carbon in silica and sequester an additional half ton per acre of carbon for possibly thousands of years.

Biochar is an agricultural amendment made by heating organic material in a low oxygen environment. The heat needed to form the char is derived from burning the gases released in the charring process. In the case of bamboo, all of the bamboo not used for construction material or other durable goods can be turned into biochar. The biochar is ground up and added to soil to improve its productivity without releasing the carbon in the char. In tropical climates biochar dramatically improves soil fertility. Biochar is considered by climate scientists, James Hansen and James Lovelock, as the fastest method of sequestering carbon in the vast quantities needed to offset humanity's production of carbon dioxide. Fast growing bamboo, the quickest source of biomass, is an obvious candidate for making biochar. Bamboo, because of the perennial rhizome mat it forms, also regenerates watersheds and protects against the loss of topsoil. Many species are drought tolerant and can create a barrier against desertification while providing a fuel and food crop with the material not being used for making durables or biochar. However, the most valuable use of the bamboo is in making building material. We can help build the market for bamboo by specifying bamboo for projects and by developing new and creative ways to use bamboo as a building material. As an architect I have pioneered the use of bamboo for construction in the U.S. My company obtained the first ICC Evaluation Services report for structural bamboo in 2004. We are currently working on ICC certification for a bamboo composite for use in construction as a structural material.

The growth rate of bamboo is up to 20x the production rate of trees commonly used for lumber and nearly 3x that of the very fastest growing trees. The result is that a tremendous amount of building material is produce by each acre of bamboo. Unlike trees bamboo produces an annual crop providing regular income for the farmers growing it. As mentioned unlike most trees the bamboo plant is not killed when it is harvested. It is more like mowing a lawn than cutting down a forest. The living rhizome mat of the bamboo plant continues to protect against erosion.

There are well over a thousand species of bamboo. Bamboo has a PR problem to deal with as a result. There are invasive species of bamboo that are problematic. However there are many species which are excellent for construction that are not invasive. The durability of the bamboo varies dramatically between species and there have been problems with some of the bamboo flooring made from nondurable species or immature bamboo. All bamboo is not the same! It takes a bit of research to find out which products perform but for the sake of the planet I encourage that effort.

How much bamboo will need to be planted? To absorb the entire 30 billion ton green house gas (GHG) output of humankind *without emission reductions* would require an area roughly 5x the size of the state of Texas planted in bamboo. That is a lot of land but it is not beyond the range of possibility and we will make GHG emission reductions in the coming years significantly reducing the amount of land required. To absorb the entire carbon dioxide output of the United States (again without emission reductions) would require an area planted in bamboo about the size of Texas. Distributed over the possible bamboo growing areas this is again within the range of possibility. The United States government has spent $1.8 billion a year on the Conservation Reserve Program holding 35 million acres of farm land out of production. That land converted to bamboo production would offset 20% of the entire carbon dioxide output of the USA. Of course, not all of that land is appropriate for growing bamboo, but it does give an idea of the potential for using bamboo as an offset.

By our efforts we shape the world we live in. Our decisions ripple out into the world affecting everyone around us. Many of these impacts extend out in time for many years. I am heartened by the fact we are actively addressing the climate issue by reducing the energy needs of our buildings. This is very important work. In addition, what if going beyond mitigating the negative impacts of our buildings on the environment, our buildings could now have a restorative power simply by their existence. Each building could be an embodiment of the balance we seek.

Imagine the end of global warming. Imagine the earth in balance. It is a personal decision limited only by our imagination.

The Bamboo Compendium

Bernt Carstenschulz
architectural design

Motivations to write the 竹 compendium :

Information about bamboo are scattered in diverse places such as books, electronic documents and websites making it more difficult than necessary to access them. Similarly to periods when information has been buried in books, it is now buried in websites or electronic documents, a clumsy and time consuming way to get hold of them.

The revolution of information technology has shaken in the last 20 years the way society, businesses and science are working and the digitalization of information has the capacity to reveal crusts of errors, to fix them and enable a faster and easier access to what really matters.

Being not an expert, I noticed with bewilderment when compiling this encyclopedia, that botanical names and their synonyms have become a system almost as complex as Chinese bamboo names within their 5000 years of history and diverse geography.

In addition, poorly and adventurous transcripts from Japanese bamboo names might have been acceptable during the 19th century, but are certainly not present-day. This is a quite awesome situation, but unfortunately, not a positive one and is in dire need to be addressed.

The 竹 compendium wishes to address formerly mentioned problems by being a central repository with a powerful and quick search-engine in which information is poured and classified. This dictionary uses the advantages of information technology to democratize the access of information by making it available to everybody interested and concerned by this subject.

Similarly to other collaborative projects, the 竹 compendium wishes to leverage the knowledge of the international bamboo community to become the first resource about all information bamboo.

Everybody is invited to review the initial work and subsequent revisions to address possible errors and to further refine the 竹 compendium by adding their knowledge for the profit of all.

Thus, the 竹 compendium will not only be an initial free download (however, donations are very welcome), but all subsequent updates will be accessible free of charge. These updates will reflect the pace information is flowing in.

At this present date these classifications of idioms have been implemented and can be accessed within the blink of an eye :

[Known limitations : The framework of Apple's Dictionary does at present only allow to search words in Latin, Chinese, Japanese and Korean]

botanical names and their synonyms

local names in Latin script

language search

script search

local names in Thai script and transcription

local names in Japanese kana and kanji and transcription

local names in Korean hangul and transcription

local names in Chinese in traditional, simplified ideograms and pinyin

These further classifications are expected to be partially implemented before initial release:

geographic locations

genera

rhizome types

morphology descriptions

Further additions could be high quality imagery, physical attributes (ex. for building purposes), and other suggestions will be examined attentively.

Admittedly, the most exciting way to have the 竹 compendium with you would be on the Apple iPhone, as its implemented capacities such as GPS, capable camera, Chinese ideogram drawing, powerful search capabilities and great display among others, in a small lightweight portable device would allow to even further extend the compendium in usefulness.

Already, a 竹 compendium mobile for the Apple iPhone is in the planning phase, but as the programming of this kind of application is beyond this authors scope, it can not be distributed for free. An adequate amount will be charged to cover the costs of development.

At present, the 竹 compendium is only available as plug-in for the Mac OS X 10.5 Leopard dictionary.

About the author:

Bernt Carstenschulz' enthusiasm for bamboo started when visiting the ZERI pavilion at the World Expo 2000, Germany, which deeply impacted him.

Since then, he participated in bamboo construction workshops with Jörg Stamm in Belgium and Colombia, and refined his knowledge of techniques with 門田祐一 (yuichi monden) in Japan.

After experimenting with Thai bamboo, Bernt is actually working on his first construction project, the Crimson Moon Pavilion, and in parallel on the 竹 compendium, which will be presented and released during the 8th World Bamboo Congress in Bangkok.

In Honor of Bamboo Pioneers

Susanne Lucas
CEO, World Bamboo Organization

Living creatures all around the world depend on bamboo for their survival. This includes *Homo sapiens*. We all know that for centuries, human cultures have cultivated and utilized bamboo for their daily needs and through innovation improved their livelihoods and economies.

On the village level, farmers and craftsmen developed techniques which were passed down from generation to generation. In more modern times, man has looked to science for solutions and progress. Through committed research, we have discovered new approaches of how bamboo as a managed resource can lead to the betterment of mankind.

Dedication, determination and collaboration are required to advance any scientific endeavor. There exists individuals whose lifelong commitment to bamboo science deserve our attention and honored recognition. Today, as part of the inauguration of the 8th World Bamboo Congress, we honor 4 of these great Bamboo Pioneers:

Ueda Koichiro

Krit Samapuddhi

Floyd Alonzo McClure

Walter Liese

Ueda Koichuiro 1899 - 1991 (Japan)

Koichiro Ueda was a well-known Japanese scholar recognized throughout the world as one of the leading authorities on bamboo. One of his most esteemed awards was the Order of the Sacred Treasure from the Emperor of Japan. He was professor at Kyoto Industrial College and president of the Japan Bamboo Industries Association.

Of his many published works, these two books are outstanding:

Studies on the Physiology of Bamboo, Kyoto University Press, 1960.
Bamboo, by Robert Austin and Koichiro Ueda, photos by Dana Levy, Weatherhill Inc, 1970.

A highlight in his bamboo life was a special bamboo conference at the XVII International Union of Forest Research Organizations Congress in Kyoto (1981), with 33 reports and the Inauguration of his designed Rakusai Bamboo Park, a living monument garden using bamboo as a replacement for the deforestation around Kyoto due to industrialization.

Photo of Professor Ueda taken by Walter Liese, 1979.

Krit Samapuddhi 1911 – 1991 (Thailand)

Krit Samapuddhi was the former deputy director general of Thailand's Royal Forest Department, and former managing director of Thailand's Forest Industry Organization. He was instrumental in developing the forest village system.

The forest village system, developed by Thailand's Forest Industry Organization, offers hill tribesmen and others who practice slash and-burn agriculture considerable inducements to settle down. One of its principal aims was to keep a steady labor force on hand for the long-term needs of forestry, while at the same time providing rural families with an income and other benefits from the kind of farming they choose to practice.

He published many books, including: *The Forests of Thailand and Forestry Programs* (1957), *A preliminary study in the structure and some properties of some Thai bamboos* (1959), *Forestry Development in Thailand* (1966), and *Grouping of Thai Hardwoods* (1972).

Krit Samapuddhi. Royal Forest Department, Thailand, archives.

Floyd Alonzo McClure - 1897-1970 (U.S.A.)

Floyd Alonzo McClure was one of the world's leading authorities on the bamboo plant. Born in Shelby County, Ohio, McClure went to China as a teacher in 1919 after completing his undergraduate work at Ohio State University. He stayed in China for 24 years, working most of the time as professor of economic botany at Lingnan University in Canton. When the Japanese invaded China, McClure returned to the United States and became a consultant on bamboo for the United States Department of Agriculture. In the 1940s, he was appointed honorary research associate for the National Museum of Natural History, a position he held until his death in 1970.

Floyd McClure was instrumental in the introduction of Tonkin bamboo to the world. During his tenure as an instructor and professor at Lingnan University in Guangdong, China from 1919-1941, he assigned the scientific name of *Arundinaria amabilis*. Upon a visit to China in 1925, McClure was the first to scientifically describe the plant and recognized that it was a distinct and previously unreported species. At the time, this bamboo had already been in use for building fly rods and was known by a variety of different common names. The name was amended to *Arundinaria amabilis* McClure in the doctor's honor and translated, means 'The Lovely Bamboo.'

He is best known in the United States for his book, *Bamboos: A Fresh Perspective*, by Harvard University in 1966. McClure was a contributor to the USDA Agriculture Handbook on bamboos in 1961. *The Bamboos* is the classic treatise on bamboo in U.S. literature, with sections on the vegetative phase, the reproductive phase, elite bamboo species, and propagation methods, as well as interesting historical notes, photos, and illustrations.

Frederick G. Meyer, a colleague of McClure's at the USDA, wrote this tribute : " The many friends of Floyd Alonzo McClure were saddened by his death of April 15, 1970, short a few months of his seventy-third birthday. Those who knew him personally lost a true friend, and the world lost a teacher and pre-eminent authority on bamboos, the tree grasses. A former Chinese student likened McClure's life to the villager, who, after gazing for years at the Great Stone Face on the mountain, became himself the person with wisdom, strength, honesty and solidarity like that of the mountain, the person the whole village had been searching for. Bamboo was McClure's Great Stone Face, and teacher of truth in the green plant world. ……..In fact, he died in his garden, digging a bamboo plant for a young friend. "

Walter Liese – 1926- (Germany)

If ever Germany was to have an ambassador at large for forestry, and for bamboo in particular, Prof.Walter Liese would eminently qualify for the post. His international assignments have carried him far and wide - from the lowlands of Bangladesh to the high mountains of Chile; from the humid forests of Indonesia and Vietnam to the arid zones of Nigeria and Tanzania; from the near shores of Portugal to the far shores of the Philippines. In his career as a wood biologist and forestry expert, which spans nearly five decades, Prof. Liese has stretched his faculties to their limits to become an institution in himself.

Walter Liese was born in Berlin on 31 January 1926, when the Weimar Republic was eight years old and appeared stable and prosperous. His childhood and adolescent years were spent in Eberswalde, a small town

south of Berlin where his father was Professor of Forest Botany. By the time he was seven years old, the Weimar Republic had collapsed and Adolf Hitler was in control of Germany. Like all other able-bodied German youth, Walter Liese was also drafted into war service at the age of 18.

At the end of the military service, Walter Liese pursued his studies. He chose forestry as his main subject, probably influenced by his childhood images of lush forests near Eberswalde. He studied forestry from 1946 to 1950, first in Freiburg in the Black Forest and then in Hann.Münden at the Forest Faculty, University of Göttingen. In 1951 he graduated and began his career with a one-year study on root physiology at the Forest Research Institute in Düsseldorf.

The year 1951 added another dimension in the history of botanical studies in Germany. Although palms and bamboos were botanically known through their earlier descriptions by Linné, all palms were classified as bamboos. Their structural characteristics came to be examined only much later, through the efforts of scientists like Hugo von Mohl (1845), Schwendener (1874), de Bary (1877), Strasburger (1891), Haberlandt (1924), and Solereder and Meyer (1928). Then, for some inexplicable reason, the anatomies of bamboos and palms were much neglected. It was only in 1951 that interest in these areas was revived in earnest. As destiny would have it, the seeds for this revival were sown through a chance meeting under favorable circumstances.

In April 1951, Walter Liese had started working as a research scientist at the Forest Research Institute in Lintorf, near Düsseldorf. Dr Franz Erich Eidmann, then Head of the Institute, kindled Liese’s interest in bamboo. The discussion centered on the suitability of culms as pit props in coal mines. Liese, motivated by Dr Eidmann’s enthusiasm, carried out a series of experiments on the properties of bamboo for its use in mines.

Liese also had contacts with Prof. Bodo von Borries of the Institute of Higher Microscopy in Düsseldorf, who was part of the team that developed the electron microscope. The apparatus was still a novelty then and awaiting newer applications. Liese made good use of the transmission electron microscope to study the structure of bamboo, the "new" material, and produced in 1951 the first electron micrographs on the fine structural details of the cell walls of bamboo fibers. This was followed in 1953, while working at the Institute of Forest Botany, University of Freiburg, by another series on structures in the cell walls in bamboo. These achievements brought both the researcher and the research subject into the limelight.

Liese’s six-year sojourn (1953-59) at the University of Freiburg, where he had once been a student of forestry, launched his outstanding career as a wood biologist and bamboo scientist. The study of anatomical structure using advanced microscopy and other techniques, which began there as a curiosity that developed out of a chance opportunity, became a life-time passion.

The latter half of the 1950s marked the beginning of Walter Liese’s presence in the international arena. Before joining the University of Freiburg, he had spent one year working in the wood preservation industry in Mannheim. This experience in wood preservation came of use in 1957, when Liese was contracted by the United Nations Food and Agriculture Organization (FAO) to India to study and propose an impregnation method to preserve bamboo from deterioration, and in 1958 to work on wood preservation in Indonesia. In 1958, barely eight years after his graduation, Liese was already a visiting scientist to the Commonwealth Scientific and Industrial Research Organization (CSIRO) in Melbourne, Australia. In 1962, while working at the Institute

of Forest Botany, University of Munich, he was serving as a visiting scientist at the prestigious Harvard University in the United States. Later, when his fame as a top-order forestry expert spread, many other universities - Berkeley University of the United States, Canterbury University of New Zealand, Nanjing Forestry University of China, Universidad Austral of Chile and National University of Taiwan-China — followed suit.

Although his primary vocation as a wood biologist and forest botanist prompted Liese to move to Hamburg in 1963, taking up the position of Professor of Wood Science at Hamburg University, bamboo remained a source of fascination for him. His enthusiasm on the subject attracted several young scientists, and some of them became his research partners. During the Freiburg years, Prof. Liese carried out seminal work on the histometry of the cell elements in various bamboos, with special emphasis on tissue composition. The Munich years also saw several studies being carried out on bamboo, not only on anatomy but also on the permeation properties of bamboo culms.

Prof. Liese's research on bamboo anatomy peaked during the Hamburg years (1963-91) though he still continues to work as Professor emeritus. The first stimulus came from his association with Dr Dietger Grosser, who had the aptitude and patience to search for even the most minute details in anatomical studies. Together they presented an impressive array of histological studies on bamboo — the characterization of the four basic vascular bundle structures, and their relation to taxonomical classification; variability of fibre lengths in bamboos; distribution of vascular bundles and the cell types in bamboo culms etc. Prof. Liese's joint work with Prof. Narayan Parameswaran added a competitive depth to bamboo research. Their initial research covered the fine structure of cell walls, especially of fibres and parenchyma cells. This was followed by studies on the occurrence of warty structures in certain bamboo species, fine structure of protoxylem elements, and ultrastructural aspects of bamboo cells, culms etc. Much of this research remains to date the most important contribution to the subject. In between and after these fruitful joint research associations, Prof. Liese has made several forays on his own and published research papers of excellence.

Although enamored by the lure of bamboo, Prof. Walter Liese never allowed that to affect his other academic interests — wood biology, wood pathology and wood protection. He has delivered lectures in over 50 countries on these subjects, and has carried out research on a number of related areas such as: wood and bark anatomies; fine structure of wood; wood quality; wound reactions in trees and monocotyledons; micromorphology of wood degradation; physiology and enzymology of wood fungi; and promotion of wood utilization in developing countries. A prolific writer, Prof. Liese has to his credit well over 400 scientific papers (70 of which are on bamboo and 20 on palms, mainly co-authored by Gudrun Weiner). He has also guided 70 diploma students and 35 doctoral students.

Apart from teaching at the Hamburg University, Prof. Liese also served as the Director of the Institute for Wood Biology and Wood Protection, and from time to time as the Executive Director of the Federal Research Centre for Forestry and Forest Products. During the Hamburg years, and after his official retirement in 1991, he lent his expertise to several international and national entities, including: the FAO Advisory Committee on Forestry Education (1966-90); the International Union of Forest Research Organizations (IUFRO — as President during 1977-1981 and in various other capacities from 1968 to 1995); the FAO/IUFRO Committee on Bibliography and Terminology (1964-73); the International Academy of Wood Science (as Fellow in 1966 and as Vice

President during 1969-72); EUROSILVA, the European Research Cooperation on Tree Physiology (as Chairman of the Joint Steering Committee during 1988-93 and as Vice Chairman in 1994); Deutsche Gesellschaft für Holzforschung (as Chairman for Wood Protection during 1972-76); the Research Advisory Board of the Forest Research Institute, Malaysia (1989-90); etc.

Prof. Liese was instrumental in getting the International Development Research Centre (IDRC) of Canada interested in bamboo, and played an important part in the creation of the International Network for Bamboo and Rattan (INBAR). He is often referred to as the "grandfather of INBAR".

During his IUFRO presidency Prof. Liese strongly advocated and spearheaded the involvement of developing countries in the organization, and helped focus IUFRO's activities more on issues of tropical forestry. He was instrumental in initiating the call for action on tropical forestry, which later developed into the IUFRO Special Programme for Developing Countries. It was also during his presidency that IUFRO turned truly international.

International recognition of Prof. Liese's expertise in his chosen fields was never found wanting. He was accorded honorary memberships of the Philippine Forest Research Society, Finland Society of Forestry, International Association of Wood Anatomists, Indian Academy of Wood Science, Society of American Foresters, l'Académie d'Agriculture of France, IUFRO, Chinese Bamboo Association, Academia Italiana di Science Forestate, German Society for Wood Research, Polish Academy of Science and the European Bamboo Society, amongst others. In appreciation of his academic brilliance, Prof. Liese was awarded five honorary doctorates, including ones from the University of Sopron, Hungary; University of Zvolen, Czech Republic; University of Istanbul, Turkey; University of Poznan and University of Ljubljana, Slovenia. He also received numerous medals of merit for his achievements in forestry.

Prof. Liese is very highly regarded in Asian countries, especially China and India, not only for his research contributions but also for helping Asian scientists.

Although he retired from official engagements in 1991, Prof. Liese continues to contribute to the world of forestry with his profound knowledge and extensive experience.

Since then, 10 years have passed with about 60 additional bamboo papers and a book " *Bamboo Preservation Compendium*" with S. Kumar as INBAR/CIBART Techn. Rep. 22, 231 pp., many bamboo lectures and bamboo consultancies in Ethiopia, Costa Rica, Colombia, China, Thailand, Northeast India, among other activities

The World Bamboo Organization is extremely fortunate to have Prof. Liese as a member of its Honorary Council. When he heard of the proposed 8th World Bamboo Congress in Thailand, he heartily sent emails of support and offered to help. He worked as Chairman of the WBC Paper Review Panel, and will be present to make an oral presentation entitled, *Bamboo as CO2-Sink—Fact or Fiction ?*, as well as Chair the Session entitled: In Partnership for a Better World. We all can say <thank you> with genuine sentiment to a man whose work has led to a better understanding of bamboo. Fortunately, Walter Liese is here with us today; alive and well and a true bamboo pioneer.

Walter Liese with *Guadua*

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VOLUME 2

Bamboo for Thailand and Southeast Asia

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Tracing the History, Scanning the Technology and Initiatives on Bamboo Production and Conservation in the Philippines

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Supervising Scientist, Ecosystem Research and Development Bureau

Abstract

Enhancement of bamboo production and conservation aimed at supplying enough quantity of high quality materials for the bamboo-based industries had been and still is being given so much attention so that the country becomes globally competitive as far as bamboo products are concerned. One of the approaches done is through research, development and extension not only on bamboo production and conservation but also utilization. This particular paper attempts to trace the history of research, development and extension and to scan the technology and initiatives on bamboo production and conservation in the Philippines. Specifically, the initiatives of different sectors/stakeholders on bamboo production and conservation are presented and discussed.

The country's research, development and extension initiatives on bamboo production have a very long history. Based on records, it is more than a century already. The country, however, continuously develops, packages and transfers bamboo production technologies including nursery propagation and plantation development and management. A number of government and non-government agencies/institutions including individuals and groups were and still are involved in either nationally or internationally funded research, development and extension on bamboo production.

Voluminous materials are available not only as reference for further scientific work but also for information, education and communication programs designed to promote bamboo production and conservation ot only as important commodity for livelihood development but also for biological conservation, environmental services and landscape aesthetics. A Master Plan for Sustainable Bamboo Development crafted a decade ago awaits review, rehash and repackaging for possible funding of its implementation. Renewed interests and initiatives on bamboo are due to its roles in providing livelihood options and at the same time increasing the capacity of the communities to adapt to climate change. Other recent research, development and extension initiatives and relevant recommendations for the sustainable development of the bamboo industry through scientific bamboo production approaches are enumerated.

Keywords: sustainable development, bamboo production, stakeholders

Introduction

Relevance of bamboo to human living especially in the social, cultural, economic and environmental aspects of life cannot be over-emphasized. Many agricultural or farming activities, fishery, construction, tourism, landscaping and gardening, handicraft and furniture and food industries utilize bamboo materials. The bamboo's traditional sobriquet as poor man's timber has diminished through time because of the many commercial uses that considerably compete with the traditional ones. Such condition remarkably increased the market demand for bamboo while supply was not improving due to the limited establishment of plantation. This made the price of bamboo unaffordable to local people.

During the past, supply of bamboo was very much dependent on the natural bamboo stands either in the forests or those scattered in the villages. To systematically and scientifically improve the supply of quality bamboos to support the growing bamboo-based and bamboo using industries, the need for research, development and extension on bamboo production was felt by both the government and private sectors.

It is the intention of this paper to trace the history and scan the technology on bamboo in the country by looking at research, development and extension initiatives of various stakeholders on bamboo production through the years. For almost a century, works on bamboo production have involved quite a number of research, development and extension agencies/institutions including private individuals and institutions and non-government organizations.

Research, Development And Extension Initiatives

Among the leading institutions in research, development and extension on bamboo include some state universities and colleges notably, the University of the Philippines Los Banos (UPLB); the research arms of the Department of Environment and Natural Resources (DENR) namely, the Ecosystems Research and Development Bureau (ERDB) based in Los Banos and Ecosystem Research and Development Services (ERDS) in various regions of the Philippines; the Forest Products and Research Development Institute (FPRDI) of the Department of Science and Technology (DOST) and the research arms of the Department of Agriculture (DA) such as the Bureau of Agricultural Research (BAR) and the Bureau of Plant Industry (BPI).

Some state universities and colleges like the Mariano Marcos State University (MMSU), Don Mariano Marcos State University (DMMSU), Isabela State University (ISU), Nueva Viscaya State University (NVSU), Benguet State University (BSU), Bulacan State University (BuSU), Visayas State University (VSU), Central Mindanao University (CMU), Bataan Peninsula State University (BPSU), Tarlac College of Agriculture (TCA), Pampanga Agricultural College (PAC) and others have their own research, development and extension programs on bamboo production and conservation. Some of them have collaborative works with other government and private institutions in the country and international agencies.

Funding for the many research, development and extension activities on bamboo production in the country came from national funding institutions like the Philippine Council for Agriculture and Natural Resources Research and Development (PCARRD) of the Department of Science and Technology (DOST), the National Research

Council of the Philippines (NRCP), Department of Agriculture (DA), Development Bank of the Philippines (DBP), Technology and Livelihood Resource Center (TLRC), Department of Technology and Industry (DTI), Local Government Units (LGU), congressional allocations or from Community Development Fund of politicians via their own personal prerogative. Most lucrative source of funding is from international institutions like the European Commission (EC), United Nations Development Fund- Food and Agricultural Organization (UNDP-FAO), Japan International Cooperating Agency (JICA), Japan Society for the Promotion of Science (JSPS), International Tropical Timber Trade Organization (ITTO), Asian Development Bank (ADB), International Network for Bamboo and Rattan (INBAR), World Bank (WB), World Agroforestry Center (WAC), South East Asia Regional Center for Agriculture (SEARCA) and many others.

Recently, the trend in research development and extension is regional in scope or it is collaborative work with a network of several countries in Asia or ASEAN or Asia Pacific Region and sometimes includes countries in Europe or United States of America (USA) to be able to get the necessary international funding support.

Research, Development and Extension Activities

On taxonomy and bambusetum establishment

The first report on Philippine bamboos was Bulletin 1 written by Brown and Fisher in 1918 that was published by the Bureau of Printing. Subsequently, this formed part as a one of the Chapters of the Brown and Fisher's book on Minor Forest Products of the Philippines published in 1920.

Earliest initiative related to bamboo production was the study done by the College of Forestry-UPLB and Forest Products Research Institute (FPRDI) on taxonomy. This dealt with variations in morphological characters (Quimbo, 1957) and review of the various erect bamboo species (Lindayen et. al., 1969) of the Philippines. Study on the growth and characteristics of *Schizostachyum lumampao* was done in the Makiling Forest in 1961 (Zamuco, 1961 as cited by Bumarlong, 1980). In 1971, a bibliography on minor forest products came out. This included, among others, some studies done on the propagation and utilization of Philippine bamboos.

In 1986, a book "Guide to Philippine Flora and Fauna" published by the Natural Resources Management Center (NRMC), Ministry of Natural Resources (MNR) now known as Department of Environment and Natural Resources (DENR) and the University of the Philippines includes chapters on bamboos and grasses (Vera Santos, 1986). In 1995, a book on Bamboos- Plant Resources of South-East Asia (PROSEA) was published in which Philippine Bamboo Species are included. All these provided information on the important bamboo species that have potential for commercial utilization and as basis for natural and artificial regeneration.

The establishment of bambusetum was first reported by Tamolang in 1954 presumably initiated by the Forest Products Research and Development Institute (FPRDI). The College of Agriculture and the Institute of Plan Breeding of UPLB have their own living collection of bamboo. Accordingly, through the ERDB-DENR-UNDP/FAO project, bambuseta (living collection of different native and exotic bamboo species) were established in the country in 1987. These were in Mt Makiling, Los Banos, Laguna, Loakan, Baguio City and in Nabunturan, Compostela Province. Private individuals mostly bamboo enthusiasts also established their own

collection. Example of which is Carolina Farm in Antipolo Rizal. ERDS-DENR specifically in Butuan City, Caraga region also started the establishment of bambusetum. Recently, importation of various species of semi-temperate and temperate species of bamboos from China was made. These bamboo species are being acclimatized and being used for scientific investigation at Benguet State Uninversity (BSU) in La Trinindad, Benguet. This importation presumably passed the plant quarantine policies and regulations of the country.

On bamboo inventory

Forest inventory conducted in 1988 by the RP-German Forest Resources Inventory Project included rattan and bamboo. The natural bamboo stands included in the inventory were mostly *Schizostachyum lumampao*, *Schizostachyum lima* for the erect types and also *Schizostachyum spp.* for the climbing types, being the naturally growing bamboo species in the forests. This was the first and the last inventory of bamboo stands in the forests when the Philippines still have vast forest areas. Provincial-wide inventory of erect bamboo stands mostly in the villages of some selected provinces in the country was undertaken in 1981 to 1984 (Virtucio et.al., 1983). Relevant to bamboo inventory was the study conducted on the mensurational attributes of five bamboo species in different parts of the country (Tandug, 1979). Based on FAO publication entitled, "Bamboo Resources of the World" (FAO, 2005), the Philippines has 127,000 hectares. This, accordingly, increased to 156,000 has in 2000 and 172,000 has in 2005. Figure 1 shows the bamboo production areas including the plantations established by government institutions and private individuals, groups and organizations.

On propagation and field performance

1. Sexual propagation (<u>use of seeds</u>)- ERDB (formerly Forest Research Institute) started bamboo propagation research as early as 1976 when the clumps of *Schizostachyum lumampao* in UPLB campus produced flowers and bore fruits. The fruits which are the seeds themselves were collected and used for germination and seedling culture including fertilizer application study (Lapis, 1976).

2. Macro-vegetative materials: Direct Planting of Cuttings-

a. Traditional method of bamboo propagation include the use of culms cut into 3 to 4 nodes or even longer and planted directly in the field with hole immediately below the node for watering. Use of rhizomes or division was also commonly practiced.

b. The earliest recorded studies on the propagation of Philippine bamboos dealt mainly on using culm cuttings that were directly planted in the field: For example, Curran and Foxworthy in 1912 studied directly planted cuttings of *Bambusa blumeana*, *B. vulgaris* and *Gigantochloa levis* but found to have very dismal survival percentage of 34%, 32% and 6%, respectively. Another study done by Foxworthy in 1917 in a 2 hectare plot directly planted with stump cuttings and culm cuttings had survival percentage of 59% and 40%, respectively. Mabayag in 1937 studied the propagation of *B. blumeana* culm cuttings and found that cuttings from basal portion of culms performed well under sunlight than under shade. Subsequently, Cabanday in 1957 and Agleam in 1960 studied the propagation of bamboos by various forms of cuttings and layerage. The former found 60% survival of unsplit *B. blumeana* culm cuttings while the latter found better results using unsplit culm cuttings of bolo taken from the middle and top portions of the culm.

c. In a study conducted by Baja-Lapis, Bumarlong, Tandug and Moldes in 1980 on direct planting of culm cuttings, it was reported that out of a total of 720 two-node unsplit culm cuttings taken from about 1 to 2 year old culms of *B. blumeana*, *B. vulgaris* and *Dendrocalamus merrilianus* directly planted in cogonal area had a survival rates of only 25%, 51%, and 35%,respectively, after six months. Subsequent to the above study was a project in Ilocos Norte and Bukidnon on the survival and growth of *G. levis* and *D. merrilianus* as affected by site preparation and fertilizer application, the results of which were reported by Baja-Lapis et. al., in 1984.

3. Nursery propagation using culm cuttings

a. Instead of direct planting of cuttings, nursery propagation of culm cuttings was undertaken to be able to supply quality planting stocks to plantation developers so that higher survival in the field can be assured.

b. Through trial and error method, the Caasi family in Mindanao was able to develop vegetative propagation of *Bambusa philippinensis*. At first, the Caasi's tried the rhizomes or division but found to be laborious and costly since only few propagules can be extracted from a clump. Subsequently, the Caasi's tried culm cuttings and found that is more efficient and effective if culm cuttings from 15 to 24 month old culms are used. This species and its propagation were popularized by the Caasi's in Mindanao since such bamboo species is the main propping material for banana.

c. The desire to further improve the propagation technology, graduate students in UPLB used bamboos for propagation studies in the late 1970's and early 1980's: Propagation of culm cuttings in the nursery was conducted by Bumarlong (1977); Propagation using branch cuttings was done by Palijon (1983) and Soriano (1984).

d. Use of rooting hormones in bamboo propagation: Uchimura in 1977 used rooting hormones and found that soaking of cuttings of *B. vulgaris* to 100 ppm Indole butyric acid (IBA) solution for 24 hours before planting had better rooting rates and had longer roots than stocks soaked in same concentration of alpha-naphthalene acetic acid (ANAA) and IBA; Bumarlong also in 1977studied IBA, Indole acetic acid (IAA) and ANAA in rooting cuttings of *B. blumeana* and found that 600 ppm ANAA gave the highest total dry weight and mean length of roots while the 200 ppm ANAA gave the highest mean number of roots; Palijon in 1983 found 100 ppm IBA and 100 ppm IAA were much better treatments in enhancing rooting in the nursery and survival in the field of *B. blumeana* branch cuttings. Palijon's study included the field performance of branch cuttings, the results of which was published in Philippine Agricultural Scientist, an International Journal. .

e. Use of branch marcot (marcotting) culm cuttings was introduced by an Engineer, Mr Domingo Alfonso in the early 1980's. This propagation method was one of the highlights in his Kawayan (Bamboo) Farm in Pillilla, Rizal.

f. Pre-rhizomed, pre-rooted branch cuttings were also tried. Results show great potential for use in commercial propagation of selected species of bamboos (Palijon, undated).

g. The use of mist (Palijon, 1983; Mindanao Baptist Rural Life Center in Mindanao- MBRLC, 1980's) and non-mist system or sometimes referred to as "incubation method" (Caasi, 1988; MBRLC; Philippine Rural

Reconstruction Movement-PRRM)\ in Cavite and DENR-ERDB and DENR-ERDS) in propagating culm cuttings and branch cuttings was tried, popularized and commercialized.

h. Airponic Technology in propagation- Maravilla in Iloilo City introduced the use of "airponic" that requires a million peso oxygen-rich greenhouse in the propagation not only of bamboo branch cuttings but also high value horticultural crops. This technology shows how it can effectively enhance rooting of cuttings and accelerate the growth in a very short period of time. The root zone of the cuttings is suspended in a growing chamber and intermittently pulse-misted with a nutrient solution.

i. Micro-propagation: *Tissue culture and mini-clump division*- genetically superior bamboo planting stocks, accordingly, can be mass produced throughout the year using this method (Zamora, 1994). This bio-technology was tried in the Philippines using excised embryo of S. lumampao, G*igantochloa levis* and *S. lima*. Field performance of tissue cultured planting materials done in Bataan, Zambales and Laguna were successful (Zamora and Gruezo, 1999). A sequel to this study was the use of tissue cultured materials for further multiplication into planting stocks with similar genetic quality through mini-clump division. This method involves separation of 3 to 4 month old plantlets from tissue-cultured materials into individual stems or small clumps of 2 to 3 stems. The separations can be done further at 2 to 3 month intervals.

On plantation establishment and management

1. It was in the 1915 that the first initiative on bamboo planting was done at the College of Agriculture was recorded (Villamil, 1915). In 1965, bamboo plantation development was initiated in Mindanao (Chinte, 1965).

2. From 1981 to December 1983, a project on the production and utilization of bamboos at barangay level, in Pangasinan and Quezon was implemented (Virtucio et.al., 1983). Simultaneously, a project on the development of pilot scale plantation of selected bamboo species in Rizal and Quezon provinces for cottage industries was similarly undertaken from 1981 to 1987 (Lapis, et.al., 1987). A follow through to the above project was the bamboo expansion program within the 'Lungsod Silangan" communities which was implemented from 1988 to 1989 (Virtucio et. al., 1989).

3. In 1985, the basic site requirements for some of the commercially important bamboo species and the locations in the country where the particular species may be suitable where provided by Lantican, Palijon and Saludo (1985). Such information can still be useful when plantation establishment is to be carried out. This was published in the proceedings of the International Bamboo Workshop held in Hangzhou, People's Republic of China (PROC).

5. On pests and diseases: In one of PCARRD's (1984) technical bulletin as cited by Lantican et. al., (1985), some of the pests that were observed on bamboos include termites, cottony cushion mealy bug, bamboo scale oriental migratory locust, leaf roller, tussock moth and mites. Diseases, on the other hand, include physiological and fungal diseases. It was however, mentioned that none of these pests and diseases have been reported as serious problems in nurseries, plantations and natural stands.

4. Intermediate silvicultural treatment: In 1984, Robilllos disclosed his findings on removal of spiny thickets in and around the lower portion of clumps of *B. blumeana* and decongestion of the clumps by removing high stumps from previous harvesting and cutting of deformed and overmature culms. He found that such treatment resulted to higher production and better quality of culms.

5. Study on the determination of optimum cutting and cutting age of some erect bamboo species in the different parts of the country was undertaken and the information generated was accordingly packaged and being used for dissemination. As outlined in the Master Plan for Development of Bamboo as a Renewable and Sustainable Resource (1997), the harvesting systems based on the various studies conducted in the Philippines include selective cutting and clear cutting or blanket method. The first one is conducted by cutting only selected culms or poles of the desired age while the other one requires cutting of all poles/culms, regardless of age and are totally cut leaving only the very young culms and shoots.

5. Recently, a POPEYE technology was developed by Malab (Personal Communication) which requires sustaining a 4:4:4:4 clump which is composed of 4-one-year old, 4- two year old, 4- three year old and 4- four year old culms in a clump to have continuous production.

6. On production of deformed bamboos for the furniture industry- The need to supply the furniture industry with the desired forms and shapes of bamboo materials that can make the products unique, a study on the response of erect bamboo species to artificial deformation was done in the Philippines (Pinol et.al., 1978). Encouraging results were achieved but adoption and commercialization did not pick up.

Bamboo plantation development and conservation initiative by Local Government Unit (LGU)

1. Foremost to this is the "Kawayan: Yaman Laguna" (translated in English as "Bamboo: Wealth of Laguna" project by no other than the Laguna Provincial Governor Joey Lina. The intention was to promote planting of bamboo for livelihood, conservation and environmental rehabilitation. Thousands and thousands of planting stocks of different species, with *B. philippinensis* as the most dominant, were raised and distributed to the different barangays and municipalities of Laguna and even in other provinces. The project was implemented with a consultant from Davao del Norte despite the fact that ERDB and UPLB are just stone throw away from the Office of the Provincial Governor in Sta Cruz. What exactly happens to this project, nobody knows. From personal communication with beneficiaries of the project, the species distributed to communities, which is *B. philippinensis*, was not very much acceptable.

Private initiatives on bamboo plantation development and conservation

1. One of the early users of culm cuttings for commercial production of planting materials was Engineer Domingo Alfonso. His 20 hectare farm in Pililla, Rizal mostly comprised of *B. blumeana* was established using culm cuttings. This farm used to be the source of culm cuttings utilized for propagating thousands and thousands of planting materials that were supplied to various clients coming from different parts of the country.

2. Another early plantation development initiative was in Mindanao where hundreds of bamboo planters/producers known as the Davao Bamboo Development Cooperative were organized by the Caasi to

systematize the supply of bamboo poles as banana props to banana plantations (Caasi, 1988). At first, the bamboo farms were established in La Union, Tagum, in Maco, Mabini, and in New Bataan covering a hundred hectares of idle cogonal lands, along river banks, hillsides, mountain sides and marshy areas. Then this enterprise grew and the plantation expanded several folds to meet the demands of the banana plantations. Mr. Caasi became popularly known as "Bamboo King" because of his success in promoting bamboo plantation as source of livelihood and for environmental improvement and sustainability.

List of the initiatives by other private individuals, groups and organizations on bamboo plantation development is shown in Table 1 (Virtucio and Rivera, 1995; Pastor, 1995; Alfonso, 1995; and, Caasi, 1994 as cited in Master Plan for the Development of Bamboo as a Renewable and Sustainable Resource, 1997).

From Table 1, the total bamboo plantation reported for the three major islands in the Philippines was 7,054 hectares. It will be noted that the bamboo species used in plantation for Luzon and Visayas is dominantly *B. blumeana* while *B. philippinensis* in Mindanao. If you take the percentage of the bamboo plantation established in these different islands, those in Luzon constitute only about 15 % (1,043 out of 7,054 hectares) while those in Visayas only less than 5% (312 out of 7,054 hectares) the rest, about 80% (5,699 out of 7,054 hectares) are in Mindanao. The species is dominantly *B. phlilippinensis* which is primarily intended for prop production for the banana industry. There was that *on and off use* of bamboo as props in recent years. The question is, are these plantations of *B. philippinensis* in Mindanao still exist?

Department of Environment and Natural Resources' (DENR's) programs on bamboo plantation development

1. Bamboo being considered as reforestation species not only for socio-economic but also environmental benefits of the society, development of plantation of this crop in public lands was encouraged. Moreover, the DENR's program on application and demonstration of bamboo production technology via pilot bamboo plantation in strategic areas in the country has contributed to the promotion of bamboo plantation establishment.

2. Effectiveness of bamboo demonstration plantation as a technology transfer scheme was tested from 1987 to 1990 in Region 5 where the Minor Forest Product Center of Ecosystem Research and Development Bureau (ERDB) (known that time as Forest Research Institute or FORI) was located. This project was assisted by the ERDB-USAID, and PCARRD. Table 2 shows the plantations that have been established under the DENR's programs: regular planting program; contract reforestation program through the Forestry Sector Loan Program and research and pilot plantations (Malvas, 1995; National Forest Development Office (NFDO) DENR Report (1997); Region IV and Community Environment and Natural Resources Office's (CENRO's) updated reports as cited in Master Plan for the Development of Bamboo as a Renewable and Sustainable Resource, 1997). It can be noted that the area established by the government is only small compared to the size established by the private sectors. Moreover, the type of bamboo species in this government initiative on bamboo plantation establishment was not specified in the report. It is also important to determine whether these plantations still exist or whether they are producing and supplying the industry.

There is a need to determine whether there are some more plantations of bamboo that were established by both the government and the private sectors aside from the above initiatives.

Research, Development And Extension Initiatives Of Ecosystem Research Development Service (Erds) In The Various Regions Of The Country

The Ecosystem Research and Development Services (ERDS) of DENR in the regions likewise conduct studies that have some bearing on bamboo production. Table 3 shows the list of these RDE initiatives in the regions. These initiatives were mostly application and demonstration of production technologies and conservation activities.

Research Development And Extension Initiatives Of Various Institutions With International Funding Support

1. The National Bamboo Research and Development Project (NBRDP)- The efforts and initiatives on bamboo production were characteristically scattered and less comprehensive. The DENR through its research arm, the ERDB, felt the need to implement a more comprehensive national bamboo research and development project. Thus, in 1987 such project was launched with the funding support from UNDP-FAO. This project generated research outputs on the various aspects related to bamboo production from taxonomy, physiology, phenology, pest and diseases, propagation, harvesting and management including economics and marketing. Table 4 shows the list of the studies conducted under this NBRD project.

2. The European Commission Bamboo Project – Entitled "Sustainable management and quality improvement of bamboos," this project which was implemented from 1997 to 2001. It aimed to increase the knowledge on the sustainable supply, use and quality improvement of selected bamboo species in Southeast Asia. Specifically, it aimed to develop improved management and sustained use for bamboos in the region; determine the influence of management practices on basic culm properties; to optimize the processing and performance of higher technology bamboo products based on "improved" raw material; and, disseminate the information to user groups. The implementation of the project involved 3 countries in Southeast Asia (Philippines, Indonesia and Malaysia) and 3 countries in Europe (Germany, Belgium and United Kingdom). The Philippines was tasked to conduct study of the silviculture and management of 2 bamboo species, namely *Gigantochloa levis* and *Dendrocalamus asper*. The 2 hectare plantation was established at the UP Quezon Land Grant. The results of this study were published in Bamboo and Rattan International Journal published by INBAR in 2005.

3. Australian Council for International Research (ACIAR) Project (FST/2000/127) entitled "Improving and maintaining productivity of bamboo for quality timber and shoots in Australia and the Philippines" was implemented in Southeast Asia. Professor David Midmore has served as the Project Leader and Australians and Filipinos from different agencies and institutions were serving as investigators. It has the following objectives: First, to study and implement a process to rehabilitate existing aged/and or damaged bamboo stands for shoot and timber production; secondly, the project aims to develop management technologies for sustainable and high productivity of existing bamboo plantations for shoots and timber; and, third is to improve the efficiency and quality of the bamboo timber harvest.

As expected, project will contribute to the knowledge network in Australia and Southeast Asia and so, it will build on and foster the work of INBAR and other bamboo groups. Accordingly, project has been structured

around a series of empirical experiments involving the management of bamboo spread around Australia and the Philippines. It includes formal and informal meetings designed to foster and promote associations between bamboo people and to formulate commercial arrangements.

Present National Project On Bamboo

The "Bamboo Industry Development Program: Mainstreaming Engineered-Bamboo

Products in the Philippine Raw Materials Market for Construction and Furniture," is the newly approved bamboo program being implemented by a number of collaborating institutions. The Program Leader is Dr. Ramon Razal of UPLB. It has 5 project components. The development and management of pilot bamboo plantations in selected areas in Laguna is one of the major components.

Packaged Bamboo Scientific Information And Technology

1. The Philippine Recommends for Bamboo Production published by PCARRD and the DENR National Program Coordinating Office was probably the first of a package of information on bamboo production and harvesting in the country. This was the product of the various researches conducted by the scientist and practitioners from ERDB, CFNR-UPLB, IPB-UPLB, Tarlac College of Agriculture (TCA), Kawayan Farms and PCARDD. This is being revised to include production and utilization of commercial bamboo species but also ornamental bamboos. The updated version will come out soon.

2. Agroforestry Technology Information Kit published by International Rural Reconstruction Movement (IRRM) in Cavite in which bamboo production is one of the main technology components.

3. Sustainable Livelihood Options for the Philippines: An Information Kit (Upland Ecosystem) –published by DENR where giant bamboo for propagule production, deformed bamboo production and bamboo utilization are included as alternative livelihood for the uplands.

4. Training Manual on Agroforestry published by KAPWA in collaboration with the Institute of Agroforestry, CFNR-UPLB. This manual serves as reference materials for trainors as well as for actual practitioners or users of technology.

5. Training documents on various courses namely: Reforestation, Nursery Establishment and Management, Community Enterprises, Social Forestry/Community Development and others include bamboo propagation, bamboo planting stock culture and bamboo plantation establishment and management. Compiled documents are available in CFNR-UPLB and these are used as materials for international as well as national training.

6. RISE or Research Information Series on Ecosystems (Reforestation Species) has specific volumes featuring bamboo species, their description, habitat, uses, propagation and cultural management procedures.

7. Techno-transfer series of DENR-ERDS: example is the Techno-Series,Bulletin No.1 published in 1988 entitled “Growing bamboo for livelihood and environmental protection” written in local visayan dialect side by side with English version. This features the Caasi Bamboo Technology.

8. Bamboo Farming in different language and dialects (English, Pilipino, Visaya and others) published by the DENR-ERDB/FAO-UNDP Bamboo Research and Development Project in 1995.

9. Philippine Erect Bamboos: A Field Identification Guide written by Rojo, Roxas, Pitargue,Jr. and Brinas and was published by the FPRDI-DOST which include both the native and exotic bamboo species. As a guide it provides key to the identification of each species.

10. Bamboo Production in the Philippines written by Virtucio and Roxas (2003) - the book provides a wealth of information on the bamboo industry, the bamboos and their habit, propagation methods, plantation establishment, maintenance and protection, shoot production, culm production and bambusetum development.

11. Bamboo, people, the environment: Propagation and Management, INBAR Technical Report. Volume 1 published by INBAR and Government of Netherlands.

Training On Bamboo Production

There are quite a lot of trainings related to bamboo production and utilization that have been conducted in the country. These trainings are mainly or secondarily offered by the following training providers:

1. Technology Resource and Livelihood Resource Center (TLRC) provides training on livelihood. Modules on bamboo production and utilization are included.

2. International Rural Reconstruction Movement (IRRM) and Philippine Rural Reconstruction Movement (PRRM)

3. South East Asia Research Center for Agriculture in the 1980’s where I was tapped as resource person and am proud to say that many of the State Colleges and Universities that participated in bamboo training have adopted, even modified and improved the technology.

4. Institute of Agroforestry of the College of Forestry and Natural Resources and the Institute of Plant Breeding, both of UPLB.

5. Non-Government Organization (NGO)/Foundation (like Philippine Business for Social Progress- PBSP)); religious, civic and related organization (like Mindanao Baptist Rural Life Center- MBRLC in Mindanao)

6. The Ecosystem Research and Development Bureau (ERDB) and Ecosystem Research and Development Services (ERDS) both of the Department of Environment and Natural Resources (DENR)

7. State Colleges and Universities (SCUs) specifically offering agriculture and forestry

Promotion Of Bamboo Production, Conservationand Utilization Through *National Bamboo Conferences*

Since 1996, three or four national bamboo conferences were held in the Philippines. The first was in Sarabia Manor, Hotel in Iloilo City in 1996, the second in Pangasinan State University in Lingayen and the third was in Provincial Capitol, Pili, Camarines, Sur. These served as venues for disseminating scientific information, technologies and products and for getting the support of as many stakeholders as possible.

It was during the first conference held in Bicol that a master plan for the sustainable development of bamboo industry was deemed very necessary. Thus, the second National Bamboo Conference held in Northern Philippines was used as venue to solicit comments and suggestions from the participants. Unfortunately, every after the conference nothing has changed, nothing has improved. There can be some problems somewhere.

Master Plan For The Development Of Bamboo As A Renewable And Sustainable Resource

The master plan crafted in 1997 should have propelled the development of the bamboo industry in the Philippines. However, such plan was only consigned in the dusty shelf and became habitat for subterranean organisms. This is due to lack of political support that could have provided sustained financial allocations for its implementation. Or, there was no concerted effort to push for the implementation of the Master Plan.

Political Actions And Initiatives

Numerous draft bills on national bamboo program have been filed in both houses by so many congressmen and senators already. I have been asked several times to comment on the draft bills. As a good soldier, I always abide. Unfortunately, none has moved even an inch in both houses. I am about to reach my twilight years and my only hope is to see Sustainable National Bamboo and Rattan Program or for that matter National NTFP Program being finally approved and implemented for poverty reduction, socio-economic prosperity, livelihood and environmental protection and conservation.

Renewed Interest On Sustainable Development Of Bamboo Industry

The National Bamboo Development Forum- should serve as a venue for more collaborative, unified, comprehensive, holistic approach to sustainable bamboo industry in the Philippines.

There are existing local and national bamboo organizations in the country. The Bamboo Foundation which, accordingly, was conceived as scientific organization and later became political in nature was the one responsible for holding the previous national conferences on bamboo.

Through this Foundation and through the involvement of the former President of this Foundation as Member of the Board of Trustees of the International Bamboo and Rattan (INBAR), some important/prominent political figures and presidential appointees were able to visit China and be exposed to the wonders of bamboo. A very

good well-prepared power point presentation has become available and being used to promote bamboo development in the country.

Through the Bamboo Foundation, Laguna Lake Development Authority (LLDA) and the Rotary Club, a renewed action on bamboo is initiated by again tapping the scientific community: the academe, the research and extension organizations. So many meetings were held and the idea of having bamboo summit surfaced until finally the holding of this National Bamboo Development Forum became the center piece of this renewed interest on sustainable development of bamboo.

A number of bamboo councils with members from academe, research organizations, Local Government Units, civic and religious organizations, accordingly, have already been formed in some regions/provinces in the country. A program on trainors' training on bamboo has accordingly been organized through the initiative of LLDA and Bamboo Foundation. This will train forestry and agriculture graduate to act as trainor in the various parts of the country. The Training Center of CFNR-UPLB is commissioned for this training. I hope this will push through and I sincerely hope it will not remain as a dream.

Creation Of New Bamboo Organization

While renewed interest on bamboo is gaining momentum, a new bamboo organization known as BAMBOOPHIL, was formed. This may be different from the existing Bamboo Foundation.

The need of the time is a UNIFICATION OF ALL THE ORGANIZATIONS/ STAKEHOLDERS so that sustainable bamboo development in the country can progressively move forward.

Conclusion And Recommendations

A lot of research, development and extension initiatives have been done to promote the bamboo industry in the country. There seems to be something lacking to propel bamboo development in the country. Comprehensive and holistic analysis of the problems must be carried out. Some say it is due to lack of political support and political will, financial support and other forms of incentives, discouraging/unfriendly government policies, laws and regulations. Others say, there is no sustainable development plan for the bamboo industry. The following recommendations should therefore be given attention if sustainability of the bamboo industry in the country is to be pursued:

On Development and Conservation:

1. Allocation of areas in the country for bamboo plantation development needs multi- stakeholders consultation and decision.

2. Multi-agencies should join hand in hand to engage in nationwide efforts to develop bamboo farm for various end uses.

3. Government support is required to encourage the plantation development thru incentive provision, financial, flexible policy in harvesting and transport as well as creation of markets.

4. Enabling legislation should be formulated to enjoin local government units to engage in plantation development.

5. In situ and ex-situ conservation areas for bamboo and gene bank must be established.

On Extension:

5. Vibrant extension program should be developed and pursued sustainably.

6. Diffusion of science based bamboo technologies and protocols should be done to the upland and lowland communities.

7. Local communities' participation-cum-ownership should follow a scheme that would ensure equitable benefits.

8. Government and non government support to farmers thru provision of technical assistance to interested clientele.

On Research

9. Harness the potential of climbing bamboos and other lesser-known erect bamboos

11. Micro-propagation through tissue culture for mass production improved genetic materials for the establishment of high quality plantations must be further studied

10. Studies on Carbon sequestration and storage potentials of bamboos and the roles of bamboos on climate change mitigation and adaptation must be conducted.

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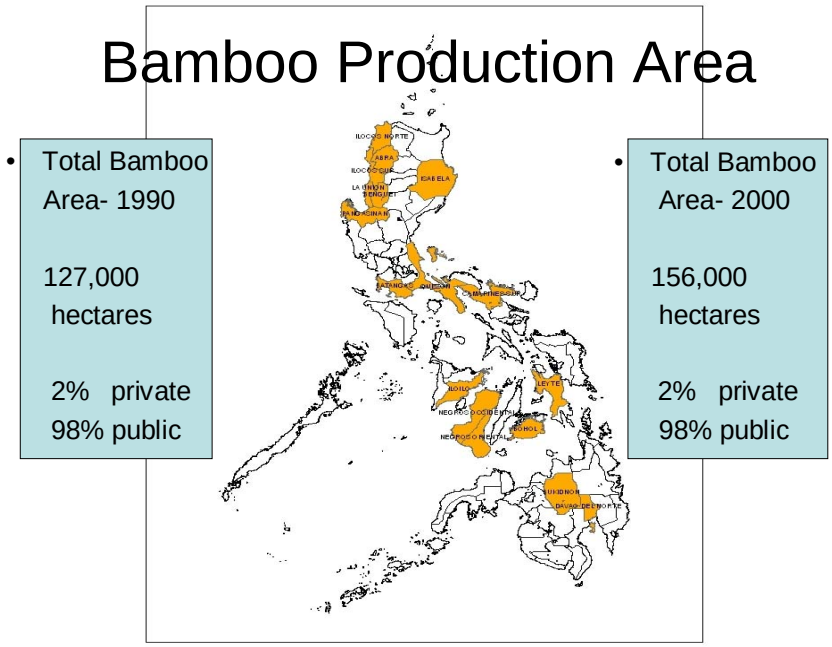

Source: Lobovikob 2005. World Bamboo Resources, FAO

Figure 1. Bamboo production areas in the Philippinensis

Table 1. Bamboo plantation established through the initiatives of private sector

Location		Owner	Species	Area
Luzon				(ha)
	Isla Verde	Jose Pastor	B. blumeana	50
	Pililia, Rizal	Alfonso Domingo		20
	Agno, Pangasinan	Doctor's Farm		5
	Pangasinan	Nepa Q Mart	D. merrilianus	50
	Coron, Palawan	Francisco Fernada		5
	Del Monte, Bulacan	Singh		20
	Bula, Camarines Sur	Mike Caya		3
	Laguna	Various private groups	B. blumeana, G. levis, B. philippinensis	890
			Sub-total	1,043
Visayas	Murcia, Negros Occ.	R. Jalandoni	B. blumeana	160
		T. TRebol		20
		N.L. Agustin Farms		30
	Isabela Negros Occ.	R. Suatenco		5
	La Castellana, Negros	Ferria Farms		14
	Manapla, Negros Occ.	Lamata Farms		14
	Cadiz, Negros Occ.	Mirasol		10
	Victoria, Negros Occ.	Maravilla Farms		10
	Moises Padilla, Negros	Ferria Farms		7
	Valladolid, Negros	Mayor Presbitero		2
	Dingle, Iloilo	Hermontt Enterprises		8
	Duenas, Iloilo	Paterno Larida		10
	Anilao, Iloilo	MaravillaEnterprises	D. asper	10
	Guimaras	Smile	D. asper	12
			Sub-total	312
Mindanao				
	Panabo Dvo. Norte	Tagum Development Company	B. blumeana, B. philippinensis	140
	Davao Norte	Nest Farm		161
		Davao Penal Colony		303
		Wakat Development Corporation		80
		F/S Dizon	B. blumeana, B. philippinensis	110
		AMS-FC		100
		SFC	B. philippinensis	5
		CFI		12
		Davao Fruits		434
		Twin River		132
	Pandadan, Tagum DN	Caasi		5
	Sn Isidro, Nabunturan	Caasi	D. atter	10
	Piang Village S.C.	Virrey	B. philippinensis	2
	Mati, Dvo. Oriental	Rabat	D. latiflorus	5
	Compostela & others	CBMC	B. philippinensis	186
	Sto. Tomas	ARSPMPC		170

	Sampao, KapalongDN			30
	Palmagil, Talaingod	Palmagil Farmers		120
	Banabanon,SanVicente	Banbanon MPC		120
	Monkayo DN	FARCOM		124
	Mapising, Taganan, Mabini DN	MCBDI	B. philippinensis	68
			D. atter	54
	Davao Province	SAWATA	B. philippinensis	2,048
		Davao Bamboo Coop		100
	Asuncion, Montevista	SAWATA	D. atter	20
	Mabini, DN	Individual Farmers		10
	Magbum, Tagum	Daniel Conde	B. philippinensis	200
	Tagum, New Corella	Alma Uy		100
	Magdaum, Tagum	Hijo Plantation		200
	Maparat, Compostela	Davao Fruits		50
	Asuncion, Davao Norte	Soriano Farms		80
	New Corella, DN	Alberta Omega		50
	Panabo, Mabini, Paco	Individual farmers		30
	Panabo, Carmen DN			30
	Anibongan,Carmen DN	Anibongan MPC		10
	Mawab, DN	Dizon Farms		200
	Monkayo, DN	Mr. Tuazon		100
	Compsotela (Valma)	Mr.Balunos		100
			Sub-total	5,699
			Over-all Total	7,054

Table 2. Bamboo Plantation Established through Department of Environment and Natural Resources' (DENR's) program

Location	Year Established	Area (Ha)
Under the regular planting program CAR		
1. Laskig Pidigan, Abra	1986	40
2. Lagangilang, Abra		52
3. Itogon, Benguet		22
4. Mankayan, Benguet	1988	48
5. La Trinidad, Benguet	1987	25
6. Paracelis, Mt. Province		38
	Subtotal	225
Region-1		
1. Burgos, Ilocos, Norte	1986	23
2. Santiago and SanEsteban Ilocos.Sur		35
3. Libidda, Ilocos Sur		26
4. Pugo, La Union		24
5. Infanta, Pangasinan		33
6. Mangatarem, Pangasinan		52
7. Natividad, Pangasinan		319
	Sub-total	512
Region IV		
1. Pinamalayan, Oriental		183
	Sub-total	183
Region VI		
1. San Enrique, Iloilo	1993	150
2. Duenas		10
3. Dumarao, Capiz	1989	8
4. Banawa, Aklan	1996	2
5. Jawili, Aklan		1
6. Mambusao, Capiz		1
7. Barotac, Nueve, Iloilo	1993	3
8. Dingle, Iloilo	1996	2
9. Kabangkalan, Negros Occ.		1
10. Lapaz, Iloilo		1
11. Lambunao, Iloilo		1
12. Maasin, Iloilo	1995	10
	Sub-total	190
Region XI		
1. Cabuyuan, Mabini Dvo Norte	1990	8
2. Langgam, Maco DN		8
3. Mabunao, Panabo DN		12

4. Marilog, Davao City	1991	20
5. Bunot, Kiblawan, Dvo Sur	1992	20
6. J.P. Laurel, Sarangani	1993	20
7. Acob, Maribel, SC.	1994	20
8. Magamit, New Bataan, DN	1990	31
9.	1991	1
10.	1993-94	50
11. Canidkid, Montevista, DN	1991-92	2
12.		1
13.		5
14. Piang Village, T'boli, S.C.	1990	9
15. Ran-ay, Banga, SC		30
	Sub-total	237
Under the Forestry Sector Loan		
CAR		158
Region I		160
Region II		30
Region III		129
Region IV		45
Region V		10
Region VI		47
Region VII		51
Region VIII		261
	Sub-total	891
Under ERDB andERDS Research Plantation		
Region I	1980	8
Region III	1989	8
Region VI		11
Region VII		11
Region X		11
Region XIII		11
	Sub-total	57
	Grand Total	2,259

Table 3. Research Development Initiatives of Ecosystem Research and Development Services- Department of Environment and Natural Resources in various region of the country that are related to bamboo production

Title of Study	Investigator	Year Conducted/ reported
DENR-CAR		
Market potentials of bamboo in Benguet	Noble	1984
Trial planting of various bamboo species at different elevations in Benguet	Ngales	1988
Integrated bamboo agricultural crop production on ISF farms in Benguet	Estigoy	1994
Effect of traditional burning of bamboo stands on the biophysical conditions	Palaganas	1995
Morphology of dwarf bamboo (*Yushania niitakayamensis*)	Tangan et al	1996
Effectiveness of rooting hormones on the survival and rooting percentage of selected bamboo species in selected areas in the Cordillera Region	Maddumba	1997
Survey indentification and pathogenecity of pest and diseases of exotic and endemic bamboo species in selected areas in the Cordillera Region	Tangan	2000
Economics of bamboo production in the Cordillera Region	Tubal	2001
Documentation of bamboo-based fallow practices management in Sablan, Benguet	Tangan	2001
Various species for rehabilitation of mine tailings pond no. 1 of the Philex Mining Corporation (PMC), Pacdal, Tuba, Benguet	Tangan	2003
DENR R-1		
Bamboo/rattan industry development project	Domingo	1991
Bamboo Research and Development Project	Virtucio et al	No date
Bamboo Plantation establishment along Agno River		
Harvesting methods of bamboo	Orallo et al 1998	
Survival and growth of bamboo species along Agno River	Tomas	2001
DENR Region 2		
Effect of hormone to the different species of bamboo	Callitong	1991
Development of plantation as show window for bamboo	Ramirez	1991
Growth performance of some bamboo species under nursery conditions		
Bamboo technology verification	Soriano et al	1995
Growth and survival of planted bamboo within the Ganano river watershed project	Patricio et al	1997
Showcasing bamboo technology for rehabilitation and development	Soriano	1999
DENR R-3		
Bamboo baseline survey in Bulacan		1998
Blue Crab fattening on bamboo cages	Pajarillaga	1996
DENR R-5		
Verification trial on bamboo marketing using Alfonso's model	Operio and Carino	1990
Masbate community-based bamboo plantation special project	Operio	1992

DENR R-6		
Evaluation of different technology transfer schemes disseminating bamboo production	Talabero	1990
Demonstration and pilot application of technology packages and production systems on bamboo and rattan		
Rehabilitation of old bamboo stands in Western Visayas	Gigare	1997
Establishment of pilot bamboo plantation on selected areas in Western Visayas	Gigare	1997
Adaptability and financial feasibility of mudcrab fattening in bamboo cages at Pan de Azucal seascape, Concepcion, Iloilo	Marquez et al	1997
D. asper pilot plantation establishment in Taminla, Duenas, Iloilo	Escario	1998
Development and designs of deformed bamboo culms for *B. blumeana*	Gigare	2006
Improving and maintaining productivity of bamboos for quality timber and shoots in Australia and Philippines	Gigare et al	2006
Rehabilitation of critical river system using bamboos and vetiver grass	Yraula et al	2006
DENR R-7		
Characterisitcs of 6 bamboo species by culm generation at Camp 7, Minglanilla, Cebu	ERDS Res. staff	1995
Effects of NPK fertilizer application, harvesting, intensity and felling cycle on culm yield of two bamboo species in Camp Minglanilla, Cebu	Lanuza et al	1996
Community-based bamboo production livelihood project in the upland	Tagra et al	1998
Effect of harvesting and felling cycle on culm yield of 5 bamboo species	Bueno	2002
DENR R-8		
Marketing of bamboo and Rattan	Fabella et al	1999
Documentation of existing rattan and bamboo production technologies adopted by farmers	Tamayo	1998
DENR R-10		
Pilot establishment of selected commercial bamboo species	Cacanindin et al	1990
Verification of propagation techniques and plantation establishment for *D. asper* in Bukidnon	Cacanindin	1990
Improving and maintaining productivity of bamboo for quality pole and shoots in Australia and Philippines	Cacanindin	2000
Determination of the demand and supply situation for bamboos in R-10	Palma et al	1994
Effects of nitrogen and phosphorus fertilizer application on the performance of some important bamboo species under the Bukidnon condition	Agne	1997
Performance of some important bamboo species as affected by fertilizer application, intensities of cutting and felling cycles ubnder Bukidnon condition	Decipulo et al	2001
Effect of harvesting age and felling cycle on the performance of some important bamboo species	Tiongco et al	2001
DENR R-11		
Bamboo and rattan livelihood project		
Transfer of bamboo production technology to ISFG beneficiaries in Davao del Norte	Balmocena	1994
DENR R-12		

Survey on the production and marketing of bamboo furniture in Palcan, Polomolok, South Cotabato	Tan et al	2005
Effect of culm size and node length on the early rooting and survival of bamboo cuttings	Jaime	1990
Potential of propagating bamboo branches for planting stock production	Pangod	1990

Table 4. Researches conducted under the National Bamboo Research and Development Project

Title of Study	Investigator	Year Conducted
Specimen collection, classification and identification of the different bamboo species found in the Philippines (nationwide)	Roxas, C.	July 1987-June 1992
Phenological observation of 7 Philippine bamboo species (nationwide)	Sinohin	July 1987 to 1992
Seed germination storage and microflora of some bamboo species (Los Banos)	Dayan	July 1987- June 1992
Vegetative propagation of D. asper and D. merrillianus under nursery condition (Los Banos)	Hoanh	July 1987- June 1992
Tissue culture of economically-important bamboo species in the Philippines	Calinawan	May 1993- may 1995
Effect of nitrogen and phosphorus on shoot development and growth performance of 4 bamboo species under Pampanga condition	Gonzales et al	January 1996 – September 2000
Microflora associated with rhizosphere of different bamboo species	Dayan	July 1987- June 1992
Bambusetum Establishment 1. (Mt Makiling, Los Banos, Laguna with 40 native and exotic species) 2. (ERDS-CAR Loakan, Baguio City with 60 native and exotic species) 3. Nabunturan, Compostela	 Roxas Tangan et al	 1990 1988
Effects of harvesting intensities and felling cycle on culm yield and biomass productivity of 4 bamboo species under Pampanga condition	Umali et al	January 1996 – September 2000
Bio-ecological and management studies of little leaf disease affecting bolo and giant bamboo in the provinces of Laguna and Quezon.	Pacho et al	July 2003 –June 2005

Bamboo (*Denrocalamus asper*) as Raw Material for Interior Composite Panel Manufacture in Thailand

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Abstract

This study reviews some of the findings of various past and ongoing research projects carried out to manufacture composite panels from bamboo (*Denrocalamus asper*) in Thailand. Experimental panels including particleboard, medium density fiberboard (MDF), and sandwich type panels having fibers on the face layers and particles in the core layer were made. Both physical and mechanical properties of above boards were evaluated. Average values of modulus of elasticity and modulus of rupture of particleboard and MDF samples were determined as 2,424 MPa, 22.57 MPa, 2,200 MPa, and 22.70 MPa, respectively. In the case of sandwich type panels such values were 1,840 MPa and 20.91 MPa. In addition to the bending properties, internal bond strength and physical properties including thickness swelling, water absorption of all types of samples resulted in satisfactory values based on Japanese Industrial Standards (JIS) for panels use for interior purposes. Surface roughness of MDF and sandwich type panels was also determined using a stylus type equipment. It appears that bamboo which is considered as under-utilized specie may provide profitable and marketable panels products in Thailand. Such panels are not only environmentally friendly but also one of the alternative ways to convert bamboo in a value-added product.

Introduction

Non-wood material based resources such as bamboo and agricultural fibers including wheat straw, kenaf, rice husk, and rice straw are getting more important as raw material to manufacture composite panels. Thailand has rich natural biological resources and diverse ecosystems that contain many non-wood materials. Unfortunately similar to many developing Asian countries deforestation and over harvesting in Thailand also created environmental awareness which focused exploratory research using non-wood renewable resources in composite panel production.

Bamboo is one of the most diverse groups of plants in the grass family which belongs to the sub-family of Bambusoidae (Zheng and Guo 2003). It is widely recognized as an important non-wood forest resource due to not only its excellent mechanical properties but also its high socioeconomic benefits. Housing, packaging and transportation are only few examples its common utilization for many years in Asian countries (Zhang and Yonglan 1988; Xuhe 2005;Sumardi et al.2005; Wang and Joe 1983). Currently, bamboo is still considered as under-utilized non-wood species, although it has additional limited use as scaffolding, furniture units, plywood, and flooring in Thai constructional industries (Ye 1991; Ganapathy et al. 1992). Its fast growth rate and better characteristics than many other wood species makes this resource an alternative raw material for various composite panel manufacture. One of the first bamboo composite panels developed was in 1940's in China and since then, at least 28 different types of bamboo composite products have been developed (Ganapathy et al.1992). Also there have been several attempts to explore the possibility to produce panel products including particleboard, oriented standboard, plywood, and laminated composite panels from bamboo at commercial level (Bai 1996 ; Hiziroglu et al. 2005; Lee et al. 1996, Li et al. 1994; Li 2004; Chow et al. 1993, Chew et al. 1994, Chen and Hua; 1991).

Although particleboard is also used as substrate for overlays its rough surface may create certain problems resulting show through the thin films or direct finishing applications. Medium density fiberboard which is prime substrate product for furniture and cabinet manufacture is the most widely used interior type of panel in many countries including Thailand. However overall cost of MDF is more expensive and has more complicated manufacturing process than that of particleboard. Combination of fibers and particle in the form of sandwich type of panel would possibly solve this cost problem. Experimental panels with a sandwich configuration were also manufactured from bamboo. Since fibers were used on the face layers it is expected such panels had not only smooth surface with thin layer of fibers on board faces but also their overall properties were enhanced.

The main objective of this study was to explore potential suitability of bamboo to develop value-added interior panel products, namely particleboard, medium density fiberboard (MDF), and sandwich type panels having fibers on the face layers and the coarse particles in the core layer. Both basic physical and mechanical properties of experimental panels made from bamboo were tested to find if bamboo could be used to produce experimental panels with accepted properties.

Materials and Methods

Bamboo (*Dendrocalamus asper*) samples were harvested in Khon Khen, Prachin Buri bamboo plantation in Thailand. The specimens were reduced into chips using a commercial chipper before they were hammermilled for particle production. Figure 1 shows particle and fibers of bamboo used in this study. A laboratory type defibrator illustrated in Figure 2 was employed for disintegration of bamboo chips into the fibers using a pressure of 0.75 MPa, at a temperature of 160 ^{o}C for 1.5 min. before particles and fibers were dried in a kiln at a temperature of 80 ^{o}C until the furnish reached to 4 % moisture content. Later dried fibers were mixed for 4 min with 9 % urea-formaldehyde resin with a specific gravity of 1.27 and solid content of 84.8% in a rotating drum type mixer fitted with a pneumatic spray gun. Half percent wax was also added during resin spraying for the furnish. Twenty and 50% rice straw fibers and particles were also added into the various types of panels to

evaluate interaction between two types of materials. Table 1 displays experimental schedule of the study involved with MDF manufacture.

The sandwich type samples with fibers on the face layers and the particles in the core layer were also manufactured using the above set-up. The core of the panels had homogeneous mix of 95% bamboo and 5% rice straw as filler using a 8% urea formaldehyde resin. Fibers of both type of raw material were used at the same ratios for the face layer of the panels using 10 % urea formaldehyde. Particles and fibers were mixed with the adhesive and 0.5% wax in the rotating mixer equipped with pressurized spray gun. Ten replicas for each type of panel in 35 cm by 35 cm by 1.0 cm were manually formed in a plexiglass box and pressed in a hot-press at a temperature of 165 ^{o}C using a pressure of 5.2 MPa for 5 min. Average target density of the panels ranged from 0.65 g/cm^3 to 0.80 g/cm^3. Panels were conditioned in a climate room with a temperature of 20 ^{o}C and a relative humidity of 65% for about two weeks before any tests were carried out. Modulus of elasticity, modulus of rupture, and internal bond strength properties were tested on an Instron Testing Machine Model-22, 5500-R equipped with a load cell capacity of 5,000 kg. Two and six samples were cut from each panel for bending and internal bond strength tests, respectively. Figures 3 and 4 illustrate unpressed MDF and sandwich type mats. Density profile samples were then determined on Quintek Density Profilometer, Model QDP-01X. This instrument can be set to a minimum linear increment of 0.25 mm depending on the sample thickness. Four samples with a size of 15.2 cm by 15.2 cm were used to determine thickness swelling of the panels. Thickness of each sample was measured at four-point midway along each side 2.5 cm from the edge of the specimen. Later samples were submerged in distilled water for 2-h and 24-h before thickness measurements were taken from the same location to calculate thickness swelling (TS) values. Table 2 shows experimental design of sandwich type panels.

Surface roughness of the samples was evaluated using portable stylus type equipment, Hommel T-500 profilometer as shown in Figure 5. Eight specimens with a size of 5 cm by 5 cm were randomly taken from each type of panel for roughness measurements. The profilometer equipment consisted of a main unit with a pick-up drive which has a skid-type diamond stylus with a 5-µm tip radius and 90° tip angle. The stylus traverses the surface at a constant speed of 1 mm/sec over a 12.0-mm tracing length. The vertical displacement of the stylus is converted into electrical signals by a linear displacement detector before the signal is amplified and converted into digital information. Various roughness parameters such as average roughness (R_a), mean peak-to- valley height (R_z), and maximum roughness (R_{max}) can be calculated from the digital information. Typical roughness profiles of samples from four types of panels are shown in Figure 6. Definition of these parameters is discussed in detail in previous studies (ANSI 1985; Hiziroglu et al. 1996, 2004; Mummery 1993). Four random measurements were taken from each side of the samples to evaluate their roughness characteristics. Analysis of variance was used for statistical analysis of the data from the tests.

Results

Results of physical and mechanical properties of different types of panels made from bamboo are displayed in Tables 3 and 4. Medium density fiberboard samples had an average MOE and MOR values of 2273 MPa and 28.66 MPa, respectively. A previous study showed that experimental bamboo particleboard panels had 2,424 MPa and 22.57 MPa for above tests (Hiziroglu et al. 2005). In the case of sandwich type panels MOE and MOR

values of the samples ranged from 1,287 MPa to 1,910 MPa and 13.77 MPa to 26.30 MPa depending on panels density as displayed in Table 4. Based on the Japanese Industrial Standard (JIS-A 5905) 13.0 MPa is the minimum requirement for interior particleboard. Based on American National Standards (ANSI-A 208) minimum MOE and MOR requirement for grade 110 MDF for interior applications are 1,400 MPa and 14 MPa. It seems that panels manufactured in such studies, including sandwich type panels satisfied MOR strength requirements for general used based on both standards. Panel type-A with sandwich cross section had the lowest strength properties which can be related to its very low density of 0.65 g/cm^3.

Internal bond strength of the samples followed the similar trend of bending properties of the panels. Overall IB strength values of sandwich type panels ranged from 0.51 MPa to 0.84 MPa satisfying the IB strength requirements based on the JIS for general use of particleboard. Thickness swelling values of both types of samples were found to be acceptable based on the standards. The panels made from 100% bamboo fibers had 7.84% thickness swelling as a result of 2-hr water soaking. Corresponding value for sandwich type panels was 10.25 MPa with 0.75 g/cm^3 density level. Using rice straw furnish as filler in the panels reduced both strength and dimensional properties of the samples.

In general single-layer particleboard with rough surface are not used for thin overlays as substrate for cabinet and furniture manufacture. Average roughness value of bamboo particleboard was within the range of 19 µm. However both MDF and sandwich type panels resulted in much smoother surface with and average R_a values ranging from 5.08 µm to 7.50 µm. It appears that having only 5% rice straw fiber on face layers of three-layers panels did not influence significantly their surface characteristics. Panel density was found to be one of the important parameter controlling surface quality. Samples had better surface roughness with their increasing density which can be related to compactness of face layers. Based on the roughness measurement it is expected that both types of panels having fibers on the face layers can be used as substrate for even ultra thin overlay papers without having any telegraphing effect .

Conclusions

This study briefly reviewed some of the findings of several experimental works related to manufacture different types of composite panels from bamboo. In the light of preliminary results of such studies bamboo which is an under-utilized non-wood resource can be used to produce interior composite panels with accepted physical and mechanical properties. It appears that manufacturing composites from bamboo would provide a profitable and marketable interior panel products in Thailand. Such panels are not environmentally friendly but also provide an alternative way to convert this resource into panel products for furniture manufacture.

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Table 1. Sampling schedule of MDF panel manufacture

Panel Type	Raw material	Number of panels	Test Samples				
			MOE and MOR	IB Strength	TS	Density Profiles	Surface roughness
A	100% Bamboo	5	10	30	10	10	10
B	80% Bamboo-20% Rice straw	5	10	30	10	10	10
C	50% Bamboo-50% Rice straw	5	10	30	10	10	10

Table 2. Sampling schedule of sandwich type panels

Panel Type	Face/Core Ratio	Density (g/cm^3)	Number of panels	Bending (MOE&MOR)	IB	TS	Roughness
A	10/80/10	0.65	8	40	35	40	80
B	10/80/10	0.75	8	40	35	40	80
C	25/50/25	0.70	8	40	35	40	80
D	25/50/25	0.80	8	40	35	40	80

Table 3. Results of the physical and mechanical properties of MDF samples

Panel Type	MOE (MPa)	MOR (MPa)	IB (MPa)	Thickness swelling (%)		Density g/cm^3	Roughness parameters (µm)		
				2-h	24-h		R_a	R_z	R_{max}
(A) 100% Bamboo	2273	28.66	0.71	7.84	19.96	0.73	5.50	40.73	49.02
(B) 100% Rice straw	1484	15.65	0.23	33.03	40.95	0.74	5.20	39.23	46.65
(C) 80 % Bamboo 20 %Rice straw	1936	23.29	0.52	18.52	24.40	0.73	4.88	36.10	43.61
(D) 50 % Bamboo 50 % Rice straw	1850	22.23	0.38	22.26	27.46	0.72	5.20	39.23	46.64

Table 4. Results of the physical and mechanical properties of sandwich type samples

Panel type	Density (g/cm^3)	MOE MPa	MOR MPa	IB MPa	TS (%)	WA (%)	Roughness (µm)		
							R_a	R_z	R_{max}
A	0.65	1,325	13.77	0.68	9.98	38.35	7.5	39.31	54.50
B	0.75	1,840	20.91	0.84	10.25	33.90	6.25	36.82	40.81
C	0.70	1,287	17.17	0.51	23.39	90.11	6.57	38.33	43.62
D	0.85	1,910	26.30	0.73	24.78	72.53	5.08	25.34	36.53

Figure 1. Bamboo and rice straw particles and fibers

Figure 2. Laboratory type defibrator.

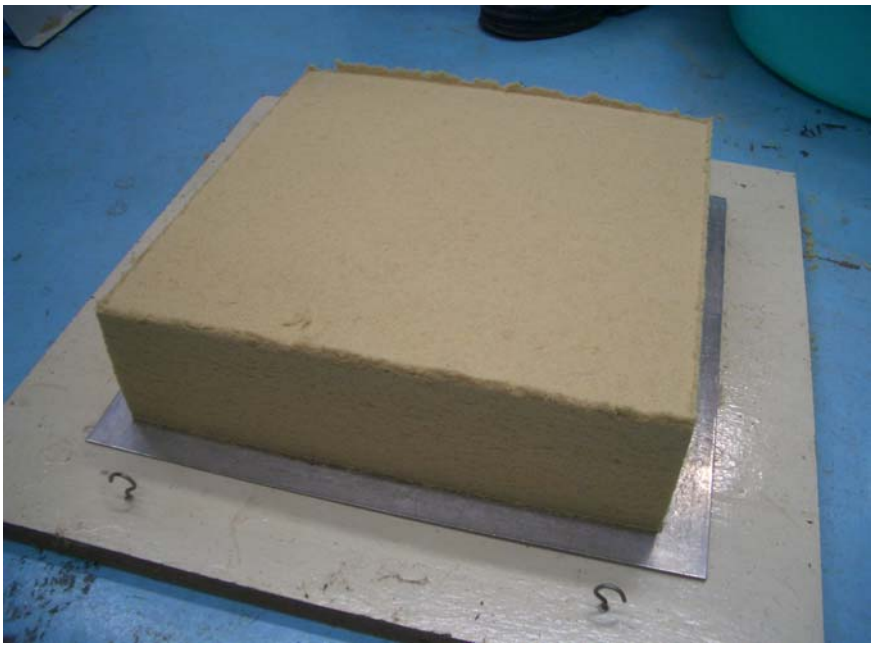

Figure 3. Unpressed MDF mat.

Figure 4. Unpressed sandwich type mat.

Figure 5. Stylus type roughness profilometer.

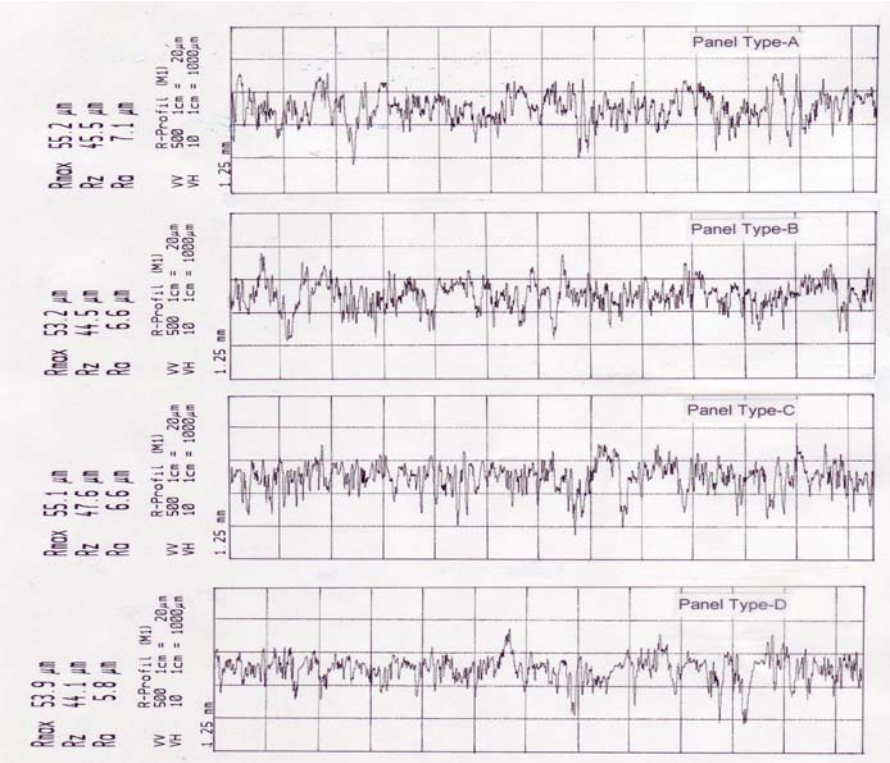

Figure 6. Typical roughness profiles of MDF samples.

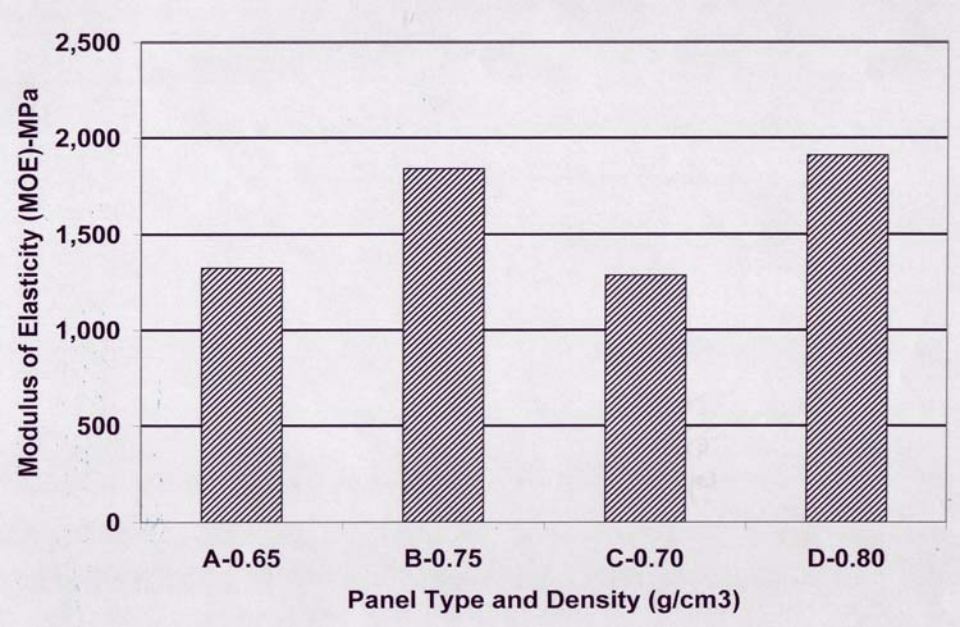

Figure 7. Modulus of elasticity of the sandwich type of samples.

Creating Sustainable Jobs and Incomes to Reduce Poverty: Lessons from Bamboo Supply Chain Development Project in North West Vietnam

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GRET

Abstract

In North-West Vietnam, approximately 60.000 families are harvesting 70.000 has of bamboo, for a yearly output of more than 800.000 tons/year. Industrial bamboo is produced mainly in Thanh Hoa province, in the poorest districts. The supply chain is characterized by low efficiency of polluting SMEs and risk of unsustainable exploitation of bamboo resources. 70% of demand for industrial bamboo is for low added-value products such as bamboo culms for construction sector, pulp and paper factories. A large amount of waste is produced in workshops, such as sawdust, planning chippings, and node waste (60 to 75% of processed bamboo culms, compared to 5% in China).

In this context, diverse strategies have been identified to enhance economic development and contribute to poverty reduction. A first approach consists of local interventions involving farmers, collectors, traders, local SMEs and policy makers. A second approach focuses on major markets and leading firms, the objective being to introduce new technologies and increase the demand for bamboo culms with a view to impact positively at scale on bamboo farm gate prices.

This paper draws lessons from those different approaches: how can poverty reduction be effectively achieved and measured; which kind of development should be promoted, and how should one intervene in market systems without creating distortion, how should different approaches be combined?

It provides some recommendations for intervention and underlines the risk of early exposure to major external players, the latter having possibly conflicting strategies and shorter term agendas, which could durably undermine potential for sound and sustainable development, in particular regarding bamboo resources. It also highlights the need for working with and strengthening local actors in order to sustain better practices. Interventions should not focus solely on few bamboo market strands but target multiple bamboo and non-bamboo products and activities.

Keywords: Bamboo supply chain, poverty reduction, nascent markets, lead firms, linkages, inclusion, resilience, income diversification, sustainability

Introduction

Thanh Hoa province: home of industrial bamboo in Vietnam

Thanh Hoa province is one of the poorest provinces of Vietnam, located 150-200 km South-West of Hanoi. Seven districts of the province belong to the 10% poorest districts in the country (61/640). Thanh Hoa North-West districts are mostly inhabited (about 80-95%) by ethnic minorities (Thai, essentially, but also Muong and H'Mong people). The poverty rate is higher than 50%, with a poverty line of 200,000 VND (0,35 USD per day per person). Luong bamboo (*Dendrocalamus barbatus* essentially) represents the main income source for about 30,000 families in the zone. North-West Thanh Hoa is the main production zone (about 70,000 ha) for luong bamboo in Vietnam (about 50% of surfaces over the country), even if there are still natural bamboos in natural (degraded) forests, like Nua (*Neohouzeaua)* or Vau (*Phyllostachys*). Bamboo culms are mostly processed in factories around Hanoi by few leading firms, procuring bamboo from surrounding mountainous provinces. Luong bamboo has good mechanical properties and big size, allowing diverse utilizations such as construction (scaffoldings), dykes reinforcement, chopsticks and paper pulp. Those products (70% of the demand for luong culms) are bringing low added-value. In parallel, high value products are also produced, such as flooring, panel boards, furniture, and handicrafts. Every year, in North-West Thanh Hoa, about 20-25 millions of culms are harvested, among which, about 35-40% are pre-processed in the zone and 60-65% "exported" as culms to the red river delta region, Hanoi, Hai Phong , Thanh Hoa and other big cities.

Main problems encountered by bamboo producers and supply chain

Agroforestry: underinvestment, overexploitation, un-sustainability

Most traders and collectors today are paying farmers according to the number of culms harvested, their size and weight, for low value products. The age is not considered as important for most of the buyers, except for pre-processing and processing workshops, as well as leading firms, requesting 3 years old culms. This is due to the fact that construction and paper industries do not require quality culms. Such practice badly impacts on yields (young culms are firstly contributing to the growth of new shoots) and decreases plantations productivity, farmers' incomes and long term sustainability of the supply chain. Besides, because of the low price paid for bamboo culms, farmers are under investing; in some places they are replacing bamboo by other more profitable crops (cassava, maize or acacia), and investors are reluctant to invest if resources are not secured over the long term. The most accessible plantations are overexploited, especially by very poor families, for whom luong bamboo is a bank for day-to-day petty cash needs (food, traditional events, medicines, school, etc.). There is therefore a need for investment in infrastructure (roads to access more remote plantations), but bamboo is no longer a priority for provincial and national authorities.

Supply chain: low efficiency, low added-value

As in the case of most supply chains in Vietnam, there is limited coordination between supply chain actors and no interprofessional organization. Leading firms (only few main companies) producing higher value products are not located in the province, bringing part of the added-value and skills to richer provinces (with better infrastructures, access to markets, human resources). Local SMEs are active but limited by a lack of skills,

capital and access to market information. They are also highly dependent on a few buyers if they can not diversify their production. A diversified industry and increased competition would limit the dependency on a few buyers and enhance the sustainability of local businesses. The present oligopsony and the limited demand for higher quality production are indeed depressing prices at the expenses of small businesses and farmers. The industrial bamboo sector in NW Viet Nam is still nascent compared to China, despite few major players. There are now 80-90 processors making medium and high-value products, but less than one third have a turnover greater than USD 500,000 per year. Of these, only a small number of companies produce high-value products such as flooring or panels.

Project intervention: main principles and achievements

With the main objective of reducing poverty by supporting local economic development, a partnership (between Prosperity Initiative Programme and GRET organization) has been established, aiming at: "Securing investment in new manufacturing plants for high- and medium-value finished Products; raising value added per bamboo culm across the industry (especially among primary processors) by identifying market opportunities for alternative higher value products and assisting small- and medium-enterprises (SMEs) to supply them; establishing sustainable buying mechanisms between buyers and farmers to ensure the sustainable exploitation of bamboo resources while meeting the needs of a growing industry; ensuring that poor farmers own the bamboo and therefore can benefit from rising prices and demand." (Mekong Bamboo 2008). Securing ownership is not an issue in North-West Vietnam, but an important one in Lao or Cambodia for instance.

A project that is being implemented by GRET (Luong Development Project or LDP) since 2005 has been progressively designed to respond to the above mentioned problems. Some activities were related to farmers and resources activities: support to farmer organizations, development of links with enterprises and markets, and establishment of nurseries, plantations, trials and demonstrations, sustainable forest management, testing of short-term intercrops to get earlier incomes for new plantations. Other activities were related to the support to bamboo supply chain down stream: within Thanh Hoa bamboo industrial cluster, facilitate exchange between supply chain stakeholders, build capacities of entrepreneurs, support small and medium enterprises (business plans, trials for new products and process, contacts with buyers, equipments, and access to finance …), support marketing, relations with investors, and tests for diversification of production. Some complementary activities were related to sector enabling environment: discussion with local government on problems and solutions for smallholders and bamboo processing entrepreneurs, multi-actors discussions and seminars, capacity building of local actors, organization of meetings and visits, exchanges with external actors on bamboo.

GRET's strategy is to be permanently present in Thanh Hoa province to implement those activities. Additionally, since end of 2008, the national staff of the project has formed a local service cooperative, the objective being for this cooperative to become autonomous after project completion, as a local service provider. This comprehensive approach and the wide range of activities that had been implemented during the last four years has been driven originally by the private sector (Ikea), together with IFC, then by increasing support of donors, identifying bamboo as a strong opportunity to reduce poverty. In 2007, Mekong Bamboo programme did join this action on bamboo supply chain, partially funding the project and supporting major players (investors, leading firms) to increase demand for higher added-value product.

While some expertise has been mobilized for the design, implementation and impact assessment of the project, no analysis has been done yet on the overall logic of intervention and how it relates to existing literature on supply chain support. Based on project achievements and past exchanges with partners, this paper discusses different approaches for effective and efficient poverty reduction, which supply chain models to promote, and how to work with local stakeholders for sound market development.

Fighting poverty efficiently: raising prices of materials only, or increasing capabilities, creating jobs and activities locally?

Case study: production of mushrooms on bamboo sawdust

Bamboo processing is producing a high quantity of sawdust, particularly from the production of slats for flooring (longitudinal splitting). The project initially worked with one women's group and one small group (five persons), willing to invest in mushroom production from sawdust. It linked the groups to input providers, markets, organized technical trainings and exchanges visits, and provided financial support for the first small steaming kilns and drying kiln. Project financial support was considered necessary given that ethnic minorities in this poor area are not able to invest, and that it was necessary to demonstrate the feasibility of this new business. Three species of mushrooms for three different markets were produced: fresh mushrooms for local market and wedding events, dried mushrooms for urban markets and Linh Chi mushrooms for Vietnamese and Chinese medicinal markets. In early 2009, two years after the start of the intervention, 50 families were involved and 5 groups (2 women groups) created. This organization of production has helped farmers to produce mycelium to extend production, develop processing (drying, sorting, packaging), and be able to reach more markets thanks to a critical size of production.

This small activity, with limited initial investment, helped to create jobs for women; production was relatively easy to manage by beneficiaries after technical support and monitoring. It enhanced technical skills and marketing capacity, provided sustainable diversification of incomes, links with market, structuring of new supply chain, new links between families and communities. Besides, it is an eco-friendly activity, with no use of chemicals and possible re-use of substratum as organic fertilizer. This activity, which targeted very poor families, was highly appreciated and supported by local and provincial authorities. The fact that mushroom production is often seen by farmers visiting project achievements as a key activity they would like to implement themselves is also a good indicator of the attractiveness of such activity. Noticeably, as an income generating activity, it releases pressure on bamboo resources (main source of cash for farmers), allowing therefore better management of bamboo plantations. Such activity is also easily replicable, as it necessitates limited investment, for a high market demand.

Yet, the financial benefit is limited (a net benefit of USD 250 per annum per family for an average production) and the overall impact on poverty in the Region is obviously not significant. Should such small-scale and flexible approaches be promoted and supported by donors, in search of large scale poverty reduction and accountability, or should other approaches, more simple and replicable, be in priority funded? What are the theoretical and practical reasons for favoring and approach or the other?

Impacting on poverty at scale: how to reach poor farmers?

Some argue that if supporting businesses allows a market price increase, it will impact on prices for the bamboo culms paid to farmers and therefore, increase their incomes and reduce poverty. This approach is considering that market forces solely can eliminate poverty, and that other non-market interventions are less efficient, and therefore less relevant; it justifies large scale intervention with major players, at the expense of locally based lengthy, complex, costly and uncertain interventions, directly with the local stakeholders. It considers economic growth, measured in monetary terms per capita, as the central indicator to measure development. To demonstrate this vision, one can measure the impact of an increase of bamboo prices on farmers' incomes, and then extrapolate how many farmers could have crossed the poverty line.

This theory is nevertheless showing some limitations. Firstly, an increase of price can not be easily attributed to a given project, as it is dictated by world prices of bamboo and other factors (price of inputs, cost of workforce, etc.). Secondly, the real price increase is questionable in a context of high inflation rates, when it is difficult to fix a proper rate and the error margin is important. Thirdly, the increase on bamboo price at farm gate can also possibly be relatively limited compared to other farmers' expenses (food, transportation, farm inputs). Thus, even if bamboo incomes did increase during a given period, it is likely, in case of strong increase of real price for many expenses, that most of farmers will be poorer. Finally but most importantly, in the case of bamboo production, an increase of prices without any farmer awareness and long term perspective could lead to overharvesting of plantations, bringing short-term higher incomes, but medium term declining yields and incomes, environmental degradation. Environmental degradation would in return nourish price increase, because of a lower offer of bamboo in quantity and quality.

Such impact assessment method would therefore overestimate the impact of bamboo prices variations at the expense of other important factors impacting also on poverty. It would then justify working without – or with limited - support locally to local actors, focusing on leading firms only in order to achieve this goal of price increase. Such approach refers directly to the "trickle-down theory," supporting that economic growth and technological change benefit the poorest, even if it is under the control of the better-off companies or people. This theory has shown its many limits in rich western countries, it is therefore undoubtedly questionable in poorer countries.

The affirmation that a farm gate price increase will be seen in case of increase of global demand is also questionable if we have a closer look at the Chinese model of development. For instance, in Anji county (Zhejiang province), one of 10 "bamboo homelands" in China, figures (Zhu Zhaohua, 2007) show that price increase is relatively limited: only 60% over 20 years time (1988 to 2006), if compared to increase in production value of moso bamboo products during the same period (210%). The production value is much related to utilization rate of culms (from 25% to more than 85%), but it did not impact much on the price paid to producers. It seems therefore that the expected trickle-down effect of an increase in demand and a better utilization rate on the price paid to farmers is not obvious. According to some findings (Perez 2007), bamboo producers in China are benefiting a lot from bamboo non-agricultural activities, including processing and sales, but those farmers are not the poorest ones. In Anji, most of farmers are also small entrepreneurs and are therefore able to invest in small equipments, new technologies, manage properly plantations, etc. Besides,

bamboo production was and is still, but differently, strongly supported by Chinese authorities (subsidies for planting initially, research, promotion of investments, etc.). The hypothesis that people can be taken out of poverty thanks to an increase in demand, based on economic theory or on partial analysis of the Chinese model, is risky. Farm gate price increase should be considered as a priority (and not increase in demand), this not being left to market forces only. Other aspects of livelihoods – not only market factors – should be taken into account to reduce chronic poverty.

Sustainable impact on poverty: a need for a more comprehensive approach

For other development practitioners working on support to supply chains, a recommended impact assessment method (Bekkers, et al. 2008), is to measure, on the following aspects, if some significant changes had been observed: on project expected outputs (promoting new products, number of SMEs trained on specific issues); on outcomes (improvement of services to SMEs, launching of new products); on increased capabilities (change in linkages between stakeholders, awareness on market opportunities); on change in performances and competitiveness of SMEs (resilience to external chocks, increased productivity and benefits); on entry of new actors in the sector, attracted by supply chain up-grading; lastly, on increase of incomes and job creation due to better efficiency of production, new enterprises, or any other activities reducing significantly poverty. This range of tools is useful to measure impact on supply chain but of course does not to give a measurement of poverty reduction. This is nevertheless a more relevant approach to poverty alleviation, as poverty, and more precisely chronic poverty is not only related to cash incomes, but it is a multi-factorial phenomenon.

As defined by Ponte (2008) "the distinguishing feature of chronic poverty is extended duration in absolute poverty. Therefore, chronically poor people always, or usually, live below a poverty line, which is normally defined in terms of a money indicator (e.g. consumption, income, etc.), but could also be defined in terms of wider or subjective aspects of deprivation. This is different from the transitorily poor, who move in and out of poverty, or only occasionally fall below the poverty line." In this view, giving farmers more bargaining power, information on markets and better access to services (credit, inputs, etc.) is important. Diversification of income sources and better linkages to diverse markets is also important. In our example, mushroom production is important in financial terms, but it is also a medium to link the poorest farmers to markets, to show that small entrepreneurs can emerge and be successful. It is also a potential first step and first source of cash incomes to develop other activities.

This complex and comprehensive approach of poverty determinants is not necessarily welcomed by donors, interested by more specific and replicable methods of intervention. Supporting leading firms as a substitute to development practitioners, to demonstrate the liberal view of development processes - if done alone without strong local intervention - is ignoring the inherent causes of chronic poverty. In-depth investment on skilled human resources locally, to support local initiatives and strengthen local entrepreneurs, should not be forgotten. As described below, the quality of the economic development promoted is as important as economic development itself. In Vietnam, very few development practitioners are directly working with local SMEs, but such experiences are very rich ones that could serve as a reference if well documented and promoted at provincial and national levels. Other current trend from donors is the budget support to governments: transfer of important financial means for action to national entities shows an increased concern for the ownership of the

development process, but does not provide necessarily added value in terms of intervention methods. Such approaches can be justified in terms of ownership and scale of impact, but experience shows that, even after decades of governmental support in Vietnam, local government bodies are still very weak, especially when it relates to market development.

Up-grading bamboo supply chain: which priorities?

Lessons learned from some innovations in Thanh Hoa province

So far, the support to the development of new manufacturing plants has not been successful. No major new investor did invest on bamboo supply chain to develop new technology. Some direct support to the Vietnamese bamboo leading firms to develop business plan, attract investors, and test new technologies is on-going and should help to increase bamboo processing capacity. The competition between two or three leading firms is still limited and this is impacting negatively on practices along the supply chain: bargaining power of pre-processing workshops is limited and supply chain management is based on short-term considerations, with no long term commitments and no investment on quality up-stream. This failure to attract new investors can be partially explained by the current economic crisis, but it is also related to the lack of attractiveness and competitiveness of the bamboo supply chain in general at the moment. Indeed, despite potential important demand, accessing new markets is very challenging for new comers and out of reach for most if not all of existing SMEs. Weak supply chains – in remote areas, with few small investors - are risky and are not efficient, for many reasons. Important investors, looking for secured and interesting returns, are therefore prioritizing investments on more mature sectors of the economy, mostly in richer locations (Mekong and Red River Delta), with more qualified workers, better infrastructures, easier access to markets.

At smaller scale, it was easier to develop new activities, as local stakeholders were more able to invest locally, investments being less important, less risky, and markets more accessible. For example, aware of the economic importance of secondary species for poor ethnic minorities, and of important markets for incense sticks in South Vietnam (Ho Chi Minh City) and handicraft baskets, the project has made the link between buyers, village authorities and small enterprises. Based on demand of a local small entrepreneur, the project has partly supported several weeks of vocational training for 20 villagers from poorest areas, to be able to produce quality round or square sticks. This activity created locally 20 new jobs, mainly for women, and was an opportunity to add value to secondary bamboo species from natural forests. 100 families used to produce rattan woven bamboo products, were supported to produce and sell bamboo baskets (with new design and better quality), through a local co-operative.

Other locally supported activity has been the building of one pre-processing workshop by the end of 2006 with project support, to produce slats for flooring and chopsticks. The pre-processing locally (near bamboo plantations) was indeed identified as a key priority to improve bamboo supply chain efficiency for the flooring market (less transportation costs and better quality control in particular). However, this business progressively reveals not being profitable – at least temporarily - because of low selling prices of chopsticks and slats, difficult quality control (age of culms in particular), quite remote location from luong bamboo main production zones (high transportation cost), and local market down-turn for bamboo flooring. The project supported the

entrepreneur to find new market opportunities (visits, linkages) and the workshop started to produce woven slats for panel boards (used for construction, shrimp farms), a product that is currently imported from China. This production allows much higher utilization rate of raw materials (60%) compared to chopsticks and slats processing (20-25% as a maximum), more added-value and additional job creation. By-products (40% of wastes) are used to produce woven mats and other handicraft products, which enjoy high market demand. Such switch of production is creating much more work for the same quantity of bamboo. In the current situation, with overexploitation of bamboo, this strategy is more profitable and sustainable. In this case, the project facilitated linkages with buyers and provided useful market information, but didn't interfere with local actors. Convinced that this activity was more profitable, the entrepreneur did switch his business model and is today less dependent on the flooring market. If the first strategy (support the development of pre-processing for flooring) revealed not being successful, entrepreneurs were nevertheless able to cope with a new situation and diversify products. Without project intervention, the pre-processing workshop would have probably stopped its activity. This intervention is questionable as it can be seen as a market distortion, the project trying to help in particular one actor at the expense of others. On the other hand, initial investments were used to produce new products, more profitable ones. Therefore project support had been useful to diversify market outlets and reinforce the resilience of this entrepreneur to market fluctuations, as well as other actors later on, eager to follow this example.

Discussion

The examples above are showing that large scale investments are difficult to promote. Besides, when supporting major players (which are not locally based due to the weakness of infrastructures) there is no guarantee that the latter will necessarily invest locally and reinforce local actors. The link between major firms and local actors is indeed very weak in Vietnam, vertical integration being non existent and collaborative approaches not yet common on bamboo supply chain.

Stefano Ponte (2008) demonstrates that "integration of people or areas into global value chains and trading relationships will exacerbate chronic poverty if the 'normal functioning' of these chains is left unchecked. This is especially the case for value chains that are driven by retailers and branded manufacturers. Where value chains are less clearly driven from Northern-based actors, integration in even 'normal' strands of value chains can have substantial and positive impacts on poverty, and where appropriate, chronic poverty. In other words, the conditions of inclusion in and/or exclusion from value chains and trade more generally are more important than inclusion and exclusion per se."

Ponte is asking to be cautious on how to support supply chains, and is demonstrating how a too fast and too strong connection to global markets can endanger local stakeholders. As it was demonstrated within the project, it is more feasible to support local SMEs to reach emerging small markets, even if the overall impact is limited. Doing so, entrepreneurs are progressively exposed to diverse external markets, the local autonomy is slowly growing, capabilities are increased and the supply chain is becoming more resilient to market changes. Supporting local and reachable markets also allows easier starting of small scale production, trials and errors. At this scale, a project can support partially the risk; provide small grants, be involved with limited expertise on market prospection. The above short case studies are showing that inclusion of actors locally was possible because entrepreneurs found opportunities to invest with limited risk, in a known – close – business

environment. More profitable but more distant and risky markets have not been explored by local entrepreneurs, despite project support and sufficient private investment capacity. Moreover, the current crisis is showing that external funds are more volatile than local money, the later being attached to local networks and commitments (political, familial, and economical). Lastly, experience showed that global investors and leading firms are more reluctant to invest in nascent industry and prefer to secure existing and reliable investments.

Such trade-offs when supporting supply chain stakeholders should be clearly identified, support and mitigating measures strongly supported. It means that the pace of supply chain support and promotion of competition should be wisely assessed. As mentioned by Ponte, the conditions of inclusions are, for this kind of nascent markets, more important than inclusion itself. Sustainable production (taking into account economic, but also social and environmental aspects of production) is necessary for a sound development. In Vietnam, leading firms still have low awareness about the benefits they could receive from a better and more responsible management. It is therefore risky to support such actors if the conditions of support are not discussed to try to improve the impact of their practices up-stream with suppliers, poor workers, farmers and bamboo resources.

If there is no "big bang" impact to be expected from such local and small scale support, it is more responsible and sustainable to give priority and seek for local markets, not to depend too much on international markets and leading firms, and a positive dynamic within a production cluster can facilitate replication. It is indeed critical to increase capabilities locally and sow the seeds of future endogenous development. If this approach can appear frustrating to development practitioners or donors – seeking short-term visible results– it is nevertheless more adapted to local actors' capacities and expectations, and therefore facilitate ownership of promoted activities.

Businesses and other supply chain stakeholders should consider their medium term interest: more investment up-stream and better integration of suppliers would help to increase quality, secure supply and diminish transaction costs and risks. Indeed, transaction costs are high because lead firms are procuring on bulk bamboo markets; it therefore necessitates sorting culms, controlling quality and age of culms. This approach is currently risky, as it is difficult to control quality properly. In the current situation, a leading firm producing bamboo flooring estimated that 10 to 20% of culms did not reach quality requirements. With a better integration up-stream and traceability, farmers would cut only quality culms, improve bamboo plantations management, and therefore have significant positive environmental impact.

Local entrepreneurs, more embedded in local dynamics, should be linked to leading firms to promote those sustainable practices. Facilitating linkages along bamboo supply chain in Vietnam, from farmers to leading firms, is a key issue for better efficiency and sustainability.

Intervention methods: finding the balance between interference and indifference

Creating new markets: the example of bamboo active charcoal

Before project intervention, there was no significant production of active charcoal from bamboo in Vietnam. This production necessitates kilns building, technical and financial support for first burning cycles, and markets. There is a large diversified potential market with high demand: charcoal from wastes (lowest prices); tube

charcoal (small-sized luong or other species, presented in bamboo baskets). Wastes of active charcoal and active charcoal itself can also be used to produce activated carbon, for which Vietnam has to import more than 95% of production. The project is currently supporting the development of a production plant for activated carbon, local investors and responsible businessmen being ready to invest. Despite this high potential demand, local entrepreneurs were not able to take this opportunity alone and supply distant national markets or international markets.

The minimum procurement for active charcoal being one container – i.e. the capacity of few kilns during few weeks - it is out of reach for most of local SMEs. Taking into account this demand and the critical size needed to reach markets, local entrepreneurs were supported by the project. The latter invested initially in the building of few kilns (hiring highly skilled workers from other provinces, convincing entrepreneurs to invest in materials and land), the majority of other kilns being built with the support of a foreign investor from the Region, seeing interest in diversifying its production sites. In addition to the construction of kilns, accessing this market necessitates costly analyses and certificates. Samples were analyzed by the project, specifications for procurement developed. For the production of activated carbon, investments and technologies needed are much more important, and the project is in this case acting as a broker to attract investors, disseminating information and advocating for local investment.

As described above, there was initially very limited supply of bamboo charcoal, and there were many entry barriers that could not be lifted by local entrepreneurs alone: financial, but also technical ones. Given the potential economic but also environmental impact of active bamboo charcoal (bamboo charcoal as a substitute to wood charcoal), the project considered that this new product was strategically important to develop. To date results are still limited to few sales of bamboo active charcoal, but if activated carbon is produced, it would have an important impact on local job creation, poverty reduction, and would also help Vietnam to limit imports of activated carbon.

Is such strong and external support justified? Is there a risk of market distortion in this particular case? Can a project so strongly interfere with the local economy? If major similar opportunities are identified, what are the alternatives for a project willing to help local businesses, if direct intervention should not be – in theory – recommended?

Discussion

The current recognized best practice when supporting supply chains in order to reduce poverty can be found in "market working for the poor initiative" (M4P) synthesis (2008): "M4P is an approach to developing market systems that benefit poor people, offering them the capacities and opportunities to enhance their lives. […] M4P requires that organizations play a facilitating role. Standing outside of the market system, facilitators work with different players within the system, to make it work more effectively. Their essential role is active and catalytic, to enable others to do rather than do themselves – stimulating changes in a market system without becoming part of it." The definition of "within" and "out" of the market system is important here. In the example above, we can say that the project is "out" of the market system when facilitating contacts between investors to develop an activated charcoal production plant, but we can say that it is "within" when subsidizing the building of kilns for active charcoal, helping entrepreneurs to buy new machines, searching actively for

outlets for a new market. This choice to support directly local entrepreneurs to develop new markets is a risky and strategic one. The project is accepting to support partially a risk with stakeholders they are working with. Doing so, they are becoming part of the market system, which is contrary to best practices promoted in this field. But when the role of projects is to act as service provider, to facilitate linkages, strengthen entrepreneurs, it is sometimes difficult to identify the limit between market support and market distortion. Is it justified to support one pre-processing workshop if the manager is facing difficulties with buyers? How far the project should support this entrepreneur, share the risk with him?

One could argue that if local entrepreneurs can not invest themselves, leading firms could be major players. Some experiences had been conducted by the project with leading firms but it was not successful, short-term commercial views overtaking longer term agreements. The above paragraph stressed that in the current situation it is easier for SMEs to sustain growth locally, as no proper linkages are in place with leading firms. In Vietnam the latter are indeed exerting pressure for cost reduction and compressing the margins of their suppliers, more especially in a situation of Oligopsony, as it is the case in Thanh Hoa. Before lead firms being able to contribute to local development, a long term intervention to up-grade supply chain for more collaborative approaches is necessary, involving leading firms and promoting responsible business and sustainable management of resources; in parallel, a short term strategy to support in priority SMEs and favor more competition between leading firms is also important to create the conditions for sound future development.

To facilitate local sustainable development at scale without leading firms and with limited project intervention, attracting responsible investors is recommended: it means that market development will not be artificially supported and that better practices, more sustainable development will be favored. It is the case for instance for the bamboo activated charcoal. When investors can not be identified, it means that the risk is too high for them. If the project is investing instead of private actors, then the decision process should be very methodically justified (environmental impact, poverty reduction, cleaner production, etc.), and the risk should be supported and accepted by donors. Doing so, the project and donors are setting a – more or less formalized - public-private partnership promoting innovation, more responsible and sustainable businesses. As noted by Warner and Kahan (2008), such involvement of donors can make the venture more attractive to other potential investors.

When development practitioners are operating in disadvantage areas, even if a real potential exist, it will not be easy to attract investors or have the support of leading firms, the latter having often short term strategies and constraints not compatible with long term and balanced development of nascent markets. Supporting directly and strongly SMEs, in this context, should not be disregarded as market distortion, as – in fact – market should be modified, in the sense of better functioning, more innovation, diversification of production, etc. To achieve this goal, public financial support (from donors and local authorities) can be used to support local actors and attract private participation into risky supply chains. Lead firms have also an important role to play, if they agree to promote more sustainable practices, for their long term interest. They should therefore not be opposed to SMEs or farmers, but linked up-stream as much as possible to increase awareness and long term commitment.

Conclusion

Up-grading bamboo supply chain for poverty reduction is a common objective of many development actors in Vietnam and in other countries. The Chinese model is attractive as it showed - in the richest provinces of China - a huge potential for jobs and value creation. Yet, determinants of poverty reduction are very complex and embedded in local situations (social, political, cultural, environmental) and global economic evolution.

Connecting local actors to global important markets can seem attractive to some experts as it could in theory have huge impact on demand locally, prices paid to farmers. But prices are determined by global factors, and experience shows that price increases are rarely significant at farmers' level. In the case of Vietnam, leading firms have the capacity to procure any materials – including pre-processed bamboo culms, in virtually any country from the Region, at lower prices if necessary. The bet that a "big bang" can appear with new technologies or big investors is therefore hazardous and impact on prices would anyway be diluted before reaching farmers if linkages up-stream are not improved, in a sustainable manner. Such work needs time and local investment, which are not necessarily compatible with the pace of investors or leading firms.

Lessons from experience are showing that the priority should be on increasing capabilities and promoting sustainable practices locally. This is possible if relatively small innovations are promoted and supported by local entrepreneurs. If the impact can only be limited in terms of scale, it is stronger and of major importance in terms of ownership and sustainability, resilience to external chocks. A too rapid and massive intervention on a nascent market would not give enough time to local actors to adjust to the new situation. As agricultural systems are quite rigid and fragile, resources could be threatened, but also the local economy. If in theory a liberalized market allows easier destruction and creation of businesses toward more efficient systems, in disadvantage areas such processes can inhibit local initiatives and mitigation measures for nascent markets can be justified.

Sowing the seeds of future economic expansion at small scale, locally, is not gratifying but is necessary for the development of nascent markets, in poor and often remote areas. The fact that some products are not necessarily promising in financial terms– such as mushroom production or bamboo baskets – does not mean it should not be promoted as it can have longer term structuring impacts. Diversification of productions and job creation, linkage to local markets, capacity building, and empowerment of actors are fundamentals that can not be easily measured in terms of contribution to the economy but that are however crucial for sustainable and responsible development. If such fundamentals are in place, linkages down-stream with leading firms will become more relevant and less risky for the local economy and bamboo resources, market development being sustain by a more resilient and more sustainably managed supply chain.

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[1] Sources: Gret documents (Luong Development Project) and Mekong Bamboo programme

[2] Project funded by various donors to support the bamboo supply chain in Thanh Hoa Province

[3] International Finance Corporation, World Bank

On-Farm Participatory Research for Development of Integrated Management of Bamboo Plantations in Northern Mountainous Areas of Vietnam

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Abstract

Development of luong bamboo (*Dendrocalamus barbatus)* plantations, with more productive and sustainable practices, promises solution to address both problems of poverty and soil erosion currently faced by a major part of the population of several districts of Northern mountainous areas of Vietnam. In Thanh Hoa Province, were about 55 000 ha of luong represents the major source of income of a large part of the inhabitants, 50% of the population, mainly ethnics, is still leaving beyond the poverty line. They are also facing a major problem of widespread soil degradation. Despite farmers are concerned by soil erosion and environmental sustainability, it is not a driving force in their adoption of new practices and they keep on looking for strategies allowing a quick improvement of their incomes.

Lessons from experience outlined the relevance of a participatory research approach to define and disseminate new technologies allowing farmers to get high income while ensuring environment sustainability. The On-Farm-Research (OFR) experimental design, implemented to test and develop more sustainable intercropping systems in new luong plantations, showed the relevance and efficiency of this approach. It also demonstrated the importance of a large scale action to get a good understanding of the array of constraints hindering farmers' strategies and ensure a broad-adoption of best-practices.

This communication deals with the main lessons drawn from these 3 years of on-farm-research and extension work on intercropping in new luong plantations, from both technical and methodological point of views. It makes recommendations on the best practices to be promoted, but also shows the difficulty to implement on farm research and promote bamboo plantations despite its many interests.

Last it gives some recommendations on the way to ensure the transfer of capacities to local actors in order to ensure a long-term agricultural development by defining by themselves the technologies addressing the changing range of constraints they are facing.

Keywords: on farm research, intercrops, bamboo, *Dendrocalamus barbatus*, groundnut, participatory planning, sustainable development

Introduction

Luong bamboo: a major source of income and a way to reduce soil erosion

Thanh Hoa province, located 150-200 km South-West of Hanoi, is one of the poorest provinces of Vietnam. According to the official list of the 61 poorest districts (61/640), seven districts of this province are belonging to the 10% of poorest districts of the country. In these mountainous districts, mainly inhabited by ethnic minorities (Muong, Thai), poverty rate is higher than 50%, with a poverty line of 200,000 VND/month/person (1 USD= 17 500 VND). The livelihood of these smallholders is based on mixed farming (lowland rice, short term crops such as cassava, sugarcane and maize on slopes, small livestock farming, bamboo plantations and forests) and relies on a large extent on a giant Bamboo (*Dendrocalamus barbatus*, locally known as Luong) plantations. Most of them grow bamboo as a "living bank", providing regular and safe income available at any time. With about 55 000 ha, North-West Thanh Hoa is the main production zone for *luong bamboo* in Vietnam (about 50% of surfaces over the country). Every year, in North-West Thanh Hoa, about 20-25 millions of luong culms are harvested (more than 550 000T/year). Luong good mechanical properties and big size allow a wide range of utilizations, such as construction, dykes reinforcement, paper pulp, and production of chopsticks, flooring, panel boards and handicraft (Gret 2008).

In Vietnam 75% of the total land area is hilly or mountainous, with a large part (about 35%) suffering from various degrees of water erosion or fertility decline (Thai Phien et al. 2002), after several years of short term intercrops grown with unsustainable practices generating high rate of soil erosion (cassava, sugarcane, maize, etc…). Upland soils, especially steep slopes, are highly prone to quick soil erosion and depletion, due to their light texture, low organic matter and low levels of nutrients (Howeler 2002; Thai Phien et al. 2002; Storey n.d.). These soils, once they are bare (or only partially protected by low vegetal cover), are very sensitive to run-off (Podwojewski et al. 2008; Valentin et al. 2008; Orange et al. 2007), especially in areas like Thanh Hoa, where heavy rainfalls and storms occur in a short period (May to September). Thanks to "its extensive fibrous roots system, the leafy mulch it may produce on the soil surface, its comparatively dense foliage which protects soil against beating rains, and its habit of producing new culms from underground rhizomes which allows harvesting without disturbing the soil" (Zhou et al. 2005) bamboo is favored for its ability to reduce run-off and fertility loss (Kleinhenz et al. 2001; Farelly 1984; Storey n.d.). Planting *luong* is therefore a sustainable source of incomes for smallholders, having positive environmental impact and bringing sustainable incomes.

Main limitations to luong planting

In the 70's and 80's, government local agencies were widely involved in the support and incentive to the augmentation of surfaces dedicated to luong plantation. Most of the researches on luong plantation and management practices were conducted in the 70's (PI, 2008) and only few were carried out afterwards (PI 2008, Nguyen Hoan Nghia 2005). However, researches on bamboos of Vietnam were not totally completed for a field or species at a period of time, but various and scattered in different units and regions, so that this makes it difficult for people to follow and apply (PI 2008). Moreover, except some technical procedures edited by extension services, like "The Technical procedure to plant Luong" (MARD 2000), few actions are currently

carried out by government agencies promoting luong sustainable development. It results in difficulties for developing luong compared with crops more integrated to the market through agro-industries companies (sugarcane, cassava, maize but also acacia for paper). Indeed, such companies provide active and strong incentives to farmers (technical advices, advances for inputs…). These difficulties are reinforced by the lack of income during the early years of luong plantations, as one has to wait 5 to 7 years before the first harvest.

Main principles and objectives of project action

To tackle these issues, identify and transfer to farmers best practices for luong planting and management, in 2005, Research and Technological Exchanges Group (Gret) started to locally assess and select a comprehensive set of practices, from luong planting to harvest management (planting density, quality of seedlings, season of plantation, intercropping in early years, fertilization of newly planted and mature plantation, rehabilitation of degraded plantations, harvest management), before running activities to disseminate the best practices. Most of the tested techniques will not show significant results before one or two more years. However, trials on intercropping newly planted bamboo with other crops, launched in 2006, already provided interesting results.

These activities are part of the comprehensive set of actions implemented by Gret to develop and structure the local bamboo value-chain and to improve the positioning and income of small-holders. One component focuses on farmers and resources, through the support to the development of homestead nurseries and new plantations, the implementation of trials and demonstrations on planting and sustainable forest management, the support to farmers' organizations and creation of links with enterprises and markets. Other activities are related to the support to bamboo supply chain down stream: facilitate exchange between supply chain stakeholders, build capacities of entrepreneurs, support small and medium enterprises, support marketing, relations with investors, and tests for diversification of production. Some complementary activities were related to sector enabling environment: discussion with local government on problems and solutions for smallholders and bamboo processing entrepreneurs, multi-actors discussions and seminars, capacity building of local actors, organization of meetings and visits, exchanges with external actors on bamboo.

This communication deals with the main lessons drawn from these 3 years of on-farm research and extension work on intercropping in new luong plantations, from both technical and methodological point of views. It makes recommendations on the best practices to be promoted, but also shows the difficulty to implement on-farm research and promote bamboo plantations despite its many interests. Thus, it shows how long sustainable practices promotion can be hindered by smallholders' short term agendas and specific financial and social constraints, and need a comprehensive approach to ensure a sound long-term development.

Project Methodology

On-Farm-Research and Participatory Research

OFR is a research model based on a cooperative effort (between researchers, technicians and farmers) targeting the identification, development or adaptation, and use of technologies specifically tailored to meet farmers' needs and constraints.

Main principles of OFR and Participatory Research

The concept of Participatory and On-Farm Research initially attained wide-scale use in the 70's by researchers and agronomists, as a response to the failure of top-down Transfer-of-Technology model. Technology packages developed under controlled conditions of research stations failed to meet resource-poor farmers' needs and means (for example they were requesting more inputs that what farmers could afford, were not taking into account farmwork planning,...) and where not broadly adopted. Participatory approach is primarily based on the assumption that agricultural technology must emerge from the farmers' needs as they co-identify them. It underlies the need to consider farms as complex systems composed by an array of interrelated matters (technical, environmental, institutional , social and economic) which hinder farmers strategies and practices (Selener n.d.) to define technologies which can be effectively adopted by farmers and benefit to the farm as a whole.

This OFR process is based on innovation co-construction, through:

1. Introduction of technical innovations which are locally not yet found on steep slopes (new crops and/or new tending practices);
2. Adjustment of techniques and extension method to the variability of the local conditions (different types of soil, slopes, etc) and to the farmers' means and constraints;
3. Improvement of dialog and confidence between farmers and agronomists;
4. Dissemination (or extension) of these practices from Farmers' Fields' Schools.

Farmers do not only provide land and labour, they are also involved in the selection, monitoring and evaluation of the tested technologies. OFR involves several levels of control and management exercised by farmers and researchers (from Researcher-Managed OFR to Farmers-Participatory OFR). Rhoades (1982) defined four stages in which farmers could be more or less involved: 1) Definitions of problems to be solved; 2) Research of possible solutions; 3) Experimentations of these solutions; 4) Assessment of the results. The method adopted here sought a participation of farmers in all stages. Indeed success of Participatory Research is embedded in the quality and steadiness of exchanges between farmers and researchers. The local anchorage of the project agronomists and technicians (who are living in the countryside, in two traditional houses located at less than 1 hour from all trial fields) is one key of its intervention success.

A participatory definition of problems and planning

Participatory Rural Appraisals were organized in each communes of action and identified the lack of income during the early years preceding the first harvest (usually done 5 to 7 years after planting) as a main constraint preventing farmers from planting luong (together with the competition with other crops and tree species providing higher income on the short and medium run while getting incentives from agro-industries companies). It also outlined that farmers are used to intercrop newly planted luong with short-term intercrops providing high income with techniques having negative impact on both soil fertility and luong growth. Prior to project action, there was no specific research or technical advice for farmers regarding these issues.

Then, focus groups were organized in 3 communes to select crops improving erosion control while ensuring short-term income. Farmers and agronomists discussed the negative impact of cassava, sugarcane and maize on both soil fertility and bamboo growth due to unsustainable practices (no or low mineral fertilisation, no cover crop). They also debated the possible interest of replacing them by other short-term crops: groundnut, soybean, mongo bean and sesame. Indeed these crops and more especially groundnut were proved to have better impact on soil erosion thanks to faster-developing and wider vegetal cover (Steiner 1985, Putthacharoen et al. 1998, Thai Phien et al. 2002). Legumes were also expected to increase the quantity of N available in the soil for luong while not much competing with it for light, water and other nutrients (thanks to a low spatial competition of foliage and roots systems between the two crops).

Farmers who were interested in running trials were registered and involved in trials design and implementation. They were provided with technical and financial support from project and had to respect one specific crop management sequence, to ensure a homogenous experimental design. Financial support (initially project covered 50% of expenses) was provided to allow poorest farmers to get involved in trials and follow agreed crop management sequence. Such financial support is also often necessary to encourage farmers to shift from cultivation of crops for which they get advances on inputs from agro-processing factories. Other farmers registered to get seeds and technical support and test these crops on "demonstration plots". For these "demonstration plots" there were no fixed operational sequence and part of the plots was monitored to provide "transitional results" on operational sequences less extensive than in trials (as farmers applied lower density and less fertilizer). Last, several farmers decided to keep growing the same intercrop than usually (cassava, maize, sugarcane) and their results were monitored too as "reference crops".

A strong technical support

Farmers were provided with a strong and steadiness technical support through:

1. One-Day Farmers' Field Schools (half day dedicated to theory, half day for practicing in field) organised at hamlet and village scale on intercropping practices (for each crop : sowing date, fertilization, planting density, tending practices, pest management);
2. In 2008, two technical leaflets: (addressing groundnut and soybean intercropped with luong) were printed to be used as a technical reminder for trained farmers (as farmers are not used to take notes during trainings) and to facilitate dissemination of sustainable practices;
3. Regular visits of technicians providing farmers opportunities to discuss and solve agronomic problems likely to reduce yields (pest, diseases, unsuitable practices, etc…).

A joint evaluation of results

A particular attention was paid to allow a common evaluation of trials results, involving farmers, local authorities and agriculture services. Two types of restitution seminars were organised a few days before harvest:

- One-Day Seminars were organised in each village. They gathered farmers involved in trials on short-term intercrops but also those benefiting from project support for luong new plantations, village leaders and project collaborators.

- One-Day specific Seminar was organised in one commune (gathering most of project trials) in which were also invited commune and district authorities and representatives of agricultural extension services.

These seminars gave stakeholders the opportunity to visit trials ran in the commune, to discuss results presented by project technicians and to make proposals for the following cropping seasons (which new crop or techniques to be tested? Where? ...). In addition to these seminars, project organised visits for farmers and local authorities from other projects (Hadeva in Phu Tho, Gret project in Houa Phan Laos). These projects working on luong plantations were planning to test, promote or support short-term intercrops in new luong plantations. They visited trials and demonstration plots and met some farmers growing short-term intercrops in their new luong plantations.

An iterative process

Five series of trials and demonstration plots on short-term intercrops were run from spring 2006 to autumn 2008 (Table 1). Running trials during several seasons and in different locations is essential to assess both agronomic and economic results under variable annual climatic and market conditions while promoting wide-scale extension. It was also the opportunity to regularly refine trials through an iterative assessment process: after each harvest, farmers where invited to discuss the results. Crops selection evolved according to results, to confirm the suitable crops and replace unsuitable ones. In 2007, following good yields obtained for groundnut, farmers decided to test new cultivars (L14 and L20) purchased by project in other provinces. These improved varieties were expected to provide higher yield than “local” variety. At the end of the second phase, farmers decided to test mixed intercrops (luong + groundnut + cassava, luong + groundnut + maize). They target win-win strategies: gain profit from positive impact of groundnut on soil and additional income from cassava or maize, while reducing economic risk (diversification).

Project support method evolved too (Table 1). In 2008, to avoid some problems met during previous year (some farmers were not able to purchase enough fertilizer or to spend enough labour due to family problems) it was decided to increase the financial support of farmers running trials to cover 100% of the expenses. To improve the homogeneity of the experimental design, it was also decided to reduce the number or farmers involved in trials and do several replications on each plot. Indeed, soil condition can drastically change from one plot to another one (due to cropping history, slope...) and even within one plot (soil fertility being usually lower on the top of slopes than on the base). Doing several replications in one plot allowed to reduce this variability.

Table 1 : main evolution of trials objectives, scale, assessment and reorientation

Project phase	*Objective*	*Trial scale*	*Results of participatory assessment*	*Reorientation*
LDP 1st phase (spring 2006)	Compare: - Food and industrial short-term crops (groundnut, taro), - Spice and medicine crops (kudzu, ginger) - tephrosia hedgerows)	-12 trials, - On 5 species, - In 3 communes. - 1 district (Ngoc Lac)	- Kudzu and taro not suitable - Groundnut, Ginger and tephrosia suitable	- Keep on assessing groundnut and tephrosia - Test other crops (soybean, mongo bean and sesame) in both spring and autumn seasons
LDP Interim phase (spring-autumn 2007)	Compare: -"Reference" crops (cassava, maize, sugarcane) - Groundnut, soybean and sesame; - Keep on assessing tephrosia	- In 5 communes - In 2 districts (Ngoc Lac, Thuong Xuan); - 83 households (for trials, demonstration and reference crops) - 105 *sao** (5.25 ha)	- Groundnut ensure the best agro-economic results; - Cassava and sugarcane keep arising farmers interest	- Keep running trials on groundnut, soybean and sesame - Run trials on mixed intercrops (groundnut + cassava, groundnut + maize).
LDP 2d phase (spring-autumn 2008)	- Keep on running trials on legumes and sesame. - More trials on groundnut as previous trials outlined its agronomic and economic interest. -Introduce and test 2 new cultivars L14 and L20 - Less trials (but replications)	- In 9 communes; - In 4 districts**; - Results monitored for: 45 Households; 95 plots	- Groundnut ensure the best agro-economic results; - L14 is the most suitable variety; - Mixed intercrops showed good results	- No more trials but support for seeds for "demonstration plots" - more demonstration plots on groundnut with new practices (high density, early sowing) - keep testing mixed intercrop

* 1 sao = 500m²

** Project activities extended to 2 new districts (Ba Thuoc and Quan Hoa), located in the north-western part of Thanh Hoa province.

Extension Work

As explained above, seeds and technical support were provided to a larger number of farmers who were not involved in a formal OFR. Such "demonstration plots" were expected to promote a wider and more sustainable adoption of the appropriate techniques. Crops and technical trainings were achieved together with OFR similar activities. Support for seeds was limited to 2 *sao*/household (0.1 ha), in order to maximise number of beneficiaries. From spring 2008, project decided to provide its support through the establishment of seeds banks. Seeds were provided to farmers as a loan to be reimbursed right after harvest. Then seeds were borrowed to other farmers for the following cropping season. That way, seeds banks were expected to expand and sustain the dissemination of crops (especially groundnut): demonstration plots outline the agronomic and economic interests of these crops, while seed banks encourage more farmers to try such model on their own plots (by reducing investment costs). They also gave access to more farmers to new cultivars not locally available (L14 and L20). More than 400 families grew groundnut on about 30 ha of new luong plantation during this project's

stage. More than 90 families grew soybean on 10 ha. About 50 km of Tephrosia were also planted as contour line and hedgerows.

Description of project achievements

Trials results

Outcomes expected form crops (legumes and sesame) tested by farmers were threefold:

1. Provide a short term income similar or higher than crops traditionally intercropped with newly planted luong (cassava, maize, sugarcane);
2. Limit the soil erosion occurring on local steep slopes and increased by crops usually selected;
3. Promote luong growth, instead of competing with it, to ensure a faster development and allow earlier first harvest.

Results presented here were discussed with and agreed by both farmers and local authorities

Agro-economic results (Vogel 2007, 2008)

The main result drawn from this OFR is that groundnut is the most suitable crop to be intercropped with newly planted luong on steep slopes within this locality.

Table 2 : Yield of crops monitored in 2007 and 2008

T/ha	*Spring 2007*	*Autumn 2007*	*Spring 2008*	*Autumn 2008*	***Average***
Groundnut[1)]	2.8	1.1	1.9	1.1	1.7
Soybean[2)]	0.9	1.0	1.9	0.6	1.1
Sesame[2)]	0.4	0.3	0.4	0.3	0.3
Fresh cassava	52.3		16.5[4)]		34.4
Dry cassava	18.5		8.1		13.3
Sugarcane[3)]	64.8		41.2		53
Maize	2.7	1.4	N.D.	1.8	2.0

[1)]Yield of dry pods (as farmers are used to sell this crop);

[2)]Yield of dry seeds (as farmers are used to sell this crop);

[3)]Mean for a 3 years' cycle; [4)]Contrary to legumes and sesame, yields of cassava, maize and sugarcane were not monitored on the same plots in 2007 and 2008, so variation may not be linked to climate variations or cropping sequences;

Groundnut is well adapted to local conditions and is not much sensitive to diseases and climatic disturbances. Yields (Table 2) are close from those quoted by Thanh Hoa local Agriculture office (2.4 T/ha in 2007). Yields were lower in 2008 due to the exceptional bad weather which occurred in winter and delayed the two cropping cycles. Groundnut ensures high incomes (more than 30 millions VND/ha/year) (Table 3). Trials also outlined that groundnut got higher results when sown before the 5th of March with a high density (more than 20

plants/m²). However, groundnut is sensitive to shadow, so that it should not be grown once luong vegetative cover is well developed (2 to 3 years-old plantations). Last, the variety L14, introduced in the area by the project, ensured the best yield and income in this area (compared with local variety, and another variety introduced by project L20).

Soybean has a good potential on slope (1.7T/ha for a Net Income of 15 millions VND/ha) but should be proposed on good land and with intensive care only. Average yields obtained were lower than 600kg/ha (Table 2), leading to a negative net income average (main expenses being for fertilizers supported by project). Indeed, this crop is sensitive to soil and weather conditions and to pests and diseases regularly occurring on steep slopes, where farmers are not used or able to provide intensive cares.

Sesame mean yield was 300kg/ha (Table 2), and several households got low yields due to heavy rainfalls at sowing and/or flowering time. They got Net Income almost nil (main source of expenses being fertilizers). Nevertheless, sesame also provided good yields (600kg/ha, net income =11.5 millions VND/ha) when these two growing stages were not affected by rain.

Table 3 : Economic results of the most interesting crops monitored in 2007 and 2008

			Spring 2007	*Autumn 2007*	*Spring 2008*	*Autumn 2008*	***Annual Average***
Groundnut	NI[1)]	1000VND/ha	22 860	18 564	12 608[4)]	16 780	**35 406**
	ROI[2)]	%	4.6	5.5	1.0	2.0	3.3
	NI/ FLD[3)]	VND/day	95 250	77 350	26 913	47 026	61 635
Fresh cassava	NI	1000VND/ha		40 562		5 212	**22 887**
	ROI	%		30.9		1,7	16
	NI/ FLD	VND/day		126 757		44 962	85 859
Dry Cassava	NI	1000VND/ha		44 853		8 030	**26 442**
	ROI	%		34.2		3	18
	NI/ FLD	VND/day		131 922		10 037	70 979
Sugarcane	NI	1000VND/ha		6 193		10 762	**8 477**
	ROI	%		0.4		0.5	0.5
	NI/ FLD	VND/day		47 467		204 637	126 052
Maize	NI	1000VND/ha	6 162	2 840	ND	3 363	**9 002**
	ROI	%	5.9	2.3	ND	1.7	3
	NI/ FLD	VND/day	32 434	21 850	ND	46 364	33 549

[1)] NI = Net Income;

[2)] ROI = Return on Investment = Net Income/ Total expenses;

[3)] NI/LD = Net Income/Family Labour Days;

[4] Groundnut pods sale price is higher in autumn than in spring. Yields obtained in spring 2008 were higher than in autumn but due to winter bad climatic conditions, production quality was lower and farmers got lower price.

In 2007, **cassava** prices benefited from a 50% increase (Table 4), allowing a high economic interest (more than 30 millions VND/ha for fresh pods for a high yield of about 50T/ha) and encouraging farmers to grow cassava on larger surfaces in 2008. Nevertheless, international market fluctuations led to a drop in prices, which were reduced by half. Net Income (Table 3) drastically decreased (about 10 millions per ha, for a yield of less than 20T/ha).

Table 4 : Main evolutions of cassava price from 2006 to 2009

Price (VND/kg)	*December 2006-January 2007*	*December 2007-January 2008*	*December 2008*	*January 2009*
Fresh cassava	400	800	500	350
Dry cassava	1500	2500	1500	1300

Net Income from sugarcane (Table 3) remains lower than the one obtained for cassava and groundnut and provides a low Return on Investment (less than half of invested amount) as amount of inputs (for fertilizers and labour) is high. Moreover, harvest is very restrictive: date of this time-consuming activity is fixed by the factory and may compete with other farm activities (like rice transplanting, groundnut sowing…).

To a lesser extent, maize is also traditionally intercropped with newly planted luong. In most of the communes of project intervention, maize is grown in a very extensive way with low inputs, leading to low and variable Net Income (except in Cao Ngoc where it is widely grown due to the establishment of a maize processing company facilitating access to fertilizers). However, project did not monitor enough plots and there was a too great variability among results to draw any firm conclusion on agro-economic results of maize intercropped with luong on steep slopes. A last crop locally intercropped with luong was upland rainfed rice. Nevertheless, it was identified in few places only and was not monitored by project.

Impact on soil erosion

In Thanh Hoa Province, 2/3 of the territory is covered by hills and mountains. These soils are highly prone to erosion, especially when they are bare, due to a light structure, a low depth and low level of organic matter, especially when short-term crops were grown with unsustainable practices (no or inappropriate mineral fertilisation, no cover crop...) during several years (Tran Dinh Tro 2001, Valentin et. al 2008). Heavy rainfalls occurring in the area (1800 mm/year, concentrated in few months, from April to July) are also an aggravating factor. Mature luông plantations allow to reduce soil erosion (thanks to high roots and vegetative covers), but not the newly planted ones (4-5 first years). Intercrop can partially solve this problem if suitable crops and practices are selected. OFR trials were run to assess the impact of different intercrops on soil erosion in less than 1 year-old luong plantations.

Table 5 : Main results of trials on impact of several cropping associations on soil erosion

Cropping associations	*Spring 2007*				*Spring 2008*			
	Time	Pp (mm)	Eroded soil (kg/ha)	%	Time	Pp (mm)	Eroded soil (kg/ha)	%
Bamboo + Mongo bean + Soybean	18/06/07-06/08/07	297.3	48.6	17.3				
Bamboo + Cassava			107.8	38.4				
Bamboo+ Sugarcane			280.4	100				
Bamboo + Groundnut					25/05/08-10/06/08	147	171.2	33.1
Bamboo + Soybean							370.4	71.5
Bamboo + Maize							518	100

In spring 2007, trials showed that the amount of eroded soil with luong intercropped with legumes was only 20 % compares with luong intercropped with sugarcane and 50% lower than with luong intercropped with cassava. Trials ran in spring 2008 showed that run-off when intercropped with groundnut was only 33% of the one observed with maize, while soybean was 71.5% (Table 5). However, as soybean was harvested earlier and not immediately followed by another crop, soil erosion drastically increased after harvest. These results should be used as a rough guide only. Indeed these trials on soil erosion, done in short period (less than 3 months) without repetition were done for a demonstrative purpose rather than a scientific one. However, they corroborate other trials ran on more scientific bases in other North Vietnam hilly area ((Nguyen The Dang et al.; Thai Phien et al. 2002) and other parts of South Asia. For example, trials ran in Thailand showed that cassava grown for root production caused more than twice as much dry soil loss by erosion as mungbean, and three times more than maize, sorghum, groundnut and pineapple (Putthacharoen et al. 1998).

Other practices were also tested by farmers with project support, but results were not monitored or did not allow to draw any firm conclusions (not enough samples, too much variability). *Tephrosia candida* seeds were provided to be planted between luong lines. This two-years-cycle legume is commonly known for reducing soil erosion and improving soil when its residues are returned to soil. Trials run in Vietnam North Provinces (Nguyen The Dang 2002) showed that *"when hedgerows of tephrosia candida and/or vetiver grass were added, erosion declined to only 40-49% of reference treatment"*. From spring 2008, farmers also started to test mixed intercropping (groundnut + cassava, groundnut + maize, groundnut + sugarcane) in their new luong plantations. Such cropping systems are already commonly grown on lowlands (without luong) but not on slopes. Farmers were satisfied by results, especially for groundnut +cassava.

Further researches should be done on soil erosion reduction. Other practices showed good results in other provinces. For example, Thai phien (2002) reported that the combination of these two measures (Intercropping cassava with legumes and *tephrosia candida* hedgerows) *"improves soil fertility, resulting in higher yields of cassava and intercropped legumes as compared to the control treatment without hedgerows"*. Moreover, except one farmer who grew groundnut during 3 cycles (spring, autumn, winter) and who get low yield, slopes are left

fallow during winter and are more exposed to run-off. More work could be done to identify a cropping system ensuring a proper soil cover through the year. Studies were already carried out in other hilly areas of North Vietnam on cover crops (Affholder et al. 2008). However, although farmers are concerned by soil erosion and environmental sustainability, it is not a driving force in their adoption of new practices. They are first looking for strategies allowing a quick improvement of their incomes (Orange et al. 2008).

Impact on luong growth

Two series of trials were run to assess the impact of different crops on luong growth. Best luong survival rates were obtained with groundnut, while the worst one was observed for luong intercropped with cassava. More shoots were obtained with legumes and sesame. Biggest shoots were observed for clumps intercropped with soybean while clumps intercropped with sugarcane produced the highest shoots. Worst results were obtained with cassava (Table 6). The second series of trial confirmed the negative impact of cassava on luong growth: luong produce smaller and weaker shoots when grown close to cassava. Nevertheless by applying a distance of more than 1m between luong and cassava plants this negative impact was reduced. Mixed plantations of acacia (*keo*), luong and cassava gave the worst growth for all crops.

Table 6 : Results of trials on impact of several intercrops on luong growth

Treatments (Year 2007)	*Bamboo Survival rate (%)*		*Number of shoots/clump*		*Shoots diameter (cm)*		*Shoot height (m)*	
	Spring	Autumn	Spring	Autumn	Spring	Autumn	Spring	Autumn
Bamboo + Groundnut	95,9	97,2	2,1	4,3	1,1	1,4	1,7	1,9
Bamboo + Soybean	94,5	94,5	2,3	4,1	2,1	2,4	1,5	2,4
Bamboo + Mongo bean	94,5	94,5	2,2	0,0	1,9	0,0	1,7	0,0
Bamboo + Sesame	94,7	94,7	2,1	3,7	1,5	2,2	1,7	2,3
Bamboo +Cassava	57,5	53,5	0,3	0,6	1,4	1,1	1,1	1,7
Bamboo + Maize	85,3	85,3	1,7	2,7	1,4	2,3	1,3	1,9
Bamboo + sugarcane	94,3	91,3	1,4	2,4	0,9	1,3	2,0	3,0

Negative impact of cassava, sugarcane and maize on young luong is mainly explained by competition for light and nutrients (as their canopy is higher and their roots system more developed). This impact is limited in sugarcane fields due to the high rate of fertilizers applied. Nevertheless, it has been observed that the burning of sugarcane residues after harvest and trucks may dramatically damage bamboo shoots and leaves. On the contrary, legumes do not compete with luong for light and competition for nutrients and water is limited, while reducing soil erosion and improving soil fertility. Luong develops more and bigger shoots and can be harvested earlier.

Two years after plantation, demonstration plots implemented in Kien Tho (by the *green hill* farmers' group) showed marked differences in luong clumps development with different intercrops. Luong intercropped for 2 years (4 cropping seasons) with legumes, and more especially groundnut, showed a development close from the

one usually observed for 4 to 5 years-old luong planted in traditional way, while luong intercropped with sugarcane and maize showed a slow development.

Discussion on the main lessons drawn from experience

Running trials through OFR research was expected to provide accurate results on agro-economic potential results of different intercrops while initiating the spreading of the intercrops identified by farmers as the most suitable ones.

Scientific value of OFR

The statistical rigour of results obtained through OFR can't be the same as for agronomical trials run in station. For statistically significant information on crops (like impact of several techniques on yield and income, comparison of several cops…) a larger number of plots is requested to have enough replications of different cropping systems and/or treatments and conduct variance analysis. With OFR, it is difficult to set a large experimental design of plots with similar soil conditions, as farmers are smallholders with specific soil conditions (various locations, cropping history...). Then, even with financial support, farmers tend to adapt recommended techniques to their means, working calendar (trials barely coming first) and most of all, short-term strategy (leading them, for example, to reduce time invested for one crop showing low development to limit financial risks). Such modification in operational sequence make analysis and comparison more complicated. Moreover, trials are highly time consuming and request skills (for monitoring, data capture and analysis). It limits the number of crops and techniques which could be successfully tested and monitored by project. As a consequence, it was not possible to get all the statistically significant data initially expected, more especially regarding mixed intercropping in luong plantations.

However, the statistical rigour of results obtained on research station often failed to ensure their broad-adoption. OFR has another scientific dimension based on a systemic perspective essential to tackle the complexity of farmers' real constraints. The assessment of real potential of a technical innovation is inseparable form the understanding of the array of constraints hindering farmers' strategies. As outlined by Chambers et Al. (1985), "the criterion of excellence is not the rigor of an on-station or in-laboratory research, or yields in research station or resource-rich farmer conditions, but the more rigorous test of whether new practices spread among the resource-poor".

Factors behind Best-Practices Wide-Scale Adoption

This 5-seasons experience was the opportunity for technicians and farmers to define test and compare several intercropping systems. Being involved at each step of the research process allows farmers to identify and select practices adapted to their needs and means. The most compelling proof is the adoption of the most suitable practices (groundnut, groundnut + maize or cassava) by most of the farmers who tested it during the following cropping seasons, until luong was too much developed to ensure a proper growth of groundnut (2-3 years after luong plantation). Moreover, in each commune, the number of people interested in intercropping groundnut with newly planted luong increased after one year of OFR and extension work. In any communes where LDP carried

out activities on intercrops, some farmers started to grow legumes (mostly groundnut) on their slopes and/or luong new plantations, without project support. Most of them started after observing results of their neighbors who got support from project. Some of them were already used to grow legumes on their lowlands but not on their slopes. This multiplying effect was facilitated by the creation of seed banks allowing a wider number of people to test groundnut without additional investment from project. OFR also provided crucial additional information on agro-economic results of the main cropping systems implemented on slopes in project area and their insertion in local farming systems. Trials also led project staff to learn more about recommendation to be done at local level for yields improvement (sowing time, density).

Moreover, most trials and demonstration plots were supported though the establishment of farmers' groups. When most of farmers' plantations are grouped in the same location, it arouses an emulation, especially in one commune where most of farmers replanted luong on the same hill (after several years of sugarcane) and enthusiastically named it "the green hill" (*doi si xanh*). This enthusiasm was reinforced by the numerous visits of their plots organized for farmers and local authorities from other communes, districts and provinces (and even three visits of Laotian people). These visits also allowed to initiate the spreading of these practices in these new locations (for example, after their visit of the "*green hill"* in Kien tho, farmers from Phu Tho, supported by Hadeva, showed a great interest for intercrop and agreed to grow them in their new luong plantations). Farmers running trials or demonstration plots were involved in each visit, and their exchanges with farmers from other places were fruitful in outlining the interest of legumes to be intercropped with luong on steep slopes.

Last, regular information and consultation of local authorities and extension services (who were more particularly involved in the pre-selection of techniques to be tested, the design of technical leaflets, restitution seminars) was also a factor of success. They appreciated the new developed practices and their positive impact on both farmers' incomes and environmental sustainability. They were supportive and facilitate project activities (by delivering on time authorizations to work in the area, to organize trainings, to establish farmers groups …)

Adoption of "Best Practices" hindered by Farmers' Short-Term Agendas

Groundnut proved to be the most suitable crop to be intercropped with newly planted luong on slopes, as it ensures high and stable income while limiting soil erosion and promoting bamboo growth. Nevertheless, other crops, such as cassava and sugarcane or maize, still arouse farmers' interest, limiting groundnut spreading on slopes. These crops also compete with the expansion of luong plantations. In Northern Provinces of Vietnam, these three crops are widely and unsustainably cultivated on slopes, despite their negative impact on soil erosion, for several reasons. Predominance of these crops in the landscape is in a large extent linked to the proximity of processing companies. Indeed, these companies offer several assets to the farmers. They provide them with technology packages (trainings, ploughing engines, access to quality seeds or seedlings, quality-fertilizers, technical advises or technical sequence...), advances to buy inputs (seeds, fertilizers, labour...) and guarantee the production purchase (but usually not the price). This way, factories compensate for three main constraints of farmers: the lack of technical advises, the access to quality inputs and the access to capital. Moreover Vietnamese farmers mostly focus on short-term agendas and are easily attracted by short-term speculative crops such as cassava and maize mainly produced to be sold abroad. As illustrated by recent

evolution of cassava prices (see above part on agro-economic results), such short-term orientated speculations are often risky.

In this context, the promotion of other models and strategies requests a specific and comprehensive support, involving all concerned stakeholders (farmers, local authorities, technicians, local agricultural extension services, agronomists, companies likely to provide input or credit…) to identify and spread best practices and provides farmers with the means to adopt them. Such approach requests appropriate means and time.

The scale of intervention into question

Gret experiences on intercropping in particular and luong in general show that the selection and sustainable diffusion of best practices request a relatively large scaled intervention, in terms of time and locations. First of all, running trials and implementing extension work in several locations (several districts and communes) allow to adjust to the variability of soil conditions (slopes, soil fertility due to different cropping history…) and economic situations (kind of infrastructures, impact of processing factories…). This variability induces the predominance of different cropping systems (sugarcane in Kien Tho, Cassava in Xuan Phu) with various yields (Table 5). As a consequence, results obtained in one commune may not appear interesting in another one (for example, trials ran in Kien Tho will not convince Tan Thanh farmers, as income obtained Kien Tho for groundnut are lower than the one obtained for cassava in Tan Thanh where soil fertility is higher).

Table 7: Comparison of yields obtained by OFR in 2008 in 3 communes

Commune (district)	*Main characteristics*	*Groundnut*		*Fresh Cassava*		*Sugarcane*	
		Yield kg/ha[1)]	*NI million VND/ha*	*Yield T/ha*	*NI million VND/ha*	*Yield T/ha*	*NI million VND/ha*
Tan Thanh (Thuong Xuan)	Groundnut and cassava were grown on cleared plots (following degraded forest)	4600	33,0	22,0	21,9	37,0	3,6
Kien Tho (Ngoc Lac)	All crops were grown on plots eroded by several years of monoculture (sugarcane, cassava…)	2280	13,7	11,0	14,3	40,0	14,0
Xuan Phu (Quan Hoa)	Groundnut and cassava were grown on cleared plots (after degraded forest)	3530	32,8	20,0	20,6	-	-

[1] Results obtained for two seasons (spring + autumn)

Furthermore, it appears essential to implement OFR during a long period (never less than 2 years) to overcome the intra- and inter- variability of climatic conditions and measure impact of crops such as legumes on soil fertility. Crops grown in spring 2008 were affected by the bad weather conditions which occurred (the longest and coldest winter faced by North Vietnam in more than 20 years). Running trials at this time only would not have show the real potential of groundnut as an intercrop with bamboo. Trials on planting and managing luong

request even longer trial period as 2 to 5 years are necessary before observing first results (in mature plantations, impact of tending practices on new shoots are obvious after 2 years of applications, while for new plantation, ones has to wait first harvest before assessing impact of introduced techniques on productivity).

Moreover, techniques introduced are often new and considerably change farmers' uses on luong plantations. Beyond the introduction of new practices, it is a matter of changing the way farmers consider their plantations. Indeed, farmers currently consider them as "safety bank", in which they invest a minimum amount of time and money (which they prefer to invest for short-term speculative crops (see § 4.b.)). To initiate a change in farmers' conception, it is essential to give them the way to test new practices during several seasons. The first years, farmers were reluctant to implement techniques proposed by agronomists (higher density, more fertilizer, more care ie. more labour), but season after season, seeing high potential of groundnut they agreed to apply these practices (even on demonstration plots, without financial support).

Beyond the issue of project scale, is the one of long run impact of such participatory research once the project withdraws the locality. Final target of such project should not be the development and diffusion of one set of new technologies, but the transfer of research and experimentation capacities to local actors to ensure farmers will be able to keep adjusting them with changing circumstances in a sustainable way. Project already paved the way to tackle this issue by supporting the creation of a local NGO (recently registered as a local cooperative) already skilled in the implementation of OFR and participatory activities. This cooperative already wins some legitimacy among local authorities and farmers, thanks to the concrete technical results already obtained, discussed and transferred by the project and the cooperative. A complementary approach could be to reinforce farmers' capacities to innovate, experiment and adapt their practices by themselves, without external support, and move toward a "farmer to farmer" experimentation network. In this case, further work has to be done to reinforce farmers' capacity to identify problems they want to address, design trials, implement experiments, assess and share results, without external support, or with a limited one from local NGO (for example to get access to information or technologies not available locally).

Conclusion

Development of Luong bamboo production and supply chain is commonly described as a way to reduce poverty while preserving environment in North Vietnam poorest districts. Despite an active period of research on luong plantation and management practices of luong in the 70's, Vietnamese authorities are currently granting few means to research and extension work for this crop.

One may be attracted to solve this issue by using results of past researches or running some additional researches in one site. However, Gret field experiences on luong supply chain in general and intercropping in new luong plantation in particular, outlines the high relevance of a more participative and comprehensive approach. Indeed development of luong and introduction of new practices are hindered by several constraints (especially the competition with other crops providing a priori a better answer to farmers' short term agendas). Such constraints have to be removed progressively and in an iterative way, by defining practices well adapted to local conditions and constraints. On-Farm-Research, with a participatory definition of tested practices and trials

planning and a joint evolution was proved to be an efficient way to demonstrate local interest of these practices and sound their sustainable adoption.

However adoption of such practices is hindered by short-term agendas of farmers and competition from other crops whose adoption is facilitated by services offered by agro-factories. As a consequence promotion of more sustainable model ensuring higher income request a relatively large scaled intervention, in terms of time and locations which may exceed project framework always limited in time. To ensure a sustainable agricultural development, project has to reinforce research and experimentation capacities of local actors. It could be done by the creation or reinforcement of local NGOs or services cooperative able to support farmers and extension services in adapting practices to new constraints. Capacities of farmers currently involved in trials could also be enhanced to create farmers to farmers' experimentation networks able to define, implement and assess their own experimentation and spread technologies and practices allowing to develop themselves their agriculture in a sustainable way.

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[1] List provided by the Ethnic Minorities Working Group (EMWG).

[2] Technical content was based on results from previous trials completed by information from the agricultural development state services at district level concerning standards and recommendation in the area for the related crops.

[3] Standards provided for lowland and intensive fertilization and tending practices

[4] Average yield obtained by excluding all plots which did not get yield. By taking them into account when, average is 600kg/ha

[5] Results not included in this table: yield in autumn = 5.1T/ha, with a Net Income = 11millions VND/ha with a ROI = 4

[6] Cassava monocropping system without fertilization.

[7] In autumn 2008, there were 2 farmers in Tan Thanh (where there was only 1 trial), 2 farmers in Phung Giao (where there was only 1 trial) and 8 farmers in Kien Tho (where there were several trials and numerous demonstration plots).

Impact Assessment of Bamboo Harvesting in the Seima Biodiversity Conservation Area, Mondulkiri, Cambodia

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Abstract

Impact on bamboo forests and local livelihoods in SBCA involves clearance for agriculture, traditional harvest for family uses, and harvest for making bamboo incense sticks. To study the impact of bamboo harvesting on bamboo resources and on family livelihoods, research was carried out in the villages of Srae Levi and O Rona. Bamboo harvesting for making incense sticks has a positive impact on the income of families in O Rona and generates a higher income than that in Srae Levi. In particular, it helps Bamboo Harvesting Families (BHFs) to alleviate food shortage during the lean period. BHFs can generate more income than non-Bamboo Harvesting Families (non-BHFs). More importantly, it is an income generating activity that supplements but does not compete with farming activities. However, the harvesting is not entirely sustainable and has negative impact on one bamboo species, *Reusei Thngor*, because its regeneration capacity cannot respond to the current level of harvesting. In addition, traditional harvest for family uses provides other benefits to families of both villages such as building materials, utensils, farm equipment, bamboo shoots for consumption, use as fallow crops in shifting cultivation and other uses in cultural ceremonies. It does not have a negative impact on bamboo forest since bamboo plants are given enough time to re-grow within the three to four years of harvesting cycle. Bamboo clearance for agriculture, on the other hand, has a more serious impact on the condition of bamboo forest in the area when compared with harvesting for making incense sticks. Furthermore, O Rona, which has better access road, easy access to market facility, and a higher population and immigration level, the rate of bamboo extraction is relatively higher than at Srae Levi.

Keywords*:* harvesting, bamboo incense sticks (BIS), impact, income and conservation

Introduction

Bamboo is largely concentrated within the world's tropical and subtropical belt in eastern and southern Asia, and South and Central America (Ohrnberger 1999). Bamboo plays a very important role in rural poverty alleviation, culture, biodiversity conservation and environmental protection in these regions (INBAR 2004; Lobovikov et al. 2007). However, this is not possible when bamboo resources are not managed sustainably. As an example, Lou and Miao (2006) reported that, in China, managing bamboo for short-term economic returns has resulted in long-term biodiversity and productivity losses.

In Cambodia, bamboo is distributed throughout the provinces in the southwestern, northeastern and eastern parts of the country. As of 2006, bamboo forest areas covered 35,802 ha, equivalent to

0.33% of woodlot forest areas in Cambodia (FA 2007). Similar to other countries, bamboo forest is important in supporting the subsistence livelihoods of rural Cambodians, protecting the environment and conserving biodiversity. Furthermore, it used to be a vital raw material for the pulp and paper industry in the year 1961 with 50,000 m^3 of bamboo culms extracted for the industry (Hang 1995). These uses have decreased since bamboo forests have come under threat from land economic concessions, agricultural land expansion, settlement, and dying-back after flowering and forest fire (ESI/SCS 2007).

The Seima Biodiversity Conservation Area (SBCA) in Mondulkiri province is a protected area of 305,590 ha, of which 6881 ha is natural bamboo forest (WCS/FA 2008a). At present, the bamboo in SBCA has great value for biodiversity conservation and local livelihoods. Nevertheless, there has been a concern about the impacts of harvesting practices on bamboo in the area from such activities as conversion to agriculture, harvesting for making Bamboo Incense Sticks (BIS) and traditional harvesting for household uses. Currently, these threats pose a challenge for SBCA. To deal with this challenge, this paper aims to assess the specific impacts of harvesting practices on local livelihoods and natural condition of bamboo forest, and to develop recommendations for improved management that would consider a compromise between livelihood enhancement and conservation within the protected area.

Methods

The Study Area

SBCA, formerly a forest concession area of the Malaysian company Samling International, was established in 2002 under the *prakas* (Declaration) of the Ministry of Agriculture, Forestry and Fisheries. At present, its management is the responsibility of the Forestry Administration (FA) with financial and technical support from the Wildlife Conservation Society (WCS). SBCA has been classified by Bird Life as an important bird area, by WWF as comprising two global 200 eco-regions, and by WCS as a last wild landscape (WCS/FA 2007). The area covers eight communes (Srae Khtum, Srae Preah, Srae Chhouk, Memong, Chongplas, Saenmonorom and Romanea) of Mondulkiri and one commune (Khsem) of Kratie province. The study was conducted in Srae Khtum commune where O Rona and Srae Levi villages were selected using cross section method. The selection of the two villages was based on two criteria (1) largely covered by bamboo forest and (2) difference in biophysical conditions. O Rona was located closer to the main road and market center, and has a higher total population than Srae Levi (Figure 1).

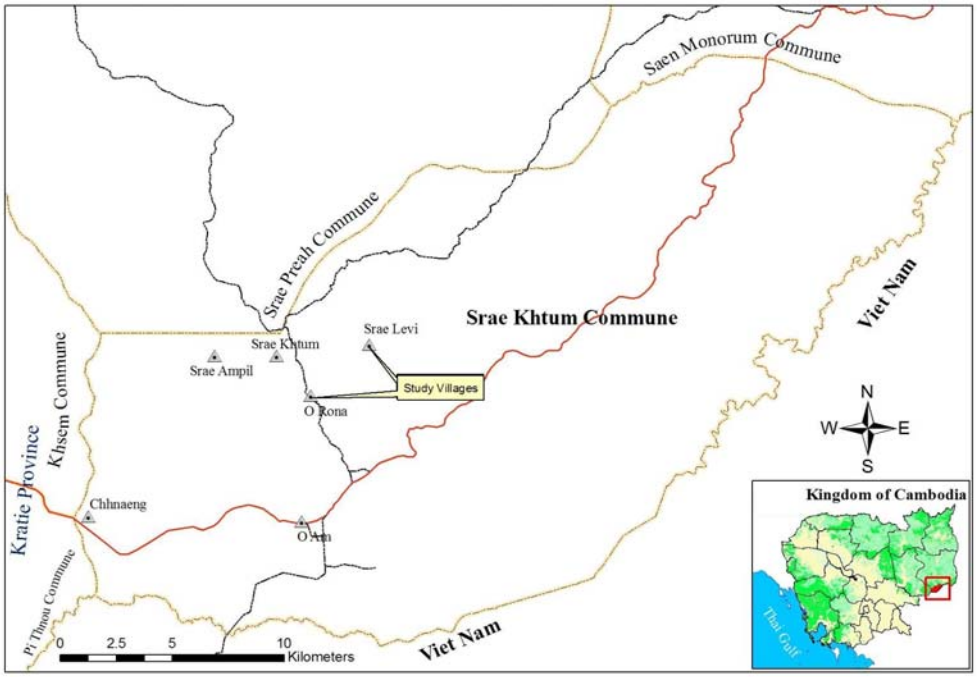


Figure 1 Map showing the location of Srae Khtum commune and the selected study villages, O Rona and Srae Levi. O Rona is located in the buffer zone and Srae Levi is located seven kilometers from the main road in the core zone.

Data Collection

Family questionnaires, key informant interviews, participatory mapping and direct field observations were used to collect primary data. With ten percent errors, 63 out of total 168 families of both villages were sampled. 43 out of 139 families in O Rona and 20 out of 29 families in Srae Levi were randomly chosen for interviews to collect socio-economic data related to income sources, food security and immigration. Key informant interviews were conducted with two village elders, two key staff of SBCA and the participatory land use planning and natural resource management committee to collect data related to the management system of bamboo resources in the area. Participatory mapping was conducted to delineate village boundaries and identify bamboo harvesting areas. Finally, direct field observations were made to collect the coordinates of the harvested bamboo forest areas using Geographical Positioning System (GPS), to identify the regeneration capacity of bamboo and to assess the appropriateness of current harvesting techniques. Desk review was employed to collect secondary data related to rules and regulations governing bamboo resources, population and map of bamboo forest areas.

Data Analysis

Descriptive statistics were used to analyze data related to income, food security and immigration, harvesting technique, harvesting volume, ownership of bamboo and other uses of bamboo. Bivariate analysis was used to

test the relationship between the engagement in bamboo harvesting and the period of insufficient rice production. Mann Whitney U test was used to analyze the impact of BIS income on family income at village level by comparing the mean ranks of family income in O Rona with mean ranks of family income in Srae Levi. Furthermore, all sampled families were categorized as Bamboo Harvesting Families (BHFs; n=31) and non-Bamboo Harvesting Families (non-BHFs; n=32). BHF refers to family who engage in bamboo harvesting to make incense sticks and non-BHF refers to family who does not. In order to analyze the specific impact of BIS income on BHF's income, Independent Sample T test was used to compare the difference of income means of both family categories. ArcGIS was used to analyze GIS data and produce maps illustrating the site impacts. T o analyze the different impact of harvesting practices on the condition of bamboo forest, secondary data of bamboo forest area 2002 was used as a baseline data to compare with GIS data collected from the filed. Finally, qualitative method was used to analyze data related to management rule and regulation of bamboo resources in the area.

Results

Village Demographics

Population in O Rona and Srae Levi is mixed of Khmer, Phnong and Stieng ethnicities. The population at O Rona is about 79% higher than that of Srae Levi (Local Administration Unit 2007). Furthermore, a greater proportion of immigrants (37.2%) was found in O Rona than in Srae Levi (5.0%), possibly because of the better road condition and market access (Table 1).

Table 1. Distribution of immigrants by village

Village	Population type		Total
	Original	Immigrant	
Srae Levi	19 95.0%	1 5.0%	20 100.0%
O Rona	27 62.8%	16 37.2%	43 100.0%

Livelihoods

The important livelihood activities of families in O Rona and Srae Levi include upland rice farming, paddy rice farming, animal raising, cash crop cultivating, resin tapping, bamboo harvesting, laboring, government work, fishing and other wild products collecting. Rice is produced in upland and paddy fields for consumption while other activities are important in producing supplementary food and generating cash income.

Income Generation

In Srae Levi, cash crops are the main contributors to total family income (71%), followed by resin (17%), wage labor (8%), civil service (3%) and livestock (1%) (Figure 1). There is no income from making bamboo incense sticks in this village. However, in O Rona, making BIS is the greatest total family income contributor (44%), followed by cash crops (41%), wage labor (10%), resin and civil service (2% each) and livestock (1%) (Figure 2).

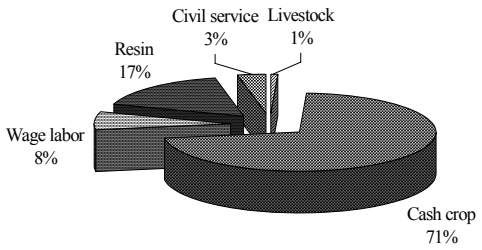


Figure 2

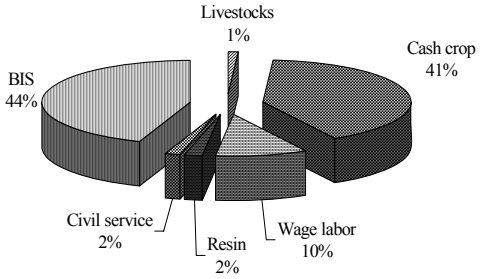


Figure 3

Figure 2: Income sources for families in Srae Levi

Figure 3: Income sources for families in O Rona

Currently, income generated from making BIS is essential for the livelihood of BHFs in O Rona since they have fewer income sources than non-BHFs. BHFs generate income from making BIS (58%), cash crops (29%), wage labor (12%) and civil service (1%) (Figure 4). There is no income generated from resin or livestock.

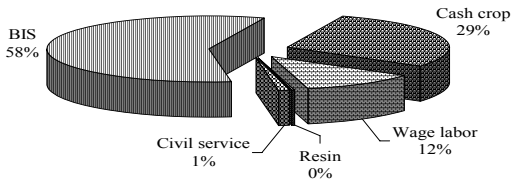


Figure 4: Income sources for BHFs in O Rona. BIS contributes more than half of the total income.

Food Security

Food shortage is a major problem of families in O Rona and Srae Levi. Only 3.2% of families (2 out of 63) reported having sufficient rice to eat year round, while 96.8% (61 out of 63) did not (Table 2). On average, they face rice shortage for 9.35 months per year. This period is even longer for BHF, i.e. almost 11 months. Those who do not have sufficient rice production must search for other livelihood options, including bamboo harvesting, to compensate for rice shortage.

Table 2. Percentage of families with sufficient or insufficient rice production

Status of rice production	Frequency	Percent
Sufficient	2	3.2
Insufficient	61	96.8
Total	63	100.0

Correlation co-efficient of Pearson Correlation test showed that there was a very strong linear relationship between the engagement in bamboo harvesting (P=.000<0.01) (Table 3). The positive relationship (.474) means that the longer the period of insufficient rice production, the more families will engage in bamboo harvesting. Therefore, it can be concluded that the increase in the period of insufficient rice production is the motive for families to engage in bamboo harvesting to make incense sticks.

Table 3. Correlation between the engagement in bamboo harvesting and period of insufficient rice production

Dependent variable	Statistic	Period of insufficient rice production
Engagement in bamboo harvesting	Pearson Correlation	.474**
	Sig. (2-tailed)	.000

**Correlation is significant at the 0.01 level (2-tailed).

Bamboo Harvesting Practices

Bamboo Harvesting for Making Incense Sticks

The data show that 72.1% of families in O Rona are BHFs (Table 4). Frequency data show that 77.4% of BHFs harvest bamboo for 15-30 days per month and 22.6% harvest for 4-14 days per month, with an average of 17.45 days per month (Table 5). Per harvesting activity, they harvested 10-50 culms, with an average of 19.13 culms (Table 6).

Table 4. Number of families who engage in bamboo harvesting to make incense sticks by village

Family category	Village	
	Srae Levi	O Rona
BHF	0 .0%	31 72.1%
non-BHF	20 100.0%	12 27.9%
Total	20 100.0%	43 100.0%

Table 5. Number of days per month BHFs harvest bamboo to make incense sticks

Number of days	Frequency	Valid Percent
4-14	7	22.6
15-30	24	77.4
Total	31	100.0

Table 6. Number of bamboo culms harvesting per harvesting activity

	N	Minimum	Maximum	Mean	Std. Deviation
Number of culms harvested	31	10	50	19.13	9.875

For harvesting techniques, 93.5% of BHFs reported clear cutting of bamboo rather than selective cutting (Table7). Additionally, bamboo was largely harvested from the forest as an open resource as 90.3% of BHFs do not own bamboo plots, only 9.7% reported owing bamboo on their farmlands (Table 8). It is clear that the current harvesting is not sustainable since BHFs do not have appropriate harvesting technique and bamboo is a free resource to be harvested from the forest.

Table 7. Percentage of BHFs reporting about clear-cutting and selective-cutting of bamboo

Harvesting technique	Frequency	Valid Percent
Selective cutting	2	6.5
Clear cutting	29	93.5
Total	31	100.0

Table 8. Percentage of BHFs reporting about owning of bamboo plot

Ownership	Frequency	Valid Percent
Own	3	9.7
Do not own	28	90.3
Total	31	100.0

Traditional Bamboo Harvesting for Household Uses

Traditionally, families in both villages have harvested bamboo for building their houses, kitchens and farm storage huts. Currently, 50.8% of families harvest bamboo for building their houses, 15.9% for their kitchens and 54% for their farm storage huts (Table 9).

Table 9. Percentage of families who use bamboo as building materials

Type of building	Cases				Total	
	Included		Excluded			
	N	Percent	N	Percent	N	Percent
House	32	50.8%	31	49.2%	63	100.0%
Kitchen	10	15.9%	53	84.1%	63	100.0%
Farm storage hut	34	54.0%	29	46.0%	63	100.0%

Moreover, 95.2% of families of Khmer, Phnong and Stieng ethnicities use bamboo-made utensils (Table 10). Bamboo-made utensils include *Sas* and *Waes* (baskets carried on the back), *Kaveng* (a tool used for weeding), knife and hoe handles, *Chhneang* (a basket used for fishing) and *Chang A* (a tool used for blowing away rice husks). Furthermore, the culms of one bamboo species (*Reusei Pok*) can be split into a thin piece which in the past was used to cut the meat of hunted animals; nowadays it is still used by the Phnong family for slicing tobacco leaves.

Table 10. Percentage of families using bamboo-made utensils and equipment by ethnicity

Answer	Ethnicity			Total
	Khmer	Phnong	Stieng	
Use	15 88.2%	41 97.6%	4 100.0%	60 95.2%
Do not use	2 11.8%	1 2.4%	0 .0%	3 4.8%
Total	17 100.0%	42 100.0%	4 100.0%	63 100.0%

Remarkably, bamboo shoots are an important food source for families of both villages as 71.4% of families consume bamboo shoots (Table 11). In particular, ethnic Phnong and Stieng families eat sour shoots in combination with rice when there is nothing else to eat.

Table 11. Percentage of families consuming bamboo shoots

Cases				Total	
Included		Excluded			
N	Percent	N	Percent	N	Percent
45	71.4%	18	28.6%	63	100.0%

Traditionally, ethnic minorities of Phnong and Stieng families practicing shifting cultivation used bamboo forest in fallow system. Moreover, bamboo is used by families of all ethnicities for building pig (25.4%) and chicken pens (27.0%) (Table 12).

Table 12. Percentage of families using bamboo culms for housing animals

Type of animal house	Cases				Total	
	Included		Excluded			
	N	Percent	N	Percent	N	Percent
Pig pen	16	25.4%	47	74.6%	63	100.0%
Chicken pen	17	27.0%	46	73.0%	63	100.0%

In the past, bamboo was commonly used by indigenous family, especially Phnong, in cultural ceremonies, but now this practice has decreased. Bamboo is still used by Phnong families in *saen proloeng srov* (rice spirit ceremony) during the rice growing stage. Data show that 66.7% of Phnong families still use bamboo for this ceremony (Table 13). The reason that some Phnong families have stopped using bamboo for *saen proloeng srov* is that there are no upland rice plots and that there has been a religious shift to Christianity.

Table 13. Percentage of families using bamboo in cultural ceremonies by ethnicities

Answer	Ethnicity			Total
	Khmer	Phnong	Stieng	
Use	0	28	0	28
	.0%	66.7%	.0%	44.4%
Do not use	17	14	4	35
	100.0%	33.3%	100.0%	55.6%
Total	17	42	4	63
	100.0%	100.0%	100.0%	100.0%

Besides harvesting for making incense sticks, the majority of families harvest *Reusei Thngor* for family uses such as housing materials, animal pens, woven materials, tools and food (85.7%), while 14.3% harvested other species for these purposes (Table 14).

Table 14. Percentage of bamboo species being harvested for family uses

Bamboo species	Frequency	Percent
Reusei Thngor	54	85.7
Other species	9	14.3
Total	63	100.0

Overall, traditional bamboo harvesting for family uses do not have a negative impact on the condition of bamboo forest since it provides enough time for bamboo to regenerate. Generally, bamboo is harvested for building, utensils and equipments every three to four years when bamboo materials start to decay.

Conversion of Bamboo Forest to Agriculture

The majority of the decrease of bamboo forests in both villages was caused by clearance for agriculture. In O Rona, within a period of seven years (2002-2008), 911 ha (41.12%) of the total bamboo area was cleared for

upland rice, cashew nut and cassava production. Additionally, 184 ha (8.31%) of the area was harvested for making incense sticks. Only 1120.2 ha (50.57%) of forest remain (Figure 5).

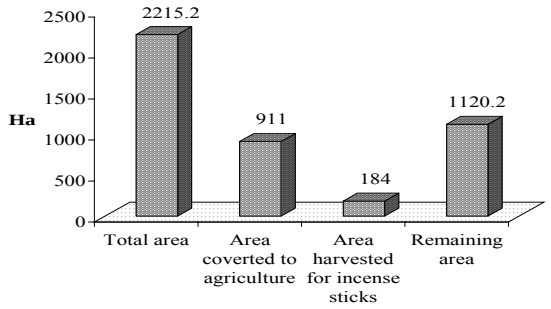


Figure 5: Decrease of bamboo forest area in O Rona over seven years

Likewise, in Srae Levi, within the same period of seven years (2002-2008), 179.05 ha (30.29%) of the total bamboo area was cleared for upland rice, cashew nut and cassava production, with 412.07 ha (69.71%) remaining (Figure 6).

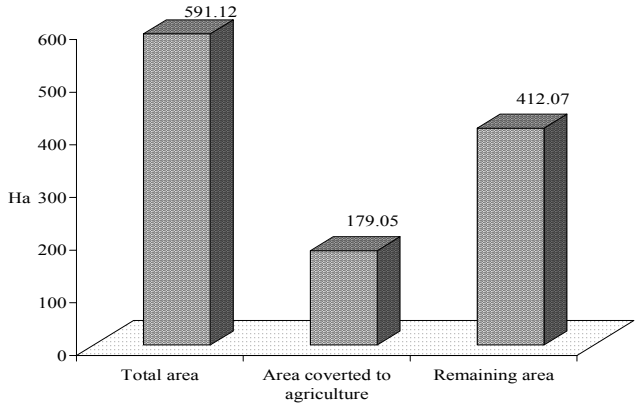


Figure 6: Decrease of bamboo forest area in Srae Levi over seven years

Rules and Regulations

There are no specific regulations governing bamboo resources in SBCA. Bamboo is classified as NTFP and managed under the existing Forestry Law (2002) together with other forest resources (Kingdom of Cambodia 2004). Management, however, is not sustainable. Similarly, the traditional rules of both villages are ineffective

because bamboo resources have been depleted and the demand increased due to better road access, market availability and increasing immigration. Additionally, the draft Participatory Land Use Planning (PLUP) By-Law (2006) in O Rona which aims to sustainably manage land and natural resources tends to be ineffective. The weakness is that Chapter 9; Article 36 of the existing PLUP By-Law governs only the management of the forest resources as a whole, and does not specifically guide the sustainable management and use of bamboo resources (WCS/FA 2008b), even though bamboo is an abundant and important resource in the village. On the other hand, the PLUP committee established in 2006 is in the process of becoming legally responsible under the national land law for implementing the PLUP By-Law.

Discussion of Impacts

Impact on Family Income

The result of Mann-Whitney U test reveals that there is a significant difference between the mean ranks of total family incomes of Srae Levi and O Rona villages, 20.50 and 37.35 respectively, with P=.001 < 0.05 (Table 15). It can be hypothesized that, through harvesting bamboo culms to make incense sticks, families in O Rona can generate higher income than those in Srae Levi. Therefore, bamboo harvesting to make incense sticks does have an impact on family's income in O Rona.

Table 15. Result of Mann-Whitney U test showing the different mean ranks of total family income between Srae Levi and O Rona

Village	N	Mean ranks of total family incomes	Asymp. Sig. (2-tailed)
Srae Levi	20	20.50	.001
O Rona	43	37.35	

Impact on BHF Income

The result of Independent Samples T test shows that there is a very significant difference between the income means of BHFs and non-BHFs, with the significance at .000 level. Mean difference shows that BHFs can generate an average income of 3530933 riels (US$882.73) per year, which is higher than the income of non-BHFs (Table 16). Therefore, it can be hypothesized that BIS income does have impact on BHF income. This BIS income is vital for BHFs in O Rona to solve the problem of rice shortage for 11 months per year.

Table 16. T-test for equality of income means of BHFs (n=31) and non-BHFs (n=32) in thousands riels local currency

Assumption of variances	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
						Lower	Upper
Equal variances assumed	4.553	61	.000	3530.933	775.455	1980.314	5081.553

Impact on Wildlife Habitat

Factors that have led to the depletion of bamboo forests in both study villages were conversion to agriculture and harvesting for making incense sticks. Traditional bamboo harvesting for family uses appears to have no negative impact on wildlife habitat as families harvest bamboo for housing materials and other utensils or equipment every three to four years and only by cutting old culms. This harvesting cycle provides enough time for bamboo plants to regenerate.

It is clear that conversion to agriculture is the leading factor for depleting bamboo forests in both villages. This loss of bamboo forests has negatively impacted wildlife habitats, e.g. those of Asian Elephant (*Elephas maximas*) and Orange-necked Partridge (*Arborophila davidi*) (Pollard et al. 2007). Within the same period of time (2000-2008), total bamboo forests converted to agriculture in Srae Levi and O Rona was 1090.05 ha, which is about six time greater than the area harvested for incense sticks (184 ha). , harvesting bamboo for making incense sticks has fewer impacts on wildlife habitat since only one bamboo species is harvested for this purpose.

The site impacts of bamboo harvesting in O Rona and Srae Levi are illustrated in Figures 7 and 8 respectively.

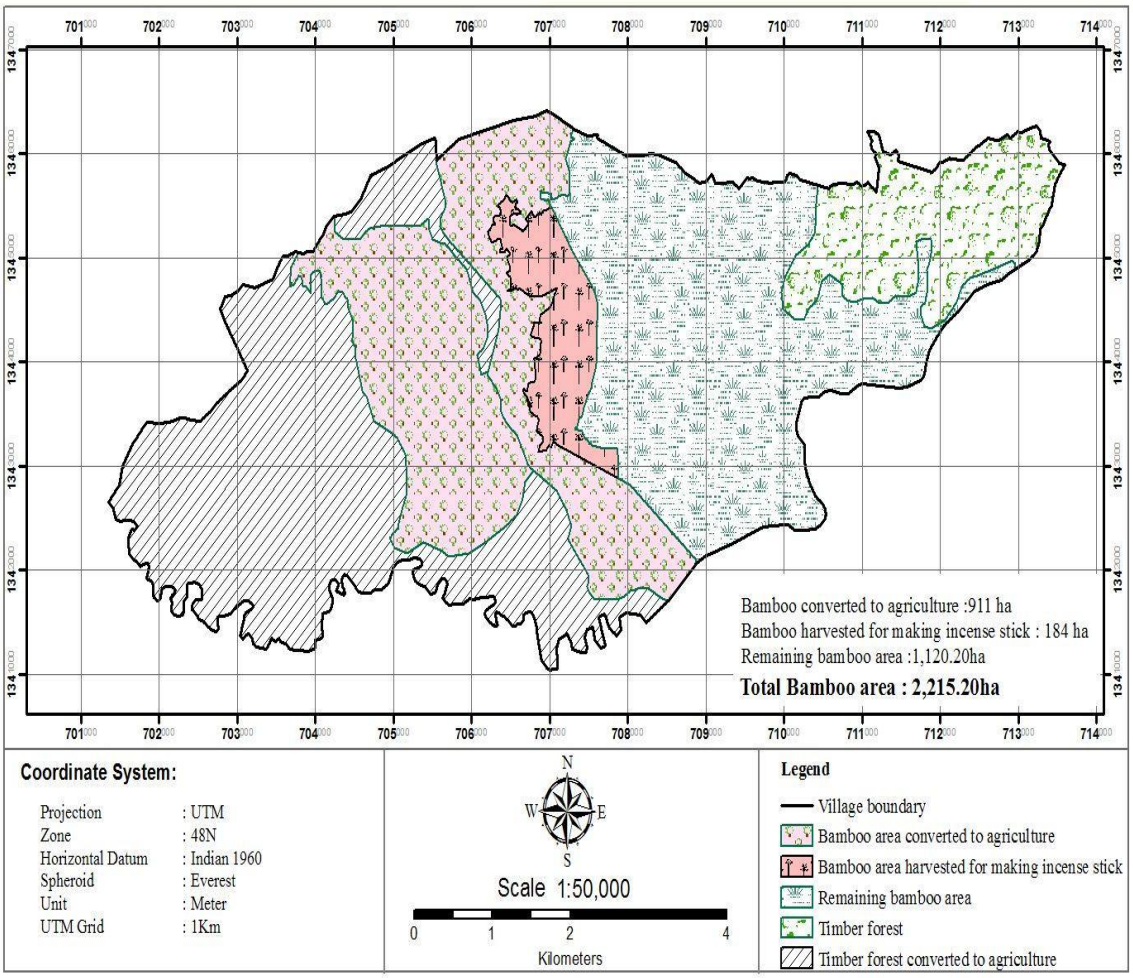


Figure 7: Map of O Rona illustrating different sites of bamboo forest affected by harvesting to make incense sticks and clearance for agriculture, see legend for the affected sites. The map also illustrates the remaining bamboo forest and timber forest areas, and timber forest area converted to agriculture.

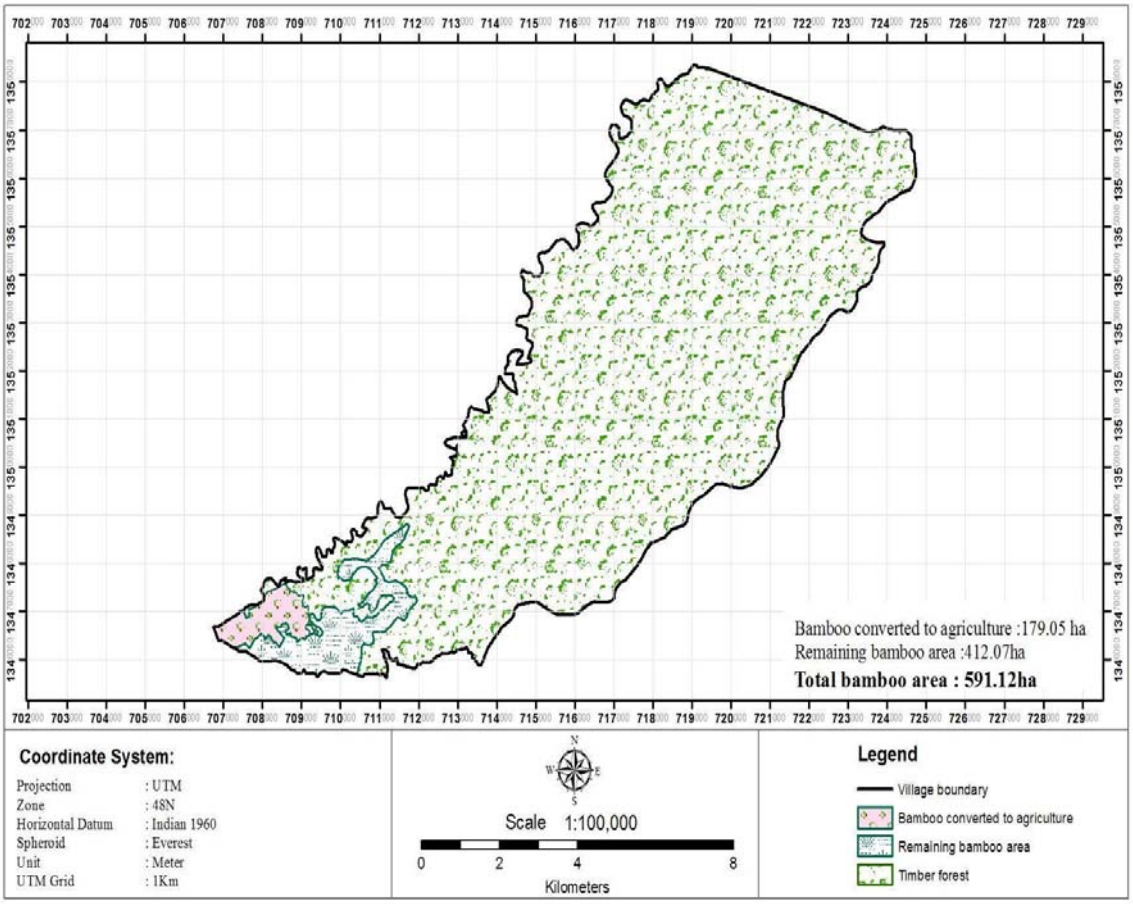
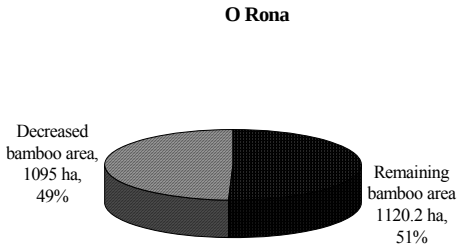


Figure 8: Map of Srae Levi illustrating the site of bamboo forest affected by clearance for agriculture, see legend for the affected site. The map also illustrates the remaining of bamboo forest and timber forest areas.

Impact of Infrastructure and Population on Bamboo Forest

The impact on bamboo forests is more serious in O Rona that has better infrastructure, market accessibility, a larger immigrant and total population. The level of bamboo extraction in O Rona is higher than Srae Levi, 49% and 30% respectively (Figures 9 and 10).



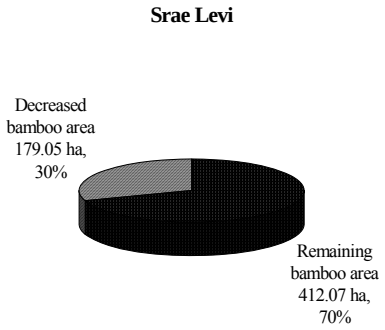


Figure 9 Figure 10

Figure 9: Decreased bamboo forest area in O Rona over seven years (2002-2008)

Figure 10: Decreased bamboo forest area in Srae Levi over seven years (2002-2008)

Impact on Bamboo Species

The dominant bamboo species in the area is *Reusei Thngor* which is used by BHFs and non-BHFs for making incense sticks and family uses. All BHFs reported harvesting *Reusei Thngor* for making incense sticks since it has long internodes (30-45 cm) and is easy to split and slice into small sticks. This bamboo species is clear-cut. Besides harvesting for making incense sticks, the majority of families harvest *Reusei Thngor* for household uses such as housing materials, animal pens, woven materials, tools and food. Observation of old bamboo plots harvested in 2005 and 2006 showed poor regeneration after three to four years of harvest. Botanically, like other plants, bamboo needs to photosynthesize and absorb nutrients to boost growth. This function was completely disabled as culms were clear-cut from the clumps, weakening regeneration capacity (Figures 11 and 12). Apparently, it can be assessed that harvesting for making incense sticks is a threat to *Reusei Thngor* because its regeneration capacity cannot respond to the current harvesting. The heavy dependence of households on *Reusei Thngor* for incense sticks and household uses together with inappropriate harvesting techniques may lead to the local extinction of the species.

Figure 11

Figure 12

Figure 11: Clear-cut bamboo clumps showing no regeneration after four years because of competition with trees for sunlight and nutrients

Figure 12: Clear-cut bamboo clumps showing poor generation after three years

Conclusion

Bamboo harvesting for making incense sticks has a positive impact on family's economy in O Rona in terms of income generation. The income helps BHFs to cope with food shortage during the lean period. However, it is not sustainable because BHFs do not have appropriate technique to harvest bamboo culms and good management practice is not in place. Most BHFs (77.4%) freely harvest bamboo almost every day per month. On average, BHFs harvested bamboo 17.45 days per month with an average of 19.13 culms per activity. They just clear-cut bamboo culms from the clumps for as long as the culms can be sliced into small sticks without considering about the suitable age of the culms to be harvested. Such harvesting does not provide enough time for bamboo plants to regenerate. Hence, it will be a threat especially to *Reusei Thngor* which is a target species for both making incense sticks and for family uses. Additionally, field assessment reveals that the regeneration capacity of *Reusei Thngor* is not able to respond to the current level of harvesting, and that re-growth of new shoots in the harvested clumps is still poor or no regeneration after three to four years. More seriously, bamboo clearance for agriculture has been identified as having a negative impact on the natural condition of bamboo forest since the cleared area is a lot bigger than the area under harvesting for making incense sticks within the same period of time. It will have negative impact on wildlife habitat if management is not improved. Besides, traditional bamboo harvesting for family uses includes building materials, utensils, farm equipments, shoots, use as fallow crops in shifting cultivation and other uses in cultural ceremony. It does not have negative impact on bamboo forest since it allows three to four years for bamboo plants to regenerate to their full size.

Recommendations

Bamboo in the area must be managed sustainably since bamboo is a very important resource for families' income generation and subsistence livelihood support as well as for biodiversity conservation. To maintain these functions, the improvement of current harvesting practices and management system is critical.

With respect to harvesting technique, agricultural department and/or other agencies that specialize in sustainable bamboo forest management, should provide appropriate harvesting techniques to BHFs to ensure the sustainable harvest and continued productivity. For instance, Chaturvedi (1988); Prasad (1988) and Suwannapinunt (1988) reported that selective cutting of mature bamboo culms at an age above three years in plots with a three-four year rotation appears to be sustainable and more products.

Additionally, SBCA should develop a management rule for managing bamboo resource building upon the existing PLUP By-law in O Rona by clearly defining the rights, user groups, collective actions arrangements and bamboo areas to be harvested. BHFs should be formed into groups to implement the rule.

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Assessment of Genetic Diversity in *Bambusa bambos* from Thailand using Microsatellite Markers

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Abstract

Analysis of 270 individuals of nine *Bambusa bambos* populations from Thailand using nine microsatellite loci showed that that a total of 296 alleles were identified with the average number of alleles per locus per population 3.66. The percentage of polymorphic loci ranged from 66.67 to 88.89 with 76.54 in average. The genetic diversity (expected heterozygosity) ranged from 0.314 to 0.415 with 0.369 in average. The genetic distances among populations were congruent with their geographic distribution. The genetic differentiation among populations (Fst) was 0.243.

The obtained results suggested that *B. bambos* populations with high genetic diversity (He > 0.369) should be regarded as *in situ* gene conservation areas in the following regions of Thailand: Amphur Maueng, Sa Kauw (He=0.440); Phukradueng, Lauy (He= 0.398); Ngao, Lampang (He= 0.415) and Saiyok, Kanchanaburi (He=0.376).

However, the *ex situ* conservation sites of *B. bambos* should be established also in other regions in Thailand using the genetic materials from the aforementioned populations. In addition,, to reduce the pressure on harvesting the shoot and stem of bamboo species in the natural forest, the bamboo food banks and plantations should also be established close to the local communities surrounding or close to the forest.

Keywords: Bamboo, *Bambosa bambos*, genetic diversity, microsatellite markers, gene conservation

Introduction

Bamboo is in the Gramineae family, which distributes naturally nearly in the whole world Dransfield and Widjaja (1995) reported that there are about 77 genera and 1,030 species of bamboos in the world. Bamboo is important for economy and livelihood of the people in Asia, Africa and America (McClure, 1966). In Thailand, 15 genera and 82 species of bamboos were recorded and most of them are sympodial type, and are commonly found in deciduous forest (Pattanvibool *et al*, 2001). Bamboos are one of most socioeconomically important species in Thailand. They grow incredibly fast and are well known as pioneer species. Bamboos are multipurpose species for many uses of basic living including food, household construction, supporting poles, baskets, handicraft, firewood, paper pulping etc. (Pattanavibool, 1998).

There are ten important commercial bamboos in Thailand and *Bambusa bambos* is one of those species. Since most of the indigenous bamboos in the forest are harvested for any various purposes the genetic status of bamboos in Thailand needs to be investigated. The extent and distribution of genetic variation within species are of fundamental importance to their evolutionary potential and chances of survival. Therefore, the assessment of genetic variation is of key importance for developing effective gene conservation plans and strategies. In this study the genetic diversity of *B. bambos* in Thailand was assessed using microsatellite markers.

Materials and methods

Young leaves of *B. bambos* were collected from nine populations in different parts of Thailand: Central, Northern, Northeastern and Southern part of Thailand. Thirty leaf samples from each culm (which was at least 100 meters distant from other culms) were collected from each population (Table 1).

DNA extraction

The procedure to extract DNA from bamboo leaf tissue was modified from Doyle and Doyle (1990) and Changtragoon *et al.* (1995). About five grams of clean leaf tissue sample were ground into powder with liquid nitrogen using a cold mortar. Then each sample was suspended in 800 µl of 2X CTAB (cethyltrimethyl ammonium bromide) extraction buffer in a microcentrifuge tube. The extraction buffer contained 4% CTAB, 2.8 M NaCl, 40 mM EDTA, 200 mM Tris-HCl, pH 8.0, and 0.4% 2-mercaptoethanol. Samples were incubated at 65 ^{o}C for approximately one hour, mixed with an equal volume of chloroform-isoamyl alcohol (24:1), and centrifuged at 13,000 rpm for 10 min at room temperature. The supernatant was transferred to a clean microcentrifuge tube, repeating this step twice. The aqueous layer was collected and precipitated by adding 0.6 volumes of cold isopropanol. The DNA was pelleted by centrifugation at 13,000 rpm for ten minutes. The supernatants were removed and the DNA pellet washed with 700 µl of 70% ethanol, repeating this step a second time. The pellet was dried for 20 minutes at 50°C and then dissolved in 50-100 µl of 1X TE buffer (10 mM Tris-HCL EDTA, pH 8.0). The quality and quantity of DNA from each sample was checked by agarose gel electrophoresis. The obtained DNA samples were kept at -20 ^{o}C.

Micosatellite analysis

Nine primer sets (Table 2) were used for the amplification of DNA from leaf samples of *B. bambos*. Polymerase chain reactions (PCR) were carried out in a final volume of 10 µl, containing approximately 20 nanograms of genomic DNA, 0.5 units of *Taq* polymerase (Invitrogen) 1X *Taq* polymerase buffer (Qiagen,Germany), 2mM $MgCl_2$ (Qaigen,Germany), 2.5 mM of dNTPs (Eppendorf) and 10 pmol of each primer. Amplification reactions were carried out using a PTC-200 Peltier Thermal Cycler (MJ Research) using the following cycling profile: 94 ^{0}C for 3 min followed by 35 cycles at 94 ^{0}C for 30 seconds, 50-60 ^{0}C for 30 seconds, and 72 ^{0}C for 1 minute, and a final extension step at 72 ^{0}C for 1 minute. The PCR products were stored at 4°C before analysis.

For DNA fragment analysis, aliquots of the amplification products were loaded on 30% polyacrylamide gel. Gels were run for 45 minutes at 1000 volts. The DNA fragments were then checked and visualized by real time

fragment analyzer, Gel Scan 3000 (Corbetta Robotics). Alleles and genotypes of each sample were scored according to molecular weight, and were estimated by comparing with a 50 bp ladder (Invitrogen).

Statistical analysis

The following genetic parameters were estimated: number of alleles per locus, allelic diversity, allele frequency, percentage of polymorphic loci, observed (Ho) and expected heterozygosity (He) , genetic distance (Nei, 1978), genetic differentiation among populations (Fst), inbreeding coefficient within populations (Fis) and inbreeding coefficient of the total population (Fit) (Weir and Cockerham, 1984; Wright, 1978) and UPGMA clustering analysis (Swofford and Olsen (1990). All calculations were made using TFPGA program (Miller 1997).

Table 1. List of the investigated *Bambusa bambos* populations

No.	Population name	Location	Sample size per population	Latitude °N Longitude °E
1	Boploy, Kanchanaburi (1)	Central	30	14o15'36. 66" 99o42'41.88"
2	Saiyok, Kanchanaburi (2)	Central	30	14o41'56.59" 98o39'50.41"
3	Thongpaphum, Kanchanaburi (3)	Central	30	14o09'46.59" 99o05'20.41"
4	Ngao, Lampang	North	30	18o41'56.10" 99o42'25.49"
5	Chaingdoa, Chiangmai	North	30	19o16'09.55" 98o54'57.44"
6	Koenkchium, Ubonrachatani	Northeast	30	15o18'29.90" 105o30'23.51"
7	Phukradueng, Lauy	Northeast	30	16o51'57.94" 101o46'07.21"
8	Amphur Maueng, Sa Kauw	Northeast	30	13o59'50.06" 102o16'38.79"
9	Amphur Maueng, Surathtani	South	30	8o57'41.73" 99o05'51.86"

Table 2. Primers details and expected PCR product size of *Bamboosa bambos* at each locus

No.	Primers	Base composition (5′→3′)	Repeat types	Expected PCR product size (bp)	GenBank Accession number
1	DTLBb1	F: GTGCGCTGATGTTGTTTGTG	$(GTT)_2TGT$ $(GTT)_2$	200	-
		R: CGGCCAATATCCATATTTCCATC			
2	DTLBb8	F: AGGTTGACCAATTTGGGGAAAG	$(CT)_3$	160	-
		R: TTTGTGTATGGTTGTAGGAAGTCG			
3	DTLBb15	F: GCC TAA AA T TTC GGG TGA TCC	$(CAA)_{19}$	280	-
		R: CAG CCG TCA CAG CTC ACA AC			
4	DTLBb20	F:CTG CCA TGG TGA CAC TAG AAC G	$(GT)_9A(TA)_3$ $(GA)_{10}$	290	-
		R: CCT CAA ACA CAG GAA TTT CAA GC			
5	DTLBb29	F: TTACAACCAAGAGAGCGCGATAC	$(GA)_5$ $GG(CA)_8$	160	-
		R: GCAGACACTTTACCGACTTCAGC			
6	DTLBb47	F: GATCAGACTTCAACACAAACGTAC	$(CT)_{16}AT$ $(CT)_7$	140	-
		R: TGTGTCAACTGTCAAGTCCTCTTC			
7	DTLBb50	R: GATAAATAACTGCATCGTTGGT	$(CT)_{16}$	150	-
		R: CAGAAGTTACTGTCAGAGAGACG			
8	AJ507491	F: TTC GTT GCT CCT GCA AGG	$(CA)_7$	150	AJ507491
		R: CTG TGG TTC TAC TAT GCG C			
9	AJ507492	F: CTA GCA AAC GCA CAG TG	$(AC)_3C(AC)_2$ $GC(AC)_4$	206	AJ507492
		R: CAG TGT GAT ACA CGT CC			

Results and discussion

Number of alleles per locus and allelic diversity in each *Bambusa bambos* population are shown in Table 3. The average number of alleles per locus per population was 3.66. Across the nine microsatellite loci analysed in 270 individuals of nine *Bambusa bambos* populations, a total of 296 alleles were identified.The percentage of polymorphic loci ranged from 66.67 to 88.89 with 76.54 in average (Table 4). There was no significant deviation from Hardy-Weinberg equilibrium at most of the investigated microsatellite loci . The genetic diversity (expected heterozygosity) ranged from 0.314 to 0.415 with 0.369 in average (Table 4). This was rather high comparing to other wild plant species in Thailand (Table 4). Even though there were some genetic studies on some bamboo species, they were mostly focused on phylogenetic relationships and clone identification (Lai and Hsiao, 1997; Nayak *et al*, 2003; Ramanayake *et al*, 2007). As shown in Figures 1 and 2 the genetic relationship among populations tentatively reflected their geographic distribution. However, one population (Amphur Maueng, Surathtani province) was closely related to Kanchanaburi population from central Thailand. This may be because some bamboo materials from Kanchnaburi may have been introduced to Amphur Maueng, Surathtani province in the past by local people. The genetic differentiation among populations (Fst) was 0.243

which was rather high comparing to Fst of other wild plant species in Thailand and ranged from 0.082 to 0.250 (Table 4). However, the inbreeding coefficient within populations (Fis =0.2060) was lower than the inbreeding coefficient of the total population (Fit = 0.4007).

Bambusa bambos populations containing much genetic diversity (expected heterozygosity) and higher than the average of genetic diversity (He=0.369) are suggested to be used as *in situ* gene conservation areas in the following regions of Thailand: Northeast: Amphur Maueng, Sa Kauw (He=0.440); Phukradueng, Lauy (He= 0.398); North: Ngao, Lampang (He= 0.415) and Central: Saiyok, Kanchanaburi (He=0.376) (Table 3). However, the *ex situ* gene conservation of *B. bambos* should also be established in additional regions in Thailand using the genetic materials from the populations included in the present study.

Table 3 Number of alleles per population and average number of alleles per locus in each population of *Bambusa bambos*

Population	Number of alleles per locus									Number of alleles per population	Average number of alleles per locus in each population
	DTL Bb 1	DTL Bb 8	DTL Bb 15	DTL Bb 20	DTL Bb 29	DTL Bb 47	DTL Bb 50	AJ 5074 91	AJ 5074 92		
1.Kanchanaburi (1)	2	1	1	3	3	12	8	4	3	37.00	4.11
2.Kanchanaburi (2)	1	1	2	8	3	12	6	2	4	39.00	4.33
3.Kanchanaburi (3)	1	1	1	7	2	10	7	2	3	34.00	3.77
4. Lampang	1	2	2	4	3	8	8	3	3	34.00	3.77
5.Chiangmai	1	2	2	2	4	9	3	2	3	27.00	3.11
6.Ubonrachatani	2	2	1	5	2	10	6	2	2	32.00	3.55
7.Lauy	3	1	2	4	1	10	5	3	4	33.00	3.66
8.Sa Kauw	2	1	2	5	2	5	7	3	4	31.00	3.44
9.Surathtani	2	2	2	2	2	8	6	2	3	29.00	3.22
Total	15	13	15	40	22	84	56	23	29	296	32.96
Average	1.66	1.44	1.66	4.44	2.44	9.33	6.22	2.55	3.22	32.88	3.66

Table 4. Heterozygosity and percentage of polymorphic loci of investigated *Bambusa bambos* populations

No.	Population names	Location	Number of alleles per population	Average number of alleles per locus in each population	Heterozygosity Ho He	Polymorphic loci(%) at 95% criteria
1.	Bor Ploy, Kanchanaburi (1)	Central	37.00	4.11	0.332 0.374	66.67
2.	Saiyok, Kanchanaburi (2)	Central	39.00	4.33	0.305 0.376	66.67
3.	Thongphaphum, Kanchanaburi (3)	Central	34.00	3.77	0.263 0.314	66.67
4.	Ngao, Lampang	North	34.00	3.77	0.278 0.415	88.89
5.	Chaingdoa, Chiangmai	North	27.00	3.11	0.284 0.340	77.78
6	Koenkchium, Ubonrachatani	Northeast	32.00	3.55	0.265 0.334	55.55
7	Phukradueng, Lauy	Northeast	33.00	3.66	0.272 0.398	77.78
8	Amphur Maueng, Sa Kauw	Northeast	31.00	3.44	0.332 0.440	88.89
9	Amphur Maueng, Surathtani	South	29.00	3.22	0.318 0.334	88.89
Average			32.88	3.66	0.294 0.369	76.54

Pops	1	2	3	4	5	6	7	8	9
1	*****								
2	0.0783	*****							
3	0.0674	0.0382	*****						
4	0.1341	0.0858	0.0991	*****					
5	0.2114	0.2405	0.2361	0.1001	*****				
6	0.1350	0.1667	0.1452	0.3007	0.4463	*****			
7	0.2444	0.2000	0.2124	0.1644	0.3250	0.4693	*****		
8	0.3905	0.3463	0.3570	0.3032	0.3772	0.5704	0.0821	*****	
9	0.1010	0.1232	0.1682	0.1169	0.2695	0.3369	0.1474	0.3287	*****

Figure 1 Nei's unbiased (1978) genetic distance among *B. bambos* populations

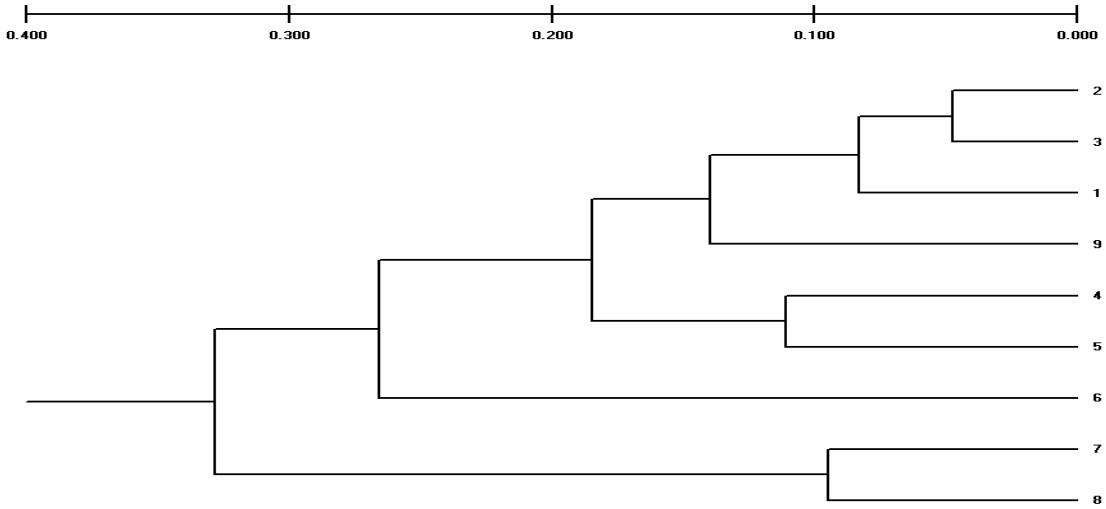

Figure 2. Genetic relationships among investigated *B. bambos* populations using UPGMA cluster analysis

Table 5 Comparison of genetic diversity(Expected herozygozity)and genetic differentiation(Fst) among populations of *B. bambos* to other wild plant species in Thailand

Species	Type of molecular markers		Genetic diversity (He: Expected heterozygosity)	Genetic differentiation among populations (Fst)	References
	Isoenzyme gene markers	DNA markers			
Bamboosa bambos		SSR (microsatel-lite)	0.369	0.243	Laphom and Changtragoon, 2005
Paphiopedilum exul		AFLP	0.301	0.082	Wanichkul and Changtragoon, 2005
Pinus merkusii	/		0.058	0.104	Changtragoon and Finkeldey, 1995
Tectona grandis	/	RAPD	0.310	0.217	Changtragoon, 2001a; Changtragoon and Szmidt, 1999; Changtragoon and Szmidt, 2000
Rhizophora apiculata	/	AFLP	0.316	0.250	Changtragoon, 2007
Rhizophora mucronata		AFLP	0.385	0.212	Changtragoon, 2007

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Connecting the Poor: Interventions in the Bamboo Value Chain. A Case from Houaphanh, Lao PDR

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Abstract

The global bamboo industry lead by China is seeing an immense growth and it is expected that this will continue even further. Lao PDR has opened its boundaries to the market economy and is promoting itself as being on the crossroads of trade between China and Southeast Asia. Although policy reforms are continuing, doing business in Laos is still a challenge for the private sector. Houaphanh a poor and remote province possesses extensive bamboo resources but is not benefiting from the bamboo business in neighbouring Thanh Hoa province, Vietnam or elsewhere. A bamboo value chain analysis demonstrated that there is potential for Houaphanh to develop its bamboo handicrafts, semi-processed products and raw materials. The bamboo sub-sector in Houaphanh is undeveloped due to a lacking enabling environment to stimulate the private sector to invest in the province. Capacity of government staff to tackle reforms and necessary insights to promote and develop marketable products is limited. Consequently private sector and poor communities have few incentives to sustainable manage and gain from trading bamboo resources. SNV builds the capacity of key actors in and around the value chain to enhance their performance in realising poverty reduction. In the bamboo value chain improvements in three key areas are made: 1. Knowledge brokering to improve the business environment; 2. Handicraft promotion and development, and 3. Piloting pro-poor business models. Through action learning, with the participation of all actors in the bamboo value chain, lessons from the field are shared to build capacity and awareness to achieve sustainable poverty alleviation by developing the private sector.

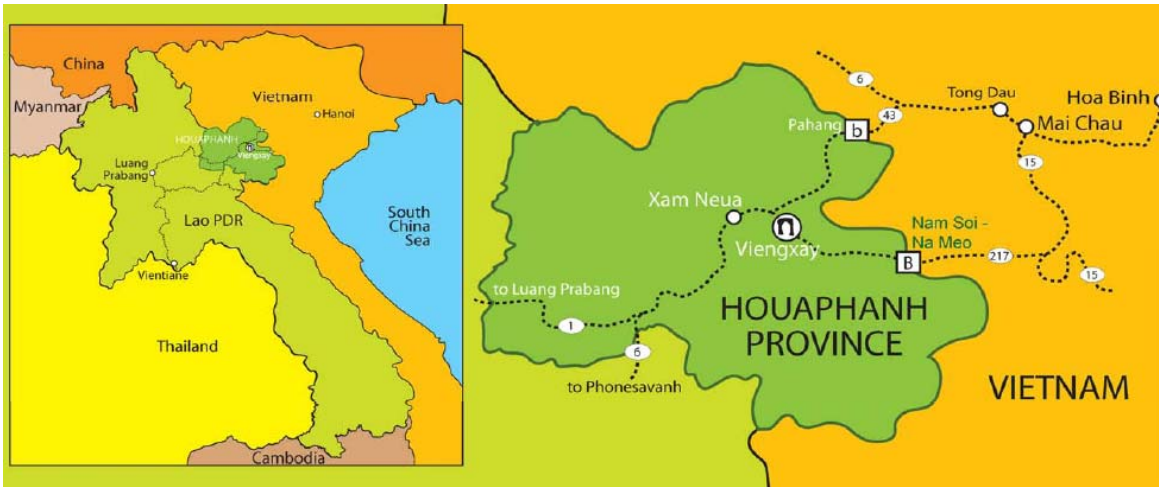
Introduction

China successfully has been the main driving force in the global bamboo industry's development over the last 15 years, with a global share of almost 80%. The total world market for bamboo is worth USD 7 billion/year with handicrafts taking up just over 40%. Oxfam Hong Kong *et al* (2006) predicts that the global market will continue to grow to an estimated value of USD 15-20 Billion/year by 2017.

In recent years Thanh Hoa province in North Vietnam has benefited from the Chinese lessons to drive local economic development (GRET – Prosperity Initiative 2008). Vietnam, Cambodia and Lao PDR together currently generate USD 261 million/year with Thailand the most important market for Cambodian and Lao bamboo sectors (Oxfam Hong Kong *et al* 2006).

Lao PDR is located in the centre of the Mekong Region, consisting of 80% mountains and plateaux and 20% lowlands adjacent to the Mekong River. The climate is dominated by monsoons with a characteristic dry season from October to April. Lao PDR is an ethno-linguistic society of 49 ethnic- and some 160 subgroups. About 60% of the population is Buddhist and 34% are belonging to indigenous religions (Schuhbeck *et al* 2006).

The Lao PDR was proclaimed in 1975 after 20 years of political struggle. Initially the communist government sought development through collectivization of agriculture designed to gain state control over production. With the introduction of the New Economic Mechanism in 1986, reform measures were made to move toward a market economy (Bestari *et al.* 2006).



Location of Laos PDR, Houaphanh Province and Vietnam, Thanh Hoa Province

Source: Provincial Tourism Office Houaphanh and SNV Netherlands Development Organisation.

Development of the country is lead by National Socio-Economic Development Plans and the Public Investment Programmes including promotion of international cooperation and domestic and foreign investment. The country promotes itself as "land-linked" instead of "landlocked", emphasizing its potential role as a trade crossroads between China and Southeast Asia (Phimmavong and Chanthavong 2008). In recent years, foreign investment flows into the country jumped in 3 years almost six-fold to USD 2,700 million in 2005. Main foreign investors are Thailand, China and Vietnam with interest in sectors such as hydropower, mining, agriculture, processing industries and tourism (SNV 2009). Laos in considered one of the fastest growing regions of Southeast Asia in economic terms with agriculture the largest sector of the economy with 51% of Gross National Product, which still only contributes to 7% of trade exports (Shaw *et al* 2007 ; SNV 2009). Despite its abundant natural resources basic infrastructure such as roads, telecommunications, water and electricity is underdeveloped (SNV 2009). Actual reforms in the various sectors lag behind government intentions as a result of inconsistent implementations, bureaucratic hindrances to application processes, lack of transparency in the regulatory framework and lack of skilled staff.

Houaphanh is the poorest province in Lao PDR and three quarters of the population are classified as poor. It has a per capita income of less than USD 50 (Kurukulasuriya 2006) against the national average of USD 491 (SNV 2009). Most socio-economic indicators also lie far below the national average. Some 90% of its land area is made up of mountainous terrain and its remoteness is measured in a 24 hours drive from Vientiane and 8 hours from Hanoi (Greijmans *et al* 2007).

Box 1. Lao Development Indicators

	Laos	Houaphanh
Population, in millions	6.1	0.3
Annual population growth rate (%)	2	3
Population living on less than USD 1 per day (%)	45	78
Under-5 mortality rate (%)	7.5	12
Labour force employed by agriculture (%)	80	94
Adult literacy rate (%)	68.5	55
Population using improved drinking water source (%)	51	23

Sources: UNDP 2002; GOL 2006; ADB 2008; SNV 2009.

Bamboo and other Non-timber Forest Products play an important subsistence role in Laos and in particular rural areas. Rural Laotians collect bamboo to use as a building material, and shoots for consumption and sale. Many farm houses are mainly composed of bamboo roofs, wall partitions and floors, ladders and furniture. Bamboo stems are also processed into fishing tools and farm implements and sometimes musical instruments (Greijmans *et al* 2007).

Houaphanh possesses extensive bamboo resources – one third of the provincial land area – but has not yet been able to take advantage of the possibilities in the world market, although it shares its border with Thanh Hoa in Vietnam, which has a thriving bamboo business. A bamboo value chain analysis, carried out and mapped in 2007, demonstrated that Houaphanh has the potential to develop its domestic bamboo handicraft markets and to

increase exports of semi-processed products and raw materials. Five separate chains were recognised: 1) raw bamboo stems; 2) handicrafts; 3) split bamboo; 4) bamboo slats and 5) bamboo shoots. Numbers of producers are difficult to estimate since communities are scattered with a low percentage of households only seasonally involved in bamboo practices. A handful of traders, mainly located near the main export borders, are involved in buying raw bamboo and handicraft products from villagers and. Semi-processed bamboo products such as chopsticks, toothpicks, blinds, incense sticks and barbeque skewers are produced in 2 factories in Viengxay district, both operating under Lao-Vietnamese ownership and exporting to Vietnam for final product development. In Sobboa district a new factory buys bamboo stems to covert into pulp destined for the Taiwanese market. Bamboo shoots are sold fresh, boiled or dried to the local market in Xam Neua the provincial Capital, or send for canning in Laos and Vietnam.

Lao products such as bamboo mats and walls are of relatively simple design with some exceptions with regards to handicrafts. However, the quality and design ranges of baskets, boxes and bags remain somewhat limited.

> Box 2: SME promoter pushes reform of Government official's role.
> "One of the steps we intend to take to improve the business climate in Laos is to change the attitude of government officials, so they do more to facilitate business rather than put up obstacles" said Manohak Rajchak, Deputy Director of SMEPDO.
> Source: Vientiane Times Newspaper - September 18, 2008.

The bamboo sub-sector in Houaphanh is undeveloped for a series of reasons. So far provincial promotional bamboo policies are yet to be developed and the local government struggles to attract the private sector to invest in the province. On the other hand inconsistent implementation of existing policies and *ad hoc* government orders still control businesses rather than creating an enabling environment. Both the private sector and communities are confronted with a confusing atmosphere of tenuous applications for a business license - varying from 2 weeks to 3 months -, sudden decisions on tax and fee collection, the setting of arbitrary quota, or the issuing of orders to halt the harvest of bamboo stems and bamboo shoots. These government rulings are often uninformed and investigations fuelling the decisions are non-existent. Information sharing or collaboration between departments for the sake of economic advancement has proven little effective and is further confused by the contradicting roles and responsibilities of the various offices. Common in this situation of stagnation is the lack of staff capacity to tackle a required reform and the necessary insights to for instance assessing market opportunities and identifying products for development. At the end of the day, depressed prices are paid to bamboo producing communities by traders who need to deal with a complex system of quotas and taxes (Greijmans *et al* 2007).

Thus, for both the private sector and communities few incentives exist to form strong business relationships. Consequently communities have few incentives to sustainable manage and gain from trading bamboo resources. A common complaint from government stakeholders is the destruction of large bamboo areas in Viengxay district and elsewhere in the province which are temporarily converted into maize plots.

In line with the goals and objectives of the Lao government's socio-economic development plan and the poverty eradication strategy, SNV supports the development of the bamboo value chain in Houaphanh province. Growth of the sub-sector and especially private sector growth is essential to create jobs and raise incomes. With smart interventions in the bamboo value chain and by working with key actors the intention is to alleviate poverty in Houaphanh. Expected outcomes are:

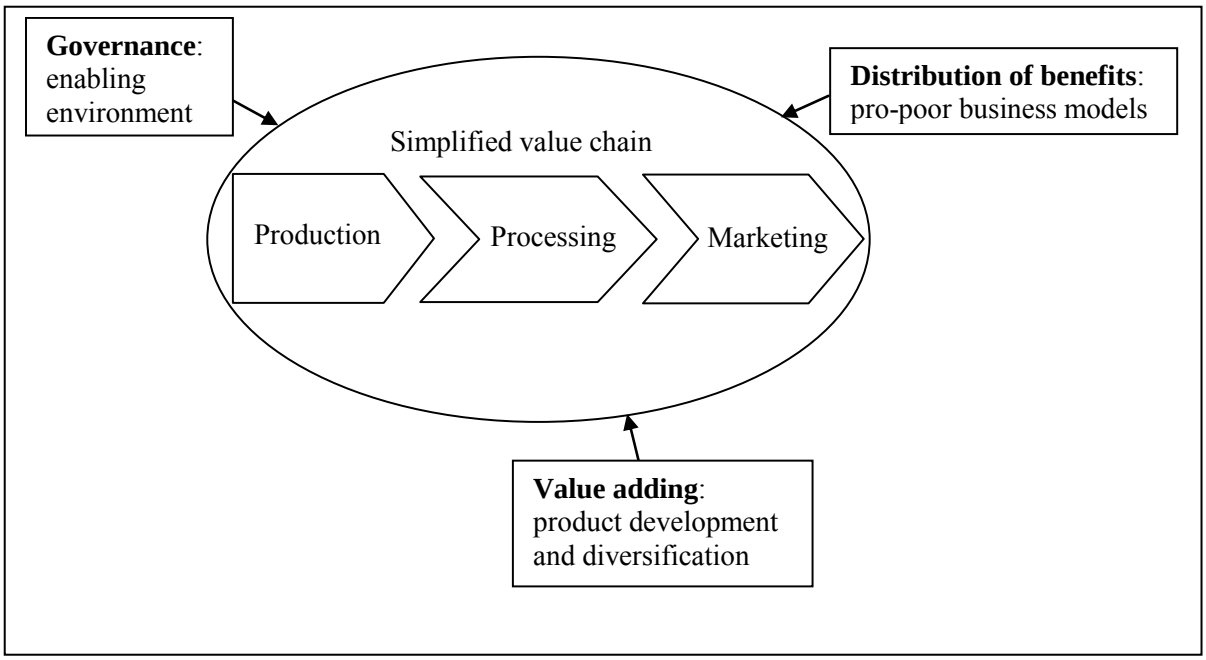
- an enabling business environment[1] in which effective and efficient investments are made
- an improved handicraft sector, with diverse products with an enabled market access, and
- sustainable business models between private sector and local producer groups.

The value chain approach and capacity building

Rural entrepreneurship development is more likely to flourish in rural areas where bottom up and the top down approaches complement each other. It requires not only the development of local entrepreneurial capabilities but also a sound local strategy. A top down approach can be effective when it is modified to the local environment that it intends to support, but ownership of the initiative need to remain in the hands of members of the local community. Local government departments need to be entrepreneurially minded and recognise bamboo activities as one of many possible activities that contribute to rural development, and seek new entrepreneurial uses of land and support local initiatives. Networking between different agencies involved in the promotion of rural development through entrepreneurship is crucial. One of the principal challenges of economic development of rural areas is the development of a socio-economic environment that is attractive to investors.

In order to create a better understanding of the workings of the bamboo sub-sector in Houaphanh a value chain analysis supported by field studies, a provincial validation workshop, and a desk study were carried out (Greijmans 2008). A value chain examines key activities that are required to bring a product from its conception, through different phases of production, to its final customer, and studies the relationships between value chain actors and their performances. The value chain approach helps to provide insight to improve the overall productivity of a sector and, where possible, benefit all actors (M4P 2008). Besides the mapping of the value chain and its involved actors and the flow of products, three other aspects need are considered, these are governance, distribution of benefits and value adding opportunities. 1. Governance in the value chain analysis is highlighted by who has power and makes decisions in the chain. External governance means the policies arrangements in place affecting the chain, enabling or not. 2. The distribution of benefits of the actors in the chain should be determined as to understand where opportunities lie to increase support, especially to benefit the poor. 3. Identifying possible improvements in quality and product diversification can be an entry point to gain higher value.

[1] The Donor Committee for Enterprise Development defines the business environment as a complex of policy, legal, institutional, and regulatory conditions that govern business activities (DCED 2008)



SNV's core business is capacity development, to support local actors to strengthen their performance in realising poverty reduction and good governance. Through the selection of competitive and value adding value chains capacity building services are provided directly and indirectly to value chain actors aiming at poverty reduction and improved inclusion of the poor. To maximise this, alliances with international and national partners are made. Key is to systematically strengthen the in-country ability for sustainable development and local capacity builders are involved and supported in the development of value chains. These local capacity builders are envisioned to replace SNV's direct services more efficiently and effectively (SNV 2007a/b). In the value chain analysis key stakeholders around the bamboo value chain emerged, both government and private sector. Organisations which play key roles to potentially make a difference and improve the value chain are assessed for their ability to contribute to this development and engaged in the development of a capacity building plan.

Bamboo value chain interventions

Key intervention areas to support the development of the bamboo value chain are the enabling business climate, handicraft sector and piloting business models aiming at providing benefits for both the private sector and communities.

Knowledge brokering to improve the business environment

Starting in 2007 and continuing in 2009 the governance aspect of the bamboo value chain continues to be an essential attention point. To appreciate the potential of the bamboo sub-sector, provincial departments and private sector participated in a study trip to Thanh Hoa province in Vietnam and to Anji in China, organized by SNV's partner Prosperity Initiate. Anji County is renowned for its successful developments in bamboo sub-

sector, and Thanh Hoa has showed that lessons from Anji can be replicated. Participants responded very positive and decided that a bamboo strategy is necessary to guide developments in Houaphanh province. Subsequently, lessons learned and discussions on the economic potential of the bamboo sub-sector were followed with by a draft bamboo vision for the province. This vision states to improve and develop:

1. policies and regulations to attract investment in the bamboo sector and increase competition,
2. facilities for better access to bamboo resources,
3. a model of sustainable management for natural bamboo resources, while allocating resources to individual households to manage and plant bamboo while increasing its areal,
4. bamboo resources into products, businesses and industries resulting in increased jobs and incomes for Houaphanh people, especially the poor.

In 2009 a provincial bamboo strategy will be created as part of the overall provincial social economic development plan 2010-2015. A series of workshops, started in 2008, are lead by the Department of Investment and Planning (DPI) and Department of Industry and Commerce (DOIC) to address hindering issues in attracting investment to the province. To take advantage of the existing national investment promotion laws it is vital to develop clarity of roles and responsibilities and improve the coordination between involved government departments. In support of this initiative the Small and Medium Size Enterprise Promotion and Development Office (SMEPDO) will play an important role. SMEPDO a representative of Ministry of Industry and Commerce has the mandate to create an enabling business environment for small and medium enterprises (SMEs) and facilitate SME development in all sectors. Previously SMEPDO shared with Houaphanh stakeholders the importance of SMEs for economic development and poverty reduction and introduced how to best promote SMEs.

Based on value chain interventions designed and implemented with key actors, lessons from the field have triggered the need to arrange discussion platforms around the bamboo business. At regular intervals over the year and at various levels – provincial, district and community – discussions between government departments, the private sector and communities are facilitated. On these occasions progress in the value chain is shared but also the appropriateness of certain policy implementations evaluated. Most importantly it allows the private sector and bamboo communities to discuss constraints they are facing and provide feedback to government departments to overcome these. It also reminds government staff of the role they are expected to perform.

Handicraft promotion and development

Provision of support to SMEs and facilitating domestic and export market development for local products is the job typically in the mandate of DOIC. However, in practice DOIC's strength lies in developing promotion policies, while it has limited understanding about the market demand and developing access to markets. A more viable provider of such services is a renowned local handicraft designer who has successfully developed and traded bamboo handicraft products and has even won local awards. This local expert is working closely with DOIC to train communities to develop a diversified range of handicraft products currently in demand, by using new and appropriate techniques and designs. He is also acting as a trader to sell the products while exploring new markets and updating market information for himself and the community groups. To ensure a sustained supply of products the local capacity builder is engaged in organising group formation of handicraft producers.

As a result of declining timber resources for furniture making, the local designer alias trader is now approached by furniture factories partner up in setting up a bamboo handicraft training centre as well as a local handicraft association.

The strength of a local capacity builder lies in his permanent local presence to provide support at appropriate times. Benefiting from the results DOIC is eventually able to organise handicraft promotion activities, such as a local bamboo trade fair.

An added benefit and likely supporting the reform of regulations, is the exposure of DOIC staff to local developments. Lessons and concerns identified will have a better chance to be more effectively communicated. These typically will be the need to ensure user rights and sustainable manage bamboo areas, but also in providing policy support to stimulate the development of strong bamboo groups able to negotiate for better trade deals.

Piloting pro-poor business models

SNV started to engage with the private sector in 2008. Suphaphone bamboo factory in Viengxai district has the desire to expand its operations and is interested to develop improved business relations with local bamboo supplying communities. Currently the supply of raw stems is low due to low prices paid to the communities. The factory owner argues that the lack of a supporting business environment forces him to reduce prices. To support the factory in its vision, and to ensure local people have a higher income from bamboo, business model scenarios are tested to identify a feasible and "win-win" business format. Scenarios range from lending, leasing and selling of simple and appropriate technologies and technical services to the community up to a co-sharing set up. Simple bamboo processing machines will be demonstrated and operational use taught to selected communities before business models can be introduced. Key to develop a sustainable business relationship with the factory is to prove to the communities that better prices will be received. Other factors which need to be considered are social acceptability of new technologies and activities, willingness and capacity of community members to take responsibility over machine use and maintenance, and potential to involve the poor and disadvantaged in the community.

On the other side, the factory owner requires to adjust his mindset. Working closely with rural communities requires patience since a business attitude of community members will need to be gradually built. Building of trust is crucial in the beginning stages and requires the provision of close support and delivery of all types of services. This will include initial business deals with communities and price agreements, which will suffer setbacks which should be allowed for.

Once the initial business model is operating for a while, lessons will need to be drawn before considering upgrading to a next scenario. By this time more serious business contracts and village business plans will be more viable to develop. Access credit will likely not be an option this year.

The promotion of the selected business models and lessons from these pilots will be shared with policy makers. Key objective is to advocate the potential pro-poor role and thus development of the province which can be credited to the private sector. These occasions are further suitable to tackle the various barriers encountered.

One of the key constraints of the factory to scale up its activities is the refusal of the local officials to increase the bamboo quota and setting aside land for a bamboo concession. Land and forest allocation is yet to be finalised in Houaphanh, or in fact in most of Lao PDR, and ownership and management of natural resources remains in the hands of the government. It argues that there is little proof to trust communities or private sector to manage bamboo resources sustainable. The factory has been unable to build up a smooth relationship with officials and poorly detailed requests do not argue in its favour.

The World Wildlife Fund for Nature (WWF) and SNV Rattan Project in Bolikhamxai province, southern Laos, has recently convinced the Department of Forestry (DOF) to award local communities to manage and trade rattan resources directly with the private sector. Key to this success was a solid management plan based on an extensive participatory inventory of rattan resources. DOF, the National Agriculture and Forestry Research Institute (NAFRI) and Provincial Agriculture and Forestry Office have now allowed further testing in the whole province. Such lessons are crucial and will be used to convince the Houaphanh government to reconsider.

Considerations

The sluggish development of the private sector opportunities in Houaphanh province is nothing new. Although it is recognised that poverty reduction requires economic growth, in many developing countries the business environment is hostile to market-led growth and private sector enterprises suffer unnecessary from regulatory barriers and regulatory costs (DCED 2008). Good governance is the key to develop a more conductive business environment. The intentions of the government are confirmed, but to keep these commitments alive they need to be held accountable. The best forum for now is in public-private dialogues between sub-sector stakeholders stimulated by Houaphanh's own backyard lessons. Such intentions need to be transformed into the willingness to listen and accept other actor's viewpoints, up to a point when reforms are facilitated aiming at stimulating private sector growth and thus of the bamboo sub-sector and increase income and employment opportunities for the poor.

The Donor Committee for Enterprise Development provides some key messages as to provide guidance in sustainable poverty alleviation through development of the private sector (DCED 2008) are:

1. A healthy business environment is essential for growth and poverty reduction.
2. Business environment reform is complex and a thorough diagnostic analysis is needed.
3. Business environment reform is always political: coalitions of support and engagement with those who wish to protect the status quo are important.
4. Government should lead and own reform

5. Ensure the inputs and participation of all stakeholders and enhance stakeholder capacity for ongoing and future reforms.
6. Ensure donor coordination, and take responsibility for quality and consistency of advice and assistance.
7. Work on "quick wins", take advantage of *ad hoc* opportunities and have a long-term perspective to ensure sustainability.
8. Understand and manage the implementation gap between the adoption of regulation or principles, and changing practice and enforcing regulations on the ground.
9. Ensure that reform process has a strong communication programme to engage and point out the benefits to stakeholders

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Our Mission

SNV is dedicated to a society in which all people enjoy the freedom to pursue their own sustainable development. We contribute to this by strengthening the capacity of local organisations.

We help to alleviate poverty by focusing on increasing people’s income and employment opportunities in specific productive sectors, as well as improving their access to basic services including water and sanitation, education and renewable energy.

Our motto, 'Connecting People's Capacities', reflects our focus on the empowerment of people and local organisations in the fight against poverty.

Establishing Industrial Bamboo Enterprises Through the Value Chain Approach

Insights from recent experiences in South East Asia

Nigel Smith and Timothy De Mestre

Abstract

Many have recognised the great potential of bamboo as an industry, yet few countries have been able to develop their bamboo industries on a large scale. A second generation of bamboo processing technologies are now offering new opportunities to overcome the technical and commercial obstacles faced by many emerging industrial bamboo sectors.

The authors reflect on experiences working with the emerging industrial bamboo sector in north western Viet Nam, Lao and Cambodia. They present a review of major challenges that have made it so hard for others to repeat the success of China's bamboo industry. Critical characteristics for lead industries in emerging industries are proposed and several established and new products are evaluated against these criteria. One product in particular stands out as a credible candidate as a lead industry for kick-starting the competitive industrial bamboo sectors in new locations around the world.

About the authors

For the last four years Nigel Smith and Tim De Mestre led a major bamboo industry development programme in Viet Nam, Lao and Cambodia – Mekong Bamboo. Working directly with businesses, government authorities and farmers they have been intimately involved in efforts to establish a competitive industry focusing on the industrial bamboo sector. Before leading the Mekong Bamboo programme, initially under IFC and Oxfam and later under Prosperity Initiative, both authors had successful careers spanning the private sector and development assistance.

Executive Summary

This paper aims to inform the reader of recent developments in the bamboo industry what will be of interest to investors, development agencies, Governments and farmers alike.

Many have recognised the great potential of bamboo as an industry, yet few countries have been able to develop their bamboo industries on a large scale. A second generation of bamboo processing technologies are now

offering new opportunities to overcome the technical and commercial obstacles faced by many emerging industrial bamboo sectors.

Recently, in the Indochina region, significant advancements have been made in establishing a viable industrial bamboo industry. These efforts have sought to promote a profitable industry, with commercial depth and a sustainable resource to improve the lives of people in poor households.

Progress has been achieved through in-depth work with private business along the value chain, farmers and community forest groups, national / local authorities and drawing on expertise from around the world, particularly China. At the same time the industry has also suffered set-backs.

These industry development experiences, including the valuable lessons of what not to do, are now sufficiently robust to be considered in other regions and countries aspiring to establish local bamboo industries. Lessons can be drawn upon for the need to balance commercial competitiveness, correctly position products in the market and deal with the complexity of the supply chains.

Specifically, experience from the emerging industrial bamboo sector in Vietnam, Lao and Cambodia suggests that, despite the apparent simplicity of the processes adopted by the Chinese industry for achieving high levels of efficiency and competitiveness, the challenges for emerging industries in replicating these are enormous. In particular, the need to simultaneously develop the right mix of secondary manufacturers, linked together within an efficient but complex supply chain, has proved beyond the means of most individual businesses or government agencies.

However, the commercialisation of second generation processing technologies and changing patterns in market demand for bamboo products may be changing the industry and, at the same time, creating new opportunities for emerging industries. Some of the new generation of technologies have important differences in their manufacturing process and product qualities that may overcome the technical and commercial obstacles faced by emerging industries.

Evidence from recent experience strongly supports the conclusion that strand woven bamboo, or similar products such as laminated woven bamboo board, are likely to be the most suitable lead industries for helping industrial bamboo sectors succeed in new locations around the world.

Introduction

Many have recognised the great potential of bamboo as an industry, be it for handicrafts, shoots or industrial processing. Yet few countries have so far been able to develop their bamboo industries beyond their traditional handicraft markets to exploit the huge potential for rural economic growth and the resulting poverty reduction. While bamboo handicrafts exist around the world, the industrial bamboo sub-sector is too often notable only by its absence.

Considerable challenges exist for those aspiring to replicate the success of regions such as Anji, Li'nan and Fujian in China. Such leading regions and their associated industries have set the benchmark in terms of cost and efficiency of production, exploiting competitive advantages from the development of dense industrial

bamboo clusters. At the same time they have seemingly lowered technical barriers to entry by commercialising much of the technology and opening the markets to bamboo-based products.

So why, with available technologies, developing markets and local bamboo resources, has it proved so difficult for others to replicate the success of China? Why have industrial bamboo clusters not emerged more widely and achieved the same large impacts on rural development and poverty reduction?

This paper reflects on the practical experience of working with the nascent industrial bamboo sector in Vietnam over the last four years in collaboration leading local businesses and experts from the Chinese industry. During this time the Vietnamese industry has had considerable success but has also suffered set-backs, not least in the recent economic crisis which has highlighted vulnerabilities in the young industry.

This paper draws lessons from this on what has worked, and what has not.

It begins with a discussion of possible reasons why industrial bamboo sectors has so far failed to grow significantly beyond China. It then proposes a number of characteristics to be identified in a lead industry for the development of industrial bamboo sectors in new locations and finally compares three similar, but different, industrial bamboo products[2] against these characteristics: conventional laminated bamboo flooring; strand woven bamboo lumber (or SWB), and; laminated woven bamboo panels.

The following section then provides further details on the product - SWB - that offers the greatest potential as a lead industry in developing the industrial bamboo sector in new locations around the world.

Finally, suggestions are offered on how some of these lessons can be turned into practical actions by those keen to kick-start the development of an industrial bamboo sector in their region, to the benefit of businesses and poor farmers alike.

[2] Variations on these products are also used extensively.

Definitions and Products

In the bamboo industry there few fixed definitions for products, especially with new products appearing all the time. For the purposes of this paper the following terms are used;

- ***Industrial bamboo sector***: is defined as the use of the hard bamboo stem, or culm, for wood-type products – everything from panels to paper, flooring to furniture, or chopstick to window frames.
- ***Conventional laminated bamboo flooring***: Flooring or panels made of regular rectangular shape bamboo slats, pressed together with glue in combinations of horizontal and/or vertical orientation to form a solid piece of flooring or panel. This can be produced either in "pure" bamboo or combination with MDF or other wooden layers. The key characteristic is that the bamboo used is from highly regular slats at their original density.
- ***Laminated woven bamboo board***: This product is made of several layers of woven bamboo mats pressed together with glue, most similar to plywood. Each mat is typically made from thin, rough, flat bamboo strips. Each layer of strips runs in a direction perpendicular to the one beneath. The surface layers are typically a single mat of interwoven strip running in perpendicular directions within a single sheet. Bamboo is in thin rough strips at its original density.
- ***Strand Woven bamboo (SWB) block:*** A hardwood lumber equivalent that is a highly compressed block of bamboo and glue, with the bamboo compressed to approximately 3 times its natural density. It is made from thin, rough, flat bamboo strips dipped in glue and roughly aligned lengthways before being compressed. The block lumber can then be further processed into anything that hardwood can, from floors to furniture, window frames to doors and much more.

Further descriptions of conventional bamboo flooring and strand woven block are included in Annex A.

Why has industrial bamboo not yet become more widespread?

There is no single reason why industrial bamboo manufacturing has not yet been extensively replicated outside China. Obstacles exist at the industry, business and product level, often interacting to increase the challenges faced. Practical experience from working with businesses involved in the industrial bamboo sector, both outside and within China, suggests the following five factors have been influential:

1. China's significant economies of scope and scale, combining efficiencies with low cost labour have made it hugely competitive in export markets and difficult for new entrants to compete - sometimes called economies of agglomeration. China's large domestic demand combined with growing export markets add to its strength. Few other countries are so lucky.

2. The most competitive modern industrial bamboo industries have developed relatively complex supply chains to produce quality bamboo timber substitute products in volume and make an acceptable return on investment;
3. Early processed bamboo hardwood products were dogged by inconsistent quality and did not live up to the considerable hype and market expectations. This problems appears to be continuing in some regions and businesses;
4. Technology transfer and adaptation to varying conditions has not always been as successful as expected.

In addition to these five systemic factors, the current economic contractions have provided further insights in to the opportunities and challenges for the bamboo industry in the future. Further discussion of each of these factors is provided below.

China's economies of scope and scale

The challenge for those outside China (countries and regions as well as private enterprises) has been how to make the transition from traditional, often small scale, processing industries to the efficiencies and scale needed to compete in the world market against China.

China's leading bamboo regions have achieved remarkable efficiencies in utilising every part of the bamboo that leaves the forest – with raw material conversion rates often exceeding 95%, including branches and leaves as well as the main culms themselves.

With every part of the bamboo being used somewhere in the industry, individual businesses are able to buy only the exact part of the bamboo they require for their particular product and achieve low unit costs of production despite some of the world's highest farm-gate prices for raw bamboo. The efficiency in material utilisation has been made possible by the development of relatively complex and geographically concentred supply chains. This is discussed in more detail below.

The strong competition for raw material among businesses means that every part of the bamboo is used for the products of greatest added value and businesses constantly strive to find ways to increase their efficiency and value addition to the bamboo.

The Chinese industry has also been relentless in its innovations in processing and machinery. These have allowed it to achieve increasing labour productivity to off-set the rising cost of workers.

For those outside of China, the efficiencies of the Chinese industry have made it very difficult to compete with in export markets. Emerging industries elsewhere often struggle with raw material utilisation rates for added value products of perhaps 15%-25%. The dramatically higher efficiencies in China mean that the sales prices of Chinese bamboo products are often lower than the cost of production of similar products elsewhere where, despite big differences in the cost of raw materials and labour.

This can be illustrated by the example of the cost of a semi-processed bamboo slat for conventional bamboo flooring in June 2008:

- In Anji County, Zhejiang China, raw bamboo cost close to USD100/ tonne delivered to the gate of the primary processing factory who processes it into to slats and a range of other semi-processed products to be sold to secondary processing businesses. The flooring factory that bought the slat paid 6.5 US Cents per slat (RMB 0.45).
- In Thanh Hoa Province, Viet Nam, raw bamboo cost close to USD35/ tonne deliver to the gate of the primary processing factory. The flooring factory who bought the slat paid 6.8 US Cents per slat (VND 1160).

So, despite an almost 3:1 cost advantage on raw material, the inefficiencies of the industry mean that the flooring company in Vietnam is actually facing higher production costs than its competitors in China. Indeed, another similar company in Vietnam actually began importing semi processed slats from China in the same year in an effort to reduce its costs while at the same time local primary processing business were struggling to find buyers for their products. This is not a problem unique to the bamboo industry – as illustrated Box 1, below.

This cannot simply be explained by a lack of reliable supply. In north western Vietnam there are around 80 primary processing bamboo businesses[3] making various semi-finished products. However, of these 80 businesses, 65% make and sell just one or two products as this is all they can find markets for. In contrast, primary processing business in Anji can make and sell 4, 5 or more products – depending on which is most profitable at the time.

What is missing in emerging industries, like the one in north western Viet Nam, is the necessary range of higher value added bamboo processing business capable of utilising all parts of the bamboo culm. The industry in Viet Nam has raw material utilisation rates for value added products of less than 25% and most primary processors struggle to find reliable buyers for their products. For example, the lack of added-value processing of bamboo sawdust means that primary processors can rarely secure any income for this major by-product stream.

[3] Figures based on a comprehensive survey of bamboo businesses in Viet Nam in 2008 – see www.mekongbamboo.org for a searchable directory of businesses. Of the 80 or so small bamboo businesses, 26% sell just one product and 39% sell two products.

Box 1: Competing with China

Paul Collier[4], in his influential 2008 book: "The Bottom Billion: Why the Poorest Countries are Failing and What Can Be Done About It", makes the follow observation regarding the economies of agglomeration.

In the 1970's when developed economies dominated manufacturing, and just before the big manufacturing shift to Asia, the cost gap between Asia and developed countries was 40:1.

Today that costs gap between China and Vietnam in the case of the bamboo industry is 3:1 which indicates that despite the lower cost bases the chances of success are still limited if history is a guide.

To avoid this during initial stages of an industries development it is wise not to try and compete in industries that benefit from scale and complex processes / steps and go direct to industries that are more stand alone, with simpler supply chains so individual business can be more efficient and competitive from the outset (See Structure B in Figure 1).

Furthermore, an equal focus on domestic markets as well as exports can reduce the need to compete head on with highly efficient manufacturing industries, such as those in China. As local industries develop over time and raise their efficiency they can then begin to take advantage of their lower cost structure to compete effectively in export markets.

Indeed, one of the remedies suggested by Paul Collier is to provide a degree of temporary protection for emerging manufacturing industries in developing countries to allow them to improve their own efficiencies without the corrosive pressure of direct competition with manufacturers in China and other major Asian manufacturers.

So, for emerging industries, any major gaps in this industrial mix of the bamboo value chain and every other business in the local industry struggles to be profitable as the competitive advantage of lower raw material and labour costs is dispersed. This has made it hard to start industries in new locations, even where there is an abundant bamboo resource, comparative cheap labour and markets with good potential.

An important further lesson from Vietnam is that individual businesses do not possess the scale to tackle these problems alone within conventional industrial bamboo supply chains. While at the same time the challenge of orchestrating a coordinated industry level response has proved beyond the means of most governments or industry associations.

The adage "you are only as strong as your weakest link" has applied to the industrial bamboo sector.

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[4] Prof. Paul Collier is the former Director of the Development Research Group of the World Bank and is currently Director for the Centre for the Study of African Economies at The University of Oxford, UK

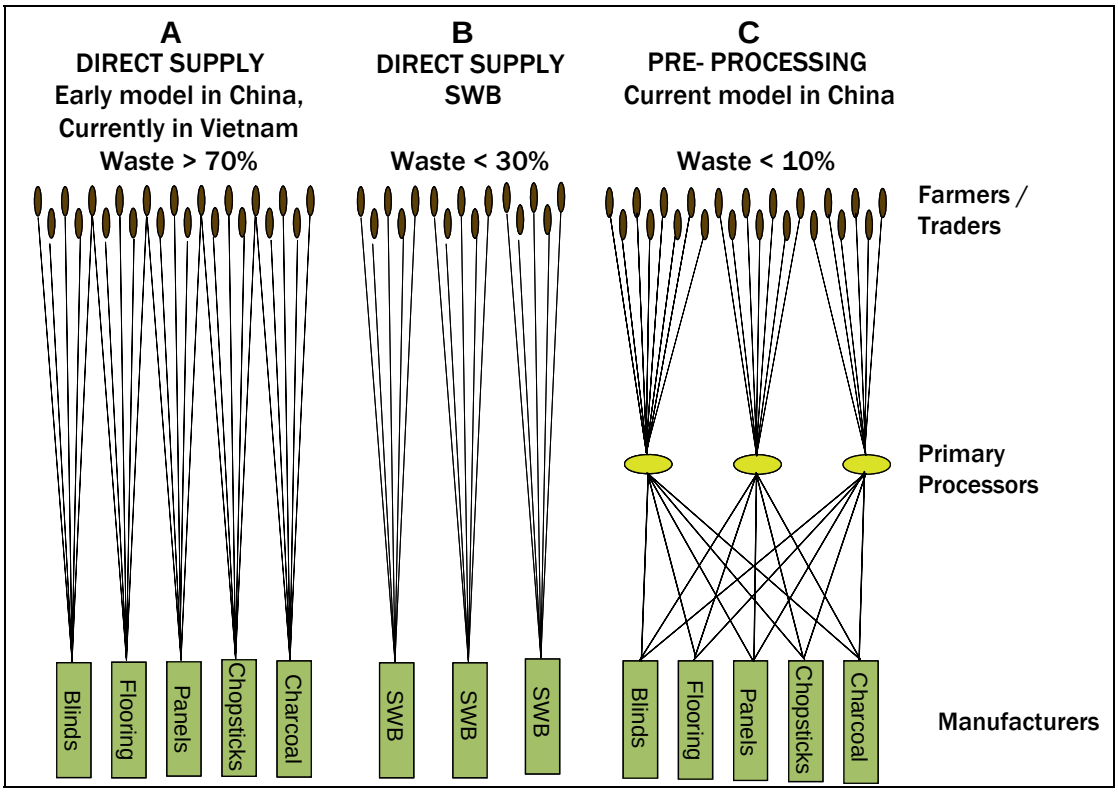

Figure 1: Industry structures

Supply Chain Complexities

The basis for China's competitiveness has been the efficiency of the industry overall rather than of any individual business, as outlined above. This has been made possible by the evolution of relatively complex but geographically concentrated supply chains.

Modern bamboo supply chains, such as in Anji, typically have three distinct layers (see Structure C, Figure 1 above)

1. Farmers sell their raw bamboo to primary processing factories.
2. Primary processing factories covert the entire culm in to a range of semi-finished products, which they sell to secondary manufacturing businesses. They are able to easily change the mix of semi-finished products in response to market demand to maximise their profit from the entire culm. Each primary processor will have several different customers, often making different end products.

3. Secondary manufacturers buy the specific type of semi-finished bamboo products they need to manufacture finished goods for sale to the market. Depending on the size of the business, each secondary manufacturer may buy semi-finished products from several primary processing factories.

It is the emergence of the middle layer – the primary processing factories – that has made possible the achievement of such high material utilisation rates. By doing the bulk of the initial processing of the bamboo in a single factory, all the various products and by-product streams can be economically collected and then sold to secondary manufacturers. Because the primary processing businesses do not need to make finished goods from all the bamboo they are able to operate profitably at a small scale with low capital investment. So they are easier to set-up and operate profitably.

In addition, the larger, more capital intensive secondary manufacturing businesses can drive down their unit costs of raw material as they only buy the precise part of the bamboo culm they need. They do not have to find alternative markets for large amounts of unwanted processing waste or invest in additional product lines to achieve the efficiencies within their own business.

Together this means that it is much easier, from a commercial perspective, to set-up and operate a bamboo business in an industry that has this structure of primary processing factories – capital investment requirements are smaller and cost of production are lower.

However, in reality these supply chain structures are complex and difficult to establish. In Anji, primary processors emerged only after there were already a large number of competing manufacturing businesses. Primary processors were able to offer immediate savings to these businesses due to their greater efficiency and so they were able to quickly restructure the industry to everyone's benefit.

The most common structure during the early stages of industry development has been a direct supply mode (see Structure A in Figure 1). Indeed, this was the early industry structure in Anji, China, and is still the most widespread structure in the industry in north western Viet Nam. This has led to emerging industries having large inefficiencies compared to the modern Chinese industry (Structure C).

So emerging industries face a major dilemma – they must adopt these complex supply chains to achieve the efficiencies needed to compete and survive yet the complexity and interdependence needed makes them especially hard to establish in an open market..

The complexity of the supply chains also creates very real problems for quality control for the manufacturers of finished goods. The quality of the end product is heavily dependent on the quality and consistency of the raw material, especially the age and species of the raw bamboo. Yet after the raw material has gone through its initial primary processing it is very difficult to have effective quality controls to indentify any problems. The secondary manufacturers therefore rely on their suppliers – the primary processors – for a major part of their quality control.

Many of the quality problems associated with some conventional industrial bamboo products have stemmed from poor supply chain management that fosters below standard raw bamboo materials, including inappropriate glues, lack of supply at critical times and bad storage techniques to name a few issues. Bringing the supply chain

under better control is usually difficult as production steps are out of the control of the end processor and price signals are often not passed down the supply chain to the farmer, trader or even the primary processer (See Structure C, Figure 1). Although a seemingly simple process this inherently complex supply chain management has hampered replication of the process in developing regions due to greater risk and lower profits. Some of these issues, if not all, have lead to failure of infant businesses.

Bamboo Hardwood Quality

Despite that fact that bamboo slat flooring and block timbers make environmental, social and commercial sense and thus have found reasonable appeal, problems with bamboo products have been encountered and too often not lived up to customer expectations. Examples of these issues include, but are not limited to:

- Failures to provide a consistence quality of raw materials, e.g. bamboo culms ages and varieties have been mixed;
- Usually linked to the previous point, failure by some manufacturers to produce consistent quality finished product, leading to variable perceptions of product
- Poor product knowledge at the point of sale, e.g. end users using bamboo products for purposes for which it is not suited and a lack of knowledge of bamboo
- A lack of independent research made publically available on bamboo product attributes and associated accreditation.
- Substandard adhesives.[5]

In general, many bamboo products have still to find widespread acceptance as reliable, value for money products but progress is undoubtedly being made.

Technology Transfer Outside China

In theory, emerging industries should be easily able to obtain the necessary processing technologies from China, Taiwan and elsewhere, especially since the emergence of specialist bamboo equipment manufacturers.

In practice, however, this has not proved as straightforward as expected. Chinese bamboo equipment has been imported into many countries, but with varying results. Considerable adaptations have often been needed to make these machines optimal with other species. In some countries, such as some in Africa, little success has yet

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[5] Adhesives are the most expensive material in the SWB process. Urea Formaldehyde (UF) and Phenol Formaldehyde (PF) are glues in common use, although different types of glue apply for different product groups. UF is more suitable to indoor products while PF is for outdoor ones. Overseas markets require strict technical criteria, aimed at limiting formaldehyde evaporating from the product. Depending on the amount of formaldehyde emission the cost of glue may vary and so does the final cost of the product.

been achieved while in others such a Vietnam, progress has been made through trial and error. However, further work continues to be needed to refine practices and machinery to make it regionally specific and thus ensure profitability. This however may not be within the resources of a new investor trying to introduce the bamboo industry to his home country but with no prior experience of bamboo manufacturing.

For some more recent processing technologies, such as SWB, the processing techniques are still at a very early stage and while good products can now be reliably produced, few businesses have practical experience in applying this technology on a commercial scale.

The Current Economic Contraction

With a worldwide economic recession the demand for some bamboo products has found some resistance compared to the rapid growth of recent years. But the impact has not been uniform, with part of the industry actually seeing a growth in demand.

Products which have emerged stronger from the current economic storm are those with clear price or performance advantages over competing products – these include strand woven bamboo block, bamboo mat board and particle board. Indeed many of these have seen demand grow as buyers search for better value and reduced costs.

In contrast, products that have less clear cost or performance advantages over alternatives have seen orders and margins decline sharply, such as conventional laminated flooring or window blinds.

This may give some indication of the true competitiveness of different industrial bamboo products and should be an important consideration for new investors in emerging bamboo industries.

Over recent year many of the more successful bamboo businesses in Anji and elsewhere have expanded their operations into new locations, in search of lower costs and higher profits. Of the more advanced and largest Chinese bamboo businesses, some were considering Initial Public Offerings (IPO) in 2008 and potential investments overseas. While these more ambitious overseas investments may still be under consideration, the market uncertainty and financial pressures in the current recession mean that it may be some time before any of these plans come to fruition. For those aspiring to build their own local industry, they will therefore need to look for investors closer to home, and seek savings inside their business, for some time to come.

Conclusions

We may conclude from these observations that, despite the apparent simplicity of the process adopted by the Chinese industry for achieving such high levels of efficiency and competitiveness, the challenges for emerging industries in replicating this are enormous.

Specifically, the need to simultaneously develop the right mix of secondary manufacturers, linked together within an efficient but complex supply chain has proved beyond the means of most individual businesses or government agencies.

However, the commercialisation of second generation processing technologies and changing patterns in market demand for different bamboo products may be changing the industry and, at the same time, creating new opportunities for emerging industries.

Identifying a Lead Industry Candidate – The Case for SWB

Having considered the reality of the challenges facing emerging industries, we may envision what might be the ideal characteristics for a business to act as a lead industry to kick start the growth of the industrial bamboo sector in a new location.

Experience to-date suggests that, although there are some sound lessons to be absorbed, simply trying to copy the route taken by Anji and other Chinese industries is unlikely to succeed.

Any lead industry must try and achieve the same efficiencies and competitiveness while avoiding the need for the complex supply chains that have proved so difficult to recreate.

With this in mind, the following characteristics are proposed for an ideal lead industry:

Market Demand

- A highly saleable product that competes well with substitutes - as perceived by the customers. As bamboo is a relatively new material in many markets, a clear advantage in terms of value, price and/ or quality would be needed to claim market share.
- A viable domestic market can help new businesses develop scale and improved manufacturing before going on to compete in export markets.
- Accessible export markets, without significant entry barriers, are important to underpin a larger and growing industry and allow progression into increasingly high value markets.

Supply and production

- Manufacturing process uses >50% of raw material in primary high value products - greatly reducing reliance on other markets or successful businesses nearby using by-products
- Simple supply chains enabling control of quality of materials and costs, essential factors in long term profitability and reputation
- Minimum efficient scale for production is low with later incremental expansion technically and commercially feasible. This allows managed investment but with reduced pressure in investment and cash flow during the early year while the businesses become established.

For sustained longer term success (in addition to the above)

- Diversified end markets, with growth potential,
- Some key markets in close proximity, to increase competitiveness via lower transport costs.
- Opportunities for downstream value addition, for example through further processing
- Sustainable, diversified, supported and expandable, raw material supply

To build a wider industry with strong local impact, in addition to the above the following characteristics are desirable:

- A sufficiently large lead industry to act as an anchor for future industry growth
- For the bamboo to be mostly owned by smallholders
- An increasingly supportive sector enabling environment for businesses and farmers alike.

Comparing three nominally similar industrial bamboo products illustrates important underlying differences against these ideal characteristics.

Characteristic	Conventional laminated bamboo flooring	Strand woven bamboo lumber	Laminated woven bamboo board
Market Demand			
• Highly saleable product	?	✓✓	✓✓
• Viable domestic market	✖	✓✓	✓
• Accessible export markets	✓	✓✓	✖
Supply and production			
• Uses >50% of raw material	✖✖	✓✓	✓
• Simple supply chain	✖✖	✓✓	✓✓
• Low minimum scale needed	✓	✓	✓
Sustained longer term success			
• Diversified end markets	✖	✓✓	✖
• Opportunities for downstream processing	✓	✓✓	✖
• Sustainable raw material supply	✓	✓✓	✓✓
Summary	✖	✓✓	✓

Conclusions

The evidence of the last four years of the industries development in Viet Nam and China, as summarised above, strongly supports the conclusion that strand woven bamboo, or similar products such as laminated woven bamboo board, are likely to be the most suitable lead industries for helping industrial bamboo sectors succeed in new locations around the world.

The Opportunity for the Future

The situation in the industrial bamboo sector is now changing. As outlined, a second generation of processing innovations are opening the door to more widespread growth of the bamboo industry. These high value-added manufacturing processes, such as a SWB and laminated woven bamboo board, are beginning to change the economics of the industry, to the benefit of all those who have struggled to copy China's.

The business model for SWB production has a number of unique features. It is becoming clear that the SWB manufacturing process lends itself to being a potential entry point for starting a host of new commercial bamboo industries around the world.

The reasons for this include:

- High material recovery rates into high-value products – 60-80% of a bamboo culm can be converted into the final product – compared to less than 15% for traditional layered bamboo flooring.
- The finished product(s) is a strong, durable substitute to hard woods, yet can be sold on the market at 20-30% less than comparable timber and still provide acceptable returns. As a direct hardwood substitute, the market is opening to sub sectors such as window frames, doors, furniture as well as normal engineered bamboo markets of flooring and panels – there is often a strong domestic market for these general construction items, making it easier for the businesses to start incrementally and exploit the price advantage over hardwoods to gain market share. (See Box 2)
- If the bamboo is owned and sold by smallholders then they could quickly benefit from the rising price and demand for their bamboo. Additionally small holders can benefit from very basic first stage processing requirements in the village thus providing additional value add labour requirements at the point of sale.
- The available investment model analysis shows that these SWB processing factories can remain profitable and highly competitive against hardwoods with bamboo prices of over USD 50 / tonne – a price which most farmers outside of China rarely benefit. This is equivalent to an income of around USD650-750 per hectare per annum from only around 50-60 days labour. Often in mountainous areas this compares extremely favourably even compared to cash crops in respect of price / production risk and sustainability.
- At current market prices, a new factory with a capacity of 5000 m3 p.a. would need an investment of around USD1.5 million (excluding land) - of which working capital is around USD200,000-300,000[6].

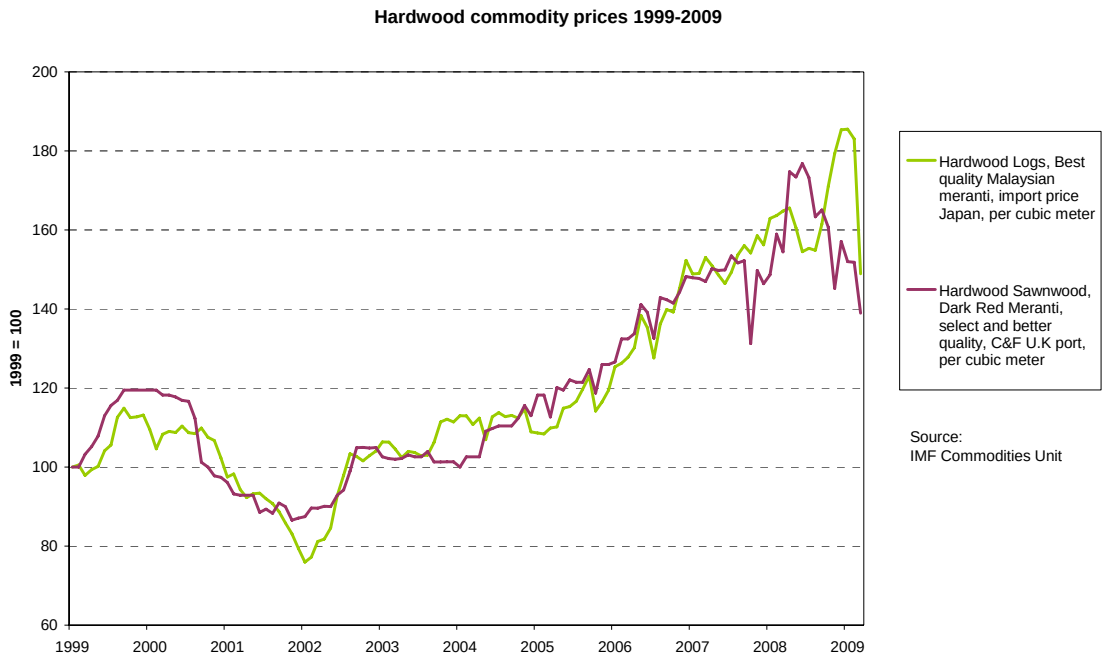
[6] Priced June 2009

Such a factory would generate revenue of over USD2.4 million per annum and annual operating profits (EBIT) of over USD700,000 per annum. Refer to Annex 2 for summarised calculations.

Box 2: Favourable Market Conditions for SWB in Viet Nam

Global hardwood prices have continued to rise in recent years in the face of limited natural wood resources and growing concerns over sustainability (see chart). This bodes well for the long term outlook for SWM in export markets.

In domestic markets, Viet Nam's demand for imported wood has been increasing during the economic development and growth of the wood processing industry. The total net domestic demand for wood products reached almost USD3.5 billion in 2008 – dominated by furniture, windows, doors and other construction materials (excluding imported timber for processing and re-export which account for a further USD+2 billion per annum).



In the domestic marketplace, studies have shown that the acceptable price for SWB lumber could range from USD 455 to USD 685 per m^3. In Vietnam, SWB will compete directly with balau ("cho chi"), a local species in medium grade hardwood in the segment of doors and window frames. The quotation for cut "Cho Chi" wood ranges from USD 570 per m^3 (origin - Lao PDR), USD 685 per m^3 (origin - Viet Nam) to USD 800 per m^3 (origin - Indonesia).

Investment modeling predicts a basic cost of goods produced of USD360-440 per m^3 for the first year from a capacity of 5000 m^3 of product per year (based on current input prices). If sold on the market at USD 540 per m^3 this would give Earning Before Interest and Tax (EBIT) of USD100-180 per m^3.- a margin of 18%-33% on sales revenue.

- A wide range of species appear to be suitable, although current estimates suggest larger diameter species (larger biomass species with thick walls), such as D Barbatus, D Asper, D. Giganteus, may be more commercially competitive as they can achieve higher material utilisation rates. In China, the most popular species used for SWB is Moso (*Phyllostachys pubescens*). In Viet Nam for example, Luong (*Dendrocalamus barbatus),* Buong (*Dedrocalamus* sp.nov.), Lo O (*Bambusa sp.*) or Tre gai (*Bambusa blumeana Schultes.*) all suit the SWB process, whereas for the traditional slat process only Luong fit the quality requirements.
- Some species with a course fibre structure may also have commercial advantages due to better glue uptake and bonding thus reducing costs of goods produced. But certainly more research and market development is required.

From a Poverty Reduction Perspective

In terms of local economic development and poverty reduction in remote and mountainous areas, the industrial bamboo sector can be especially valuable. Bamboo handicrafts can create significant employment opportunities and can be a valuable part of household livelihoods - most of the value of the product is in the labour. Yet in remote locations, the fact that finished goods are bulky and light means that transport costs are high and market access is limited, so household income opportunities are poor. Most large scale bamboo handicraft production has therefore grown up in rural areas relatively close to urban centres, with only the raw bamboo coming from more rural areas. Thus in more remote rural areas handicraft production is often limited to local markets and household use and so offers few opportunities for local growth.

In contrast, industrial bamboo manufacturing consumes large quantities of bamboo which is typically found in remote and mountainous areas. Much of the value of the finished product is in the bamboo itself. The industries also benefits from processing the bamboo reasonably close to the forest to either semi-finished or finished goods. If farmers in remote areas own the bamboo they can benefit from the growth of a local industrial bamboo sub-sector through higher prices and stronger demand for their bamboo.

The simple supply chains and commercial competitiveness of SWB offer considerable promise in enabling new industrial bamboo sectors to be established in new rural areas and thus help drive local economic development and poverty reduction.

From a commercial perspective

The current opportunity for an investment in SWB production is it is at the frontier of the industrial development cycle but technologies and markets are now proven. Margins will remain strong for many years as little competition exists for the raw material and the market demand is strong and large. Over time it is expected that these margins will come under pressure but could be maintained through careful supply chain management, the development of preferred suppliers, a continued refinement of the process, new technologies, potential accredited ethical supply chains and most importantly moving down stream into finished products of the SW material, such as furniture, doors, window frames, shipping boxes etc..

The Next Steps: Stages to launch a competitive industrial bamboo sector

If a region has significant resources of bamboo stands with culms that measure over 5 cm in diameter at the base, has reasonable access to markets and a has a domestic demand for timber then a SWB investment is a distinct possibility. The SWB process overcomes many of the country specific issues of a conventional industrial bamboo sector based on slat laminate flooring or other similar products.

A SWB investment model would be developed in three main phases, with investment review points between each:

Phase 1. Prefeasibility or Preparation Phase: initial scoping and assessment of proposed site / region.

Phase 2. Study and Analysis Phase: investment and feasibility study.

Phase 3. Investment or Partnership Phase: Ongoing and as required.

Specifically, as Phase 1 is the most logical point of initial engagement, the following detailed tasks should ideally be followed:

- Review the existing data on the bamboo natural resource and physically assess local varieties and their growth densities.
- Pilot test the bamboo culm physical properties across a range of tests to identify specific properties.
- Understand smallholders access and tenure/access rights to land and forest resources.
- Ascertain current bamboo business value chains and related activities in all subsectors.
- Assess the local business and the broader sector enabling environment for potential first stage processing SMEs or traders in the local area.
- Assess infrastructure and access to markets in the province, in relation to international and domestic markets.
- Provide a functional / generic, investment model.
- Assess human resources capacity in local area through meetings with other businesses, especially those in forestry or other similar sectors.

If required, further work should be undertaken to establish the efficiency and efficacy of linking investments in bamboo to pro-poor outcomes. This would require a review of the existing data on the local poverty rates, poverty gap and poverty headcount, and ascertaining the location of the poor in relation to the bamboo resource.

Further audits would be required to ensure that social, environmental and cultural issues were also being addressed and could be linked to additional studies such as for the accreditation of ethical supply chains and even carbon trading benefits. Another consideration might be linking any project with Reducing Emissions from

Deforestation in Developing Countries (REDD) under the United Nations Framework Convention on Climate Change. Many synergetic avenues certainly exist and need to be prioritised.

Findings from Phase 1, would be detailed in a brief report with recommendations. If positive, the Phase 1 report would also include information related to the next stage of any detailed and specific demand-focused investment study.

The main output for Phase 2 would be a work plan for developing the bamboo sector. This would be targeted around creating a triple-bottom-line business investment plan, as a process to identify and address all key issues for launching the sector anchored around a particular location while drawing on a wider value chain. It would begin the process of screening potential investors and looking for the best approach to see the local industry commence.

Conclusions

Many have recognised the great potential of bamboo as an industry, yet few countries have been able to develop their bamboo industries on a large scale. A second generation of bamboo processing technologies are now offering new opportunities to overcome the technical and commercial obstacles faced by many emerging industrial bamboo sectors.

Experience from the emerging industrial bamboo sector in Vietnam, Lao and Cambodia suggests despite the apparent simplicity of the process adopted by the Chinese industry for achieving such high levels of efficiency and competitiveness, the challenges for emerging industries in replicating this are enormous.

Specifically, the need to simultaneously develop the right mix of secondary manufacturers, linked together within an efficient but complex supply chain has proved beyond the means of most individual businesses or government agencies.

However, the commercialisation of second generation processing technologies and changing patterns in market demand for bamboo products may be changing the industry and, at the same time, creating new opportunities for emerging industries. Some of the new generation of technologies have important differences in their manufacturing process and product qualities that may overcome the technical and commercial obstacles faced by emerging industries.

The evidence of the last four years of the industries development in Viet Nam and China, as outlined in the paper, strongly supports the conclusion that strand woven bamboo, or similar products such as laminated woven bamboo board, are likely to be the most suitable lead industries for helping industrial bamboo sectors succeed in new locations around the world.

ANNEX 1 - Fact Sheet: Strand Woven Bamboo

- Strand Woven Bamboo (SWB) is a relatively new product that was first marketed in China six years ago and is known by several names such as “re-constructed board”, “Tiger Bamboo” and “Pressed Block Bamboo” to name a few. One of the most commonly used brand names that is currently copyright protected in the U.S. is “Strandwoven Bamboo”
- SWB hardwood products are created through the following summarised stages:
  - Cutting the culm from the forest or plantation;
  - Scrapping the outside green layer from the bamboo culms;
  - Cutting the culm to size and then a 2-stage splitting process of the bamboo strands;
  - Boiling the strands in a processing solution to remove any sugars and/or insects.
  - Kiln drying the strands to 10-12% moisture content.
  - Soaking the bamboo strands with glue whilst in bales, or billets,
  - Placing the bamboo strips in bales under very high pressure to compress the strands.
  - Baking the compressed bamboo in an oven until hard and dry and resin set.
  - Removing from the metal case the solid logs of bamboo and slicing them into boards and milling them like traditional hardwood.

The following pictures show the final stages of the production of the SWB block.

1. Pressing- initial stage	**2. Pressing-final stage**
	
3. Near-finished logs	**4. Finished Products**
	

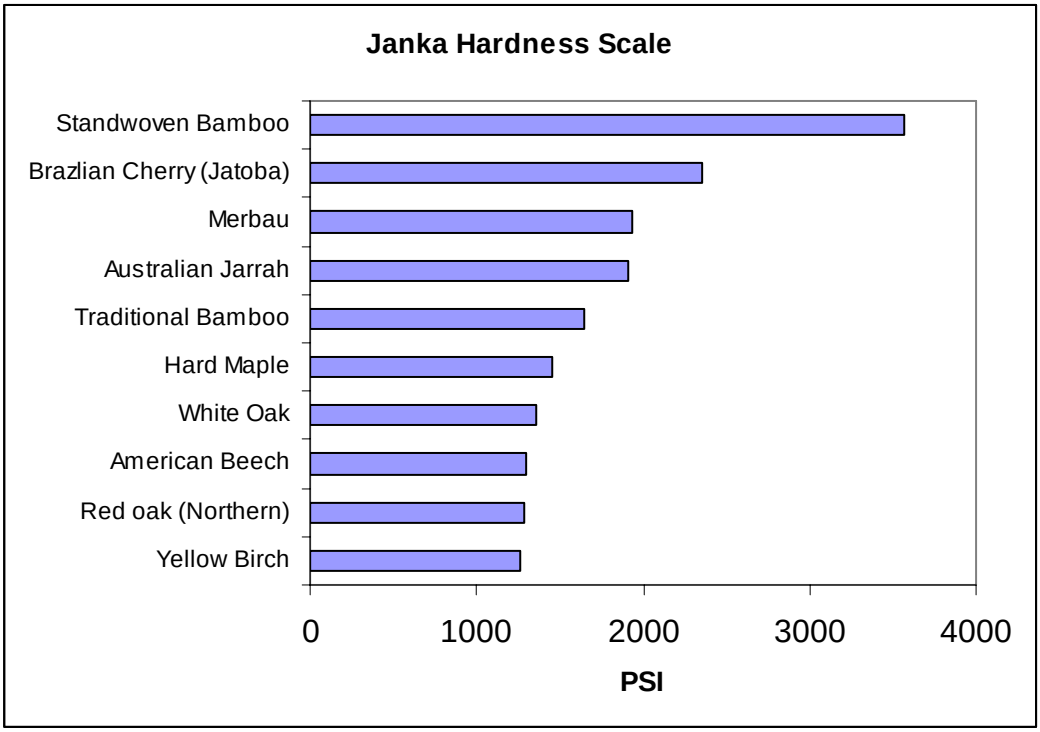
THE BENEFITS: STRAND WOVEN BAMBOO PRODUCTS AND PRODUCTION

Where the SWB is the one described above the tradition process of bamboo utilization is the lower part of the culm converted to slats for engineered board construction, the middle part into mats and / or blinds, the thinner section into chop sticks and in some instances the very top of the culm into tooth picks.

Table 1. SWB process versus the Traditional Process

	SWB Process	Traditional Process
Material cost-savings	Utilisation of the culm into higher value products: 60% - 85% of bamboo culm material	Low utilization of bamboo culm material, usually less than 25% into higher value products. Eg. conventional bamboo floorings only use 8%-10% of the culm.
Quality requirements to bamboo material	Material supplies may be various types of bamboo. It is believed that homogenous supplies of bamboo (age, variety, thickness) are important for qualities but more tests are required.	Selective to input of bamboo. Stringent demand for homogenous variety and age. E.g. In China, Moso and in Vietnam, Luong.
Market potential	SWB as a wood substitute, is open to mass market made-of-wood products and not a confined market segment of flooring, panels and furniture. Prices competition this is higher. Further testing of SWB in weigh bearing situations is required.	Conventional bamboo products, such as chopsticks, mats, and flooring are only sold to certain market segments. The growth rate therefore is limited relative to pressed bamboo.
Quality and application	SWB technical specification of hardness (2820 PSI) and dimensional stability is higher than most of iron woods and hardwoods in Group 1. SWB can be tailor formed to different dimensions as required.	Limited application. Product quality depends on various factors, including product type, material quality, processing ability and technical ability. Flooring hardness has been tested at 1450 PSI.
Financial efficiency	Estimated to be high. Net profit over turnover ratio may exceed 20%, with a payback period of 48 months maximum.	Known to be diminishing. Net profit over turnover ratio is in generally less than SWB. Eg. it is less than 5% for rough chopsticks and less than 10% for bamboo strips, etc.

Figure 2: Hardness (PSI) of SWB compared with other types of hardwood



Source: www.danskhardwood.com and www.jankahardnessscale.com; Note; The higher the PSI number the harder the surface. For additional test information (US, Europe and Australian independent test) regarding SWB please refer to www.danskhardwood.com, Dansk Fusion Manual pages 15 to 16.

ANNEX 2 Financial Analysis

Below is a summary of key variables that influence costs and returns.

Key Variables	Unit	Variable
SWB Price, Net Tax Year 1	*USD/m3*	*543*
Del. Factory Bamboo Price Year 1	*USD/kg*	*0.034*
Farm Gate Bamboo Price Year 1	*USD/kg*	*0.023*
Glue content (resin in solid form)	*%*	*10%*
Price for glue (UF)	*USD/kg*	*1.03*
Density	kg/m3	1080
Length	*mm*	*1900*
Strips length	*mm*	*2000*
Moisture content of raw bamboo	*%*	*50%*
Moisture content of SWB	*%*	8%
Utilisation of Culm	*%*	*65%*
Terminal growth rate	*%*	*-5%*
Currency Exchange	*USD/VND*	17,500

Revenue & Costs USD 000/year	10 year average	%
Total revenue	3,439	100.0%
Raw material cost	967	28.1%
Glue and chemical	886	25.8%
Electricity	85	2.5%
Direct labour	428	12.5%
Depreciation & maintenance	168	4.9%
Sales and marketing	138	4.0%
Other expenses	141	4.1%
EBIT (Earning before int. & tax)	627	18.2%

Key profitability indicators	Unit	Quantity
Total Initial Investment	USD 000	1,133
Equity	USD 000	675
Debt	USD 000	458
Modified Internal rate of return (MIRR)	%	26%
NPV (20% discount rate)	USD 000	1,128
ROE (10 yr average)	%	32%
Return on equity in year 10	%	21%
Net profit margin	%	17%
Payback period	Years	4

VOLUME 3

Bamboo and the Environment

Table of Contents

Preface

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Because of the effects of global warming of our earth, the effect of mitigation by plants, including bamboo, is very important. Bamboo is a plant with vigorous growth ability, enabling sustainable harvesting in abundance in a short time period, and has been noticed as a useful resource plant from ancient time. This plant has been utilized not only as a timber resource, but as a useful plant for environment conservation in disaster avoidance, landscaping, and so on. This session examines traditional and new viewpoints of bamboo as a solution to environmental problems such as global warming.

In the first half of this session, we will hear presentations from the indigenous areas concerning the effect of bamboo on environment issues. The contents of this part include the regional and economical effect of bamboo, the influence of bamboo to the environment and biodiversity, and the chemical influence of bamboo forests.

The great characteristics of bamboo as a plant species is also noted in the non-indigenous areas of bamboo. Even in these areas, bamboo has been planted for many purposes to alleviate environmental problems. After the coffee break, new utilization of bamboo in such areas will be introduced. Presentations concerning bamboo plantations in Europe for flood control and the potential for bamboo as an energy resource are planned.

The final part of this session includes the presentation about alleviation of global warming with the viewpoint of the economical benefit. In the past we have not discussed bamboo from this kind of view. At the end of the Session, we will discuss about how this great plant, bamboo, can help solve environmental problems.

A Study on the Environmental Role and Economic Potential of Arundinaria callosa, Munro

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Abstract

The North Eastern Region of Indian sub-continent is well known for the rich depository of bamboo. More than 65% of total bamboo populations of the country are growing in this region. Manipur is one of the eight states of the North Eastern Region situating in the Indo-Myanmar Border. The state is a hilly state. Nearly 80% of the total geographical areas of the state are the hilly terrains. The central region comprising of four valley districts are surrounded by nine different ranges of hills. The state, therefore, has unique topographical features. Besides, the unique topography, the climatic conditions prevailed in the state are of varied nature. Such features favour the growth of different bamboo species both in the valley and hilly areas. The distinguishing characteristics of the species that grow in the hills are somewhat altitude-oriented and monopodial too. The present study has been made on one of the thorny species of bamboo, *Arundinaria callosa* Munro, regarding its growth, role in the environment and its economic potential. This species is widely growing in the hills at high altitudes and as it an edible one, helps much in the socio-economic upliftment of the hilly people of the State. This green gold can be regarded as renewable wealth of the state and hence a gift of Nature.

Introduction

Bamboos, in nature, exhibits two types of growth patterns-Monopodial and Sympodial. Monopodial bamboos are mostly small sized, branched profusely at the nodes, produced thin and broad leaves and have long creeping rhizomes, such creeping rhizomes called as leptomorph type can produce nodal outgrowths every year. As it extends long, further it produces more vegetative outgrowths and new culms are formed extensively in greater numbers. They produce fast growing culms and can cover a wide area with thick populations of new culms. Sympodial growth patterns are clump-forming and have pachymorph types of rhizomes and Caespitose in nature. The monopodial bamboos include species belonging to *Arundinaria*, *Melocanna*, *Pseudostachyum* etc. These three genera of bamboos are growing abundantly and extensively in the hills of Manipur. *Melocanna* can be listed in the first, second *Arundinaria* and *Pseudostachyum* at the third place. However, Melocanna can grow successfully in the plain areas too whereas Arundinaria and Pseudostachyum cannot grow. Mostly species under the genus Arundinaria are altitude-oriented and found to grow at high altitudes and also occupied the top of hills showing its dominant characteristics. *Arundinaria callosa* syn. *Chimonobambusa callosa* is a thorny bamboo of high altitudes. It can grow luxuriantly occupying wide spaces and with larger populations.

They love the foggy, moist, climatic conditions with acidic soil. They have thorns around the nodes, thick and dark green in colour. In rainy season of each and every year, new shoots come up from the rhizomes and undergo successful vegetative propagation in nature. The young shoots are harvested on a large scale by the inhabitants and made available in the local market for 3 to 4 months continuously. The young shoots are used in making different types of delicious curry in raw, and fermented forms. Even though, in the hardly undisturbed and disturbed forest areas, it still grows extensively shaping the landscape, preventing the soil erosion and functioning as wind breaker. It has manifold applications and utilizations. The mature culms are hard and thick and hence used in making poles of huts, in fencing and in making handles of knives and swords and in making walking sticks.

Therefore, keeping with the interesting viewpoints of observations on its growth pattern and ecofriendly nature, contribution to the socio-economy of the state and favourable climatic conditions and restricted growth, the present study has been made selectively and particularly on this bamboo.

Materials and methods

Material : A thorny bamboo, *Arundinaria callosa* Munro.

Local Name – *Laiwa*

Methods :

1) Field/Ground study on the spot in its natural habitat.

   The natural habitat of this thorny bamboo is the hill tops or peaks. Ground was made visiting the spots during the months of April to July i.e. before the onset of winter season. This species was found to be extensively growing wild in the thick, undisturbed forest areas. Mostly the hill tops are covered densely by various types of vegetations and hence always remained cooled and foggy.

2) Taxonomic study based on criteria viz. Culm, Culm sheath, branching, Leaves & Phyllotaxy, Growth Patterns etc. (Photo 1)

3) Study on Plant Association – Mode & Population.

   This bamboo is truely an ecofriendly plant. Mode of plant association was studied by observing the plants growing together on the spot. Observation was made regarding the ground vegetations too. The ground soil surfaces were found to be covered by different species of bryophytes, pteridophytes and small agiospermic plants etc. The population density was observed to be high. Population of culms were counted at equal distances from a fixed point.
   (Quadrate methods). (Photograph 2)

4) Market Survey – Production, Price, Demand and Supply etc.

A survey was made at the main market places and local market of the state.

Young shoots of 2/3 nos. are tied into bundles and sold at the rate of Rs.5 to Rs.10. The fresh, edible shoots are preferred widely by the people of all caste and creeds. Mainly harvesting and selling works is done by the women folks. Both fresh and fermented ones are delicious curries of different taste and flavor. Price also varies from month to month

5) Role in Environment – Propagation and Conservation.

Mode of propagation and its abundance in the natural habitat was studied thoroughly. Vegetative propagation was observed to be very fast and fruitful. The new outgrowths grew extensively nearby the parent culms. Long running and creeping root system help in conservation in the particular eco system. Environmental factors like climatic condition, soil condition, rainfall etc. favours the natural growth of the plant. The plant is well adapted to the said environmental conditions.

Result and Discussion

Scientific Name	- *Arundinaria callosa*, Munro.
Local Name	- *Laiwa*
Habit	- Small sized, Erect, Thorny bamboo, Monopodial with 1782 – 2500 msl and above. - Foggy & Moist climatic condition. - Soil Acidity 5.6 – 6.5 (P^H)
Most Associated	- *Teinostachyum* Wightii, Beddome.
Bamboo Species	And *Arundinaria rolloana*, Gamble.
Most Favourable Area	- Hill slopes away from sunlight, in Dampy areas.
Taxonomic Character	- Culm 12-20 ft; high; 05-1 inches in diameter; Nodes single-ringed, prominent; Thorns present more than 8; Internodes nearly solid at the base; Culm-sheath deciduous, longer than the internode, Hairy & grey in colour, Imperfect blade short, subulate long fringed, short auricles present; Leaf thin, Oblong-lanceolate, hairy above on the marginal veins, Pubescent beneath, Leaf-sheath striate, glabrous ciliate on the edges. (Photograph 3)
Utilization	- Young shoots & Tender stems are boiled & used in preparation of local curries. - Culms used in making handles of knives & spears.

	- Used in making weaving implements.
	- In making walking sticks.
	- In making fishing rod.
	- Roofing of huts, fencing the walls etc.
Growth	- Fast, highly successful in vegetative propagation on the onset of Monsoon.
Period of Propagation	- Mostly June to October each & every Year.
Harvesting	- New outgrowths i.e. shoots 2-3 ft. high are harvested every year. From rainy season till the month of October. Harvested in terms of lakhs.
Status in Market	- Plenty in the local market in the season, Highly demand, 3-4 months continuously available; Raw or Fresh are consumer's choice; Good income source, affordable price.
Resource Type	- Renewable, Regeneration fast & Forest Resources.
Role in Environment	- i) Helps in landscaping ii) Prevents soil-erosion iii) Keeps the surroundings cool and fresh iv) Helps in growth of many pteridophytes, Bryophytes, algaes etc. on the ground soil. v) Do not graze by the cattles & any other livestocks, because of the presence of thorns. vi) Sometimes acts as wind breaker. vii) Ecofriendly plant.
Conservation	- Wild in nature; well – adapted to the climatic conditions & range of altitudes; Rich diversity; Hence, Natural conservation is observed.

The above findings are made after strict and keen observations made on the spots. It is traditional of the local people too, to keep at least one culm with branches and leaves at the home. Very regularly every year in the month of March or April, people of Manipur State particularly Meiteis used to observe the New Year's Day just the next of new moon. Before this day, people used to climb the Koubru Hill and worship the deities there. At this time, this plant is collected and brings home with deep faith in mind of protecting from all the worses and evils of life.

Conclusion

From the above findings and discussions made it can be concluded that this bamboo is of utmost importance to the local people both from the angle of environmental protection and economic source. Now, the global issue of climate change is agreed to be the result of environmental deterioration. Deforestation and forest firing for cultivation and communication purposes will enhance the untimely disappearance of rich flora and fauna of a region. Climate change is also a man created and invited non-recoverable phenomena. Conservation is a continuous ongoing natural process. Man only disturbs such process by creating unlawful exploitation of forest areas. Adaptation is the best means of conservation in nature. Thorny plants are considered as morphologically and physiologically modified xerophytic plants, which can withstand the strong heats and hot winds of deserts. The desert conditions are tough and hard enough to withstand for the human beings. *Arundinaria callosa* is a thorny bamboo well adapted to the high altitudes and protects itself from freely moving speedy winds and frost. So, it is the right time to explore the natural and environmental principles and laws prevailed in the living planet to make our natural resources, a sustainable one.

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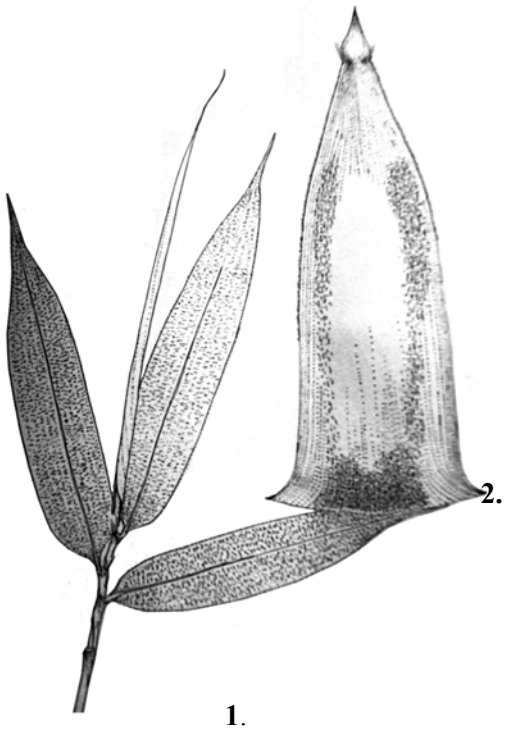

1.Leaf
2. Culm Sheath

Figure 1. Arundinaria callosa

Photograph 2 Arundinaria callosa in its natural habitat

Photograph 3 Thorny nodes of Arundinaria callosa

A Contribution to Flood Management in European Cities through Bamboo Plantations

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Abstract

In conventional wastewater management systems, the so called "end-of-the-pipe" system, Rainwater (RW) is an entire component of the collected effluent as it is mixed with urine (yellow water-YW), faeces (brown water-BW) and wastewater from sink and washing rooms (grey water-GW) before it is transported via pipes and discharged to the municipal wastewater treatment plant (WWTP). The system is well established as wastewater management system in most European cities. In the recent decades with the rise of water resources scarcity in many parts of the World and the necessity of managing flood in other parts, new approaches of RW management occurred. Among the modern techniques are recharge of groundwater through infiltration and RW harvesting. This paper is a contribution to infiltration methods. It proposes bamboo plant as filter medium to allow the runoff of RW to infiltrate and go back to the water cycle by enriching the groundwater reservoirs. It will provide the fundamental advantages of the system (RW infiltration through bamboo plantations) and will expose some limitations as well.

Keywords: Flood management – Rainwater - European cities - Bamboo Plantations – Ecological Sanitation

Introduction

Two fundamental environmental issues have caused RW to be considered differently starting from the last decades. The first one is water resources scarcity that many countries in the world as Mediterranean countries suffer. The second environmental reason relates the management of flood. The European continent falls within this latter issue. Greenpeace (2005) reported that more that 100 floods have hit Europe between 1998 and 2002, that made roughly 700 victims, rendered one half million of people homeless and caused economical loses of more than 25 billion EURO. The pick of this series of catastrophes in that period of time occurred in August 2002 (EU, 2004). Three years later (2005) stronger rainfall comes in by causing severe floods in Switzerland, Germany and Austria. As damages thousands of properties were flooded and hundreds of people forced to leave their homes. Figure 1 below is the European continent; the flooded area in the countries mentioned above is shown in red.

This alarming situation results from the combination of different factors: among them are climate change that increases the ambient air temperatures, resulting to more and more rainfall. The sealing of soils with

constructions from the development of cities reduces cultivable lands and consequently increases the runoff of rainfall. The overall direct consequence is overwhelming of wastewater treatment infrastructures with huge volume of wastewater. It is not to mention the induced consequences in terms of dramatic increase of investment costs for construction and maintenance of wastewater treatment plants. It makes sense therefore to consider RW separately by not mixing it with the other effluents to reduce the volumes arriving at the WWTP and therefore reducing the risks of flood. In doing this a key point is to infiltrate the effluent near to the source. Searching for new ways in municipal water management, decentralised solutions for the rainwater runoff must also be found as a matter of course in order to refill the aquifers when using them for local water supply (Otterpohl et. al., 2002). Furthermore in nowadays researches on RW management, Matsushita et. al., (2001) reported that infiltration is seen as one of the best methods to let RW back to the natural water cycle.

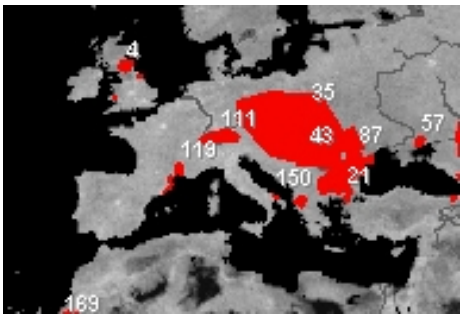
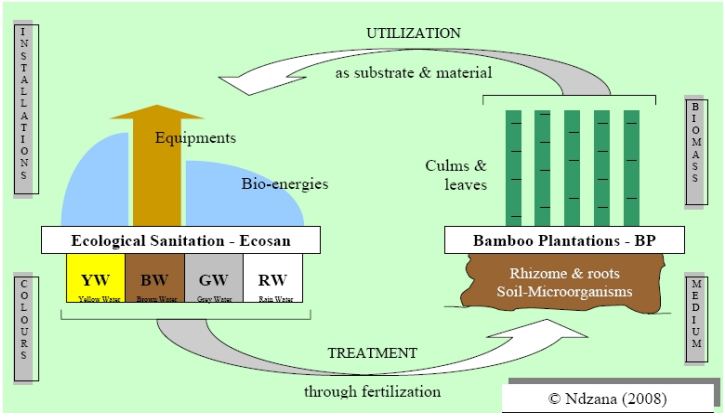


Figure 1. The most flooded area in Europe, August 2005

The most known techniques that allow the infiltration of RW include surface infiltration, hollow infiltration, infiltration in trenches, tubing infiltration or pit infiltration. Surface infiltration through a bamboo plantation (bamboo filter: the Bamboo Plantation Rain Water Management-BPRWM) is the purpose of this paper. In fact at the Institute of Wastewater Management and Water Protection of the Hamburg University of Technology-TUHH a research work on Wastewater Management with bamboo plantations is going on. Figure 2 below presents a simplified structure of the research (the ecosan-bamboo concept) where the waste streams of Ecological Sanitation-ecosan (a decentralized approach of sanitation -with source separation collection and treatment of the waste streams- that aims at nutrient recovery and water reuse for agricultural purposes) are collected and treated separately in the underground part of bamboo plantation (rhizome and roots). In fact bamboo utilizes water and nutrient content of these streams to grow. This results in the production of biomass that could serve the ecosan system again in terms of construction of ecosan superstructures or feeding bio-energy units.



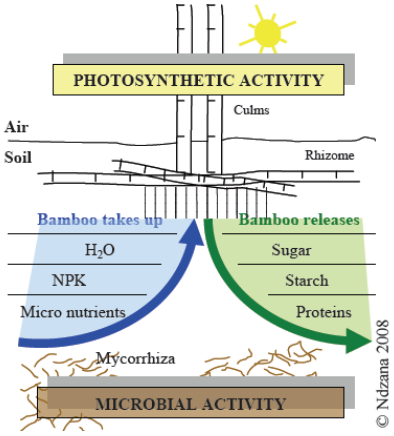


Figure 2. Figure 3

Figure 2. The Ecosan-bamboo concept (source: Ndzana, 2008)

Figure 3. Simplified bamboo nutrient uptake mechanism (source: Ndzana, 2008)

On the one hand the system developed at the mentioned Institute has potential for implementation in Europe: because the sewer system for RW exists in most European cities RW can be diverted with control. This means that in the existing RW sewer system, measures to take can be put in place so that RW is diverted with control on the catchments' area of runoff and volumes diverted. On the other hand the potentialities of bamboo allow it to act as a filter medium of wastewater. Bamboo plantations possess a very dense underground structure governed by the rhizome that grows continuously during the whole life of the plant. The rhizome system constitutes the structural foundation of the plant, in which nutrients are stored and through which they are transported (Liese, 1985). Because bamboo is the fastest growing plant on the Earth (Villegas et. al., 1990) it has potential to take-up large quantities of nutrients. A simplified mechanism of nutrient uptake is shown on figure 3 above. The combined actions of microbial activity in the soil through mycorrhiza and the photosynthetic activity through sunshine provided to bamboo plant allow it to use water and absorb macro and micronutrients. In turn the bamboo plant will basically release sugar, starch and proteins into the soil for the benefit of soil microorganisms. Moreover the plant is regenerative; once it is planted there is no need to replant it rather is there a need of harvesting the mature culms. Although bamboo is an exotic plant for Europe, it develops very good and normally there. Bamboo was reintroduced in Europe in the 20s from Central China and Japan (Eberts, 2004). The project "Bamboo for Europe" is the living fact not only for the interest of Europeans in bamboo, but also the scientific proof that bamboo can contribute efficiently to some extend and remedy or alleviate some environmental treads such as flood within the European Community.

The concept of infiltration of RW through the bamboo filter will be presented and the paper will discuss the main advantages provided and limitations for the system.

Materials and Methods

The experimental set-up

A schematic experimental set-up of one of the installation in which investigations are performed is shown on figure 4 below. Basically it is a container –called reactor in this paper- of 160 litres in which bamboo is planted. Openings were made at the bottom pat of the reactor to allow effluent collection. The reactors are in open air inside the inner yard of the Institute. The soil in the reactor is of two different layers; the first layer is the top soil in which the rhizome and the roots of bamboo plants are lain. It allows rapid percolation of influent through the reactor. The second layer is a gravel layer of 5.00 cm that enables the rapid leaking of influent arriving from the upper part. Grown bamboo plants were transplanted from a living stand of the Botanical Garden of Hamburg and put into the containers. The bamboo specie used is Phyllostachys *viridiglaucescens* (P. *viridiglaucescens*), a hardy bamboo specie that resist winter temperatures up to -22°C.

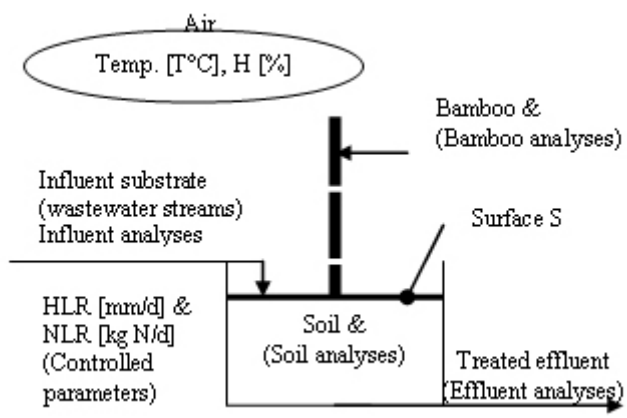


Figure 4. Schematic experimental set-up

Soil characteristics

The soil in the reactor is a mixture of compost, sand and crushed bark. It will be called soil in this paper. The proportion of each component is shown in table 1 below. The nutrient content of soil was analysed for the macronutrients Nitrogen (N), Phosphorus (P), Potassium (K) and Magnesium (Mg) according to LUFA (Landwirtschaftliche Untersuchungs-und Forschungsanstalt) method of measurement "Gehaltklasse von LUFA" as presented in table 1 below. The composition of soil achieves permeability between 10^{-6} and 10^{-3} m/s. According to LUFA method a normal soil contains from 8 – 12 mg/100 g Mg. Because the Magnesium content of soil was very low (see table), 10 g Mg in form of $MgSO_4$-$7H_2O$ was added in each reactor in a soluble form by mixing with tap water. In fact Mg plays a very important role in the photosynthesis of plants for nutrient

absorption. The pH and conductivity of the soil were measured by using the German standards methods for soil and analysis.

Table 1. Soil characteristics and pH and conductivity

Soil								
Composition			Nutrient content (mg/100 g)				pH and conductivity	
Compost	Sand	Crushed bark	N (kg/ha)	P	K	Mg	pH-$CaCl_2$	LF
85%	10%	5%	< 40 little	16–30 normal	> 50 over fertilized	1-4 poor	6,17	-0,31

The issue of acid rain occurs only in highly polluted urban areas. It sometimes causes RW to be regarded as a problematic source of water. But RW is basically a very good source of water as it contains a very limited amount of pollutants. In fact the nutrient content and organic matter of RW is insignificant compared to those of urine or grey water, making RW to be an important component of water resources. Due to its low nutrient content the matter of RW management by the bamboo filter relies not in the nutrient uptake aspect rather on the evacuation of RW through percolation in the bamboo filter, thus on the capacity of the bamboo bed to act as a filter for RW. Therefore RW is not percolated through the reactor rather a mixture of urine and tap water (which contains much more nutrient than RW) to investigate the long term effect about bamboo filter clogging in case some nutrient remains in it that may disturb the basic role of the bamboo filter bed: filtration. The substrate is a mixture of urine and tap water (U+TapW). High rates nutrient content of substrate based on urine nitrogen were defined: 400, 800, 1200 and 1400 kg N/ha/a. The substrate was feed into the 9 reactors (3 for 400 kg N/ha/a, 2 for 800 kg N/ha/a, 2 for 1200 kg N/ha/a and 2 for 1400 kg N/ha/a) so that less losses of nutrient from the effluent occur as the clogging effect due to nutrients is researched.

Concept of diversion of RW

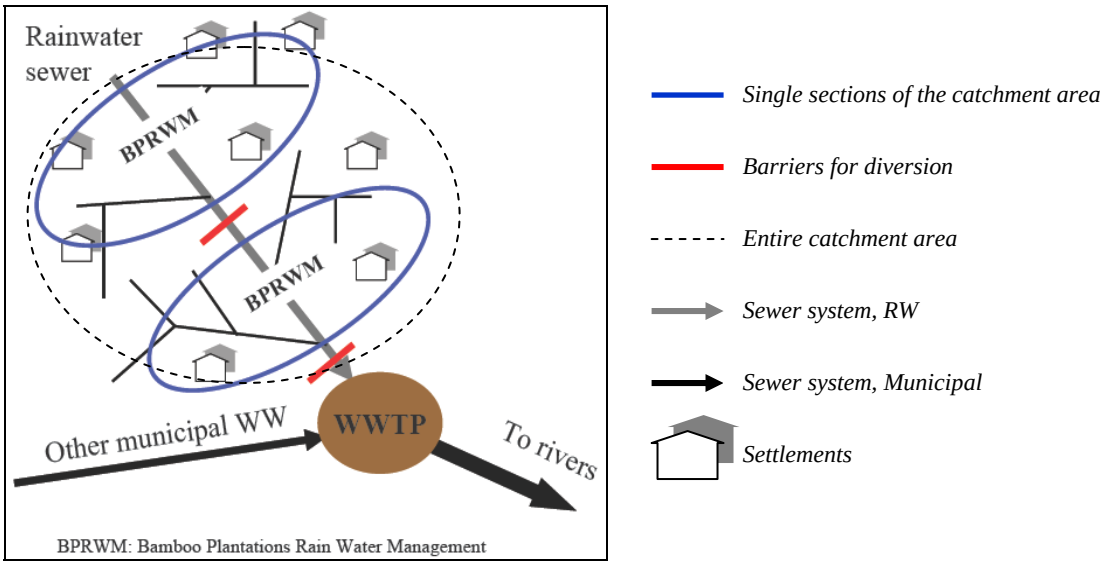


Figure 5. RW diversion concept

Figure 5 above is the concept of diversion of RW in a given area where a sewer system of RW exist and conveys RW into the sewer system of wastewater prior to treatment at the WWTP. The aim of it is to divert RW from its conventional flow line and rather infiltrate that influent into the aquifer with the use of the bamboo filter: the BPRWM. The entire catchment area (interrupted circle on figure 5) corresponding to a collection line of RW is broken down into single sections (oval blue line on figure 5) by introducing nodes in the main RW sewer (see on figure 5 the red divisions). These are sort of barriers (seen in red on figure 5) that prevent the flow of RW in the main collection line continuously rather favour the gathering of RW in the corresponding single section. Fundamentally the RW sewer system is not destroyed rather participates in the collection of RW on a given single section of the catchment area. Technically this is feasible as the collection of RW to the main drain that leads directly to the WWTP is done by gravity and RW converges therefore towards the same point. Where necessary depending on the slope of ground in place the gathering of RW may need a pumping system. Bamboo filters are installed within each single section of the entire catchment area. The topography of the entire catchment area is an important factor in the breaking down of it into single sections. Thus single sections of the entire catchment area will be of different sizes.

Results and Discussion

Clogging effect due to nutrient content of substrate

Figures 6 and 7 below are respectively results about the Total Organic Carbon removal from the substrate (TOC) and the uptake of phosphorus by the system soil-bamboo as function of nutrient content of the substrate. For figure 6 the TOC removal efficiency varied from 74.6, 87.1, 90.8 to 91.1 respectively for 400, 800, 1200 and 1400 kg N/ha/a. Independently of the nutrient content of the substrate nearly 250 mg/l organic carbon was found in the effluent. For figure 7 the uptake of phosphorus by the system soil-bamboo was nearly 100%: 97.9% as average for all reactors. In order to separate the activity of soil from the one from bamboo the conductivity the conductivity in the top soil was measured. Initial soil conductivity at the beginning of the experiment was 201 µS/cm. In the course of the study it decreased (detail results are not shown) in all 9 reactors. An average decrease was 37%, meaning that the salts content of the soil decreased as conductivity correlates with salts content. This result was not expectable as usually addition of urine to the soil for certain crops such as vegetables results in the increase of conductivity (Pearson et. al., 2007). In the case of bamboo the decrease of salts concentration in the top layer of soil can be explained by the statement of Kleinhenz and Midmore (2001) that the top soil of bamboo stands is typically aerated and natural mineralization of nutrients is usually quicker there than in the deeper layers. The effectiveness of absorption of plant-available ions by the dense root system of bamboo is in this horizon. This explains the other well-known statement that bamboo plants sequester nutrients in its top layers. Further investigations are carried out on the nutrient content in bamboo culms and soil to confirm and comfort this thesis.

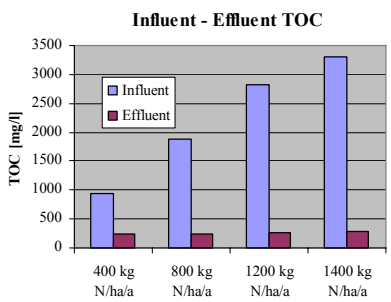


Figure 6. Influent and effluent TOC

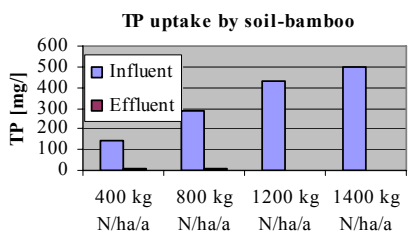


Figure 7. Total Phosphosrus (TP) uptake by soil-bamboo

The bamboo filter design in a single section of the catchment area

The design of the bamboo filter (BPRWM) is presented with its efficiency in terms of rough calculations and the advantages and its limitations mentioned and discussed. The calculations are made for a city like Hamburg, with relatively high rainfall in Europe (800 mm/a). The demonstration case is considered to show how the diversion is done and the bamboo filter is installed within the settlements for the infiltration of RW into the aquifer. Figure

8 below is a plan view of a single section of the entire catchment area within which the bamboo filter is installed. The settlement concerned in this single section is composed of 6 buildings for which the bamboo filter is dimensioned. The RW flow in the main sewer (see in grey colour in figure 8) is interrupted by

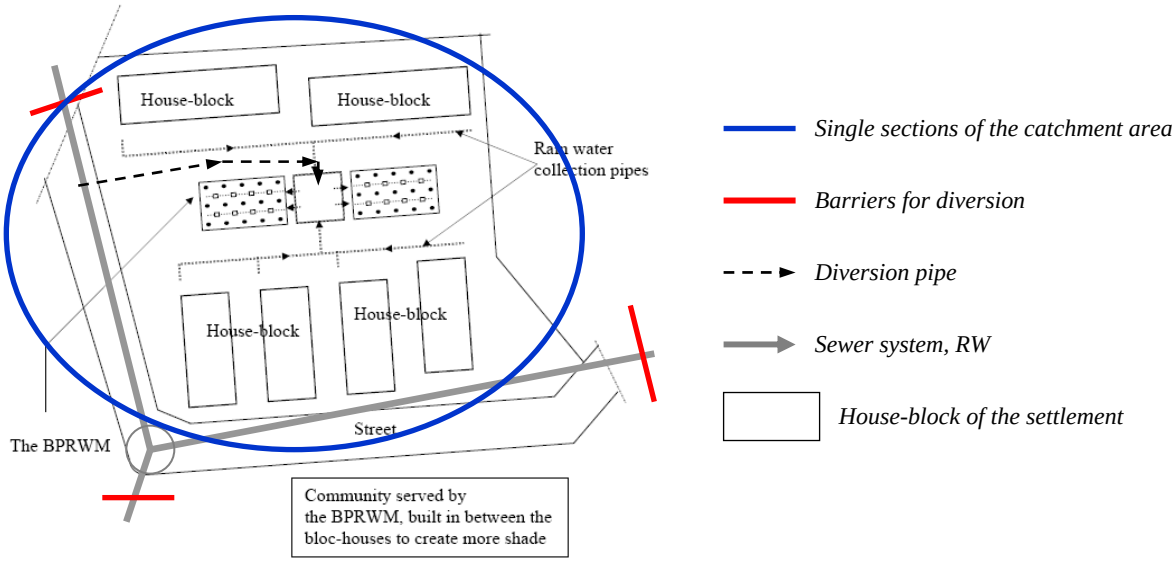


Figure 8. Plan view of single section of catchment area including the bamboo filter

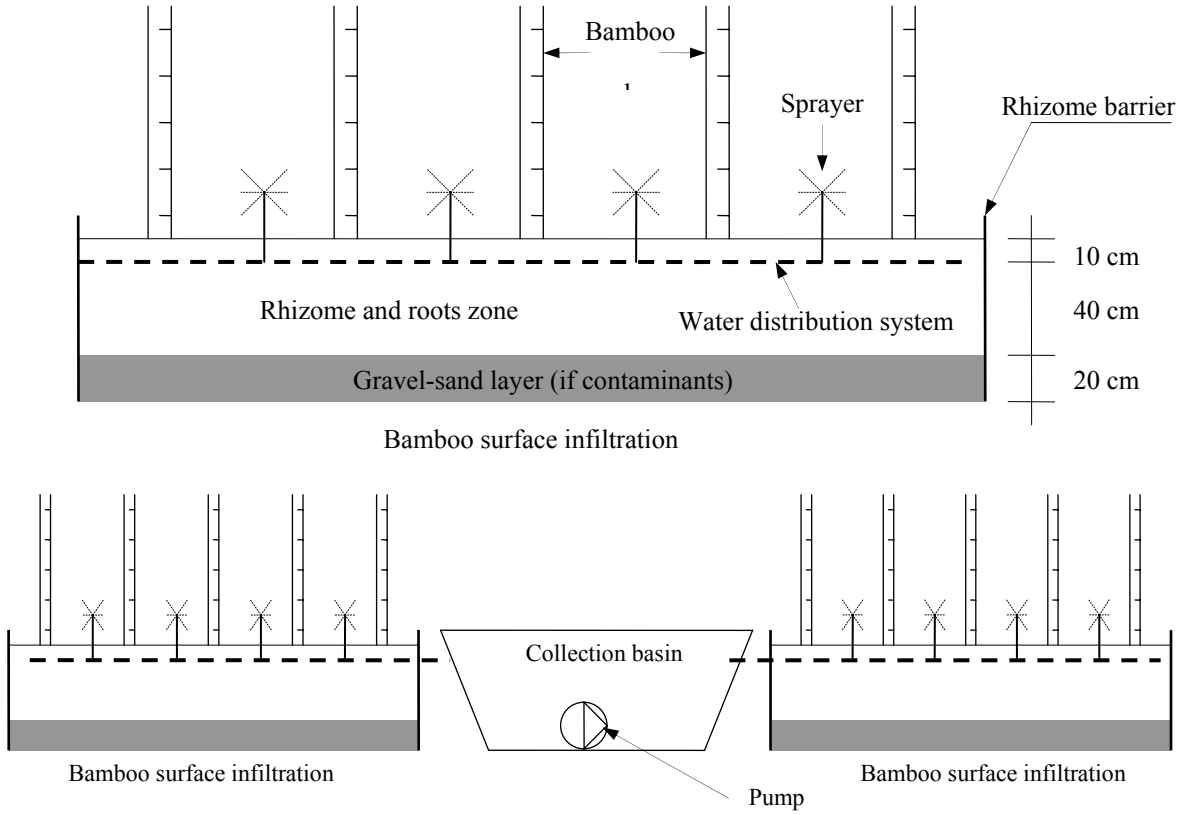


Figure 9. Cross section of the bamboo filter; the collection basin and the bamboo surface infiltration

barriers (see in red on figure 8) that provoke diversion to the bamboo filter via pipe; the diversion pipe (see black interrupted arrow on figure 8). Depending on the case according to the slope of the ground a pump may be needed at the junction of the main RW sewer and the diversion pipe.

The design of the bamboo filter shows a collection basin (in the middle) and two bamboo surface infiltration beds placed each by side of the collection basin. (see figure 8). While being an infiltration area, the role of the collection basin is to gather the RW diverted from the main sewer and to evacuate RW on the bamboo surface infiltration beds in an intermittent fashion at regulated velocity via a piping system (see water distribution system on figure 9). It must allow a retention time of 3 days rainfall on the surface considered. The pump in the collection basin pumps the gathered RW to the bamboo surface infiltration beds through the piping system that could be installed above ground or a few centimetres in the top soil of the bamboo filter. The water is spread on the bamboo infiltration bed through sprayers as shown on figure 9 above.

Calculations for design

The stormwater source control design guidelines (2005) stipulate that the amount of space required for stormwater source controls is a direct function of: the volume and intensity of rainfall hitting the site, and the associated rainfall capture target, the amount of impervious area on the site, the area of infiltration surface on the site, the rate of infiltration into the infiltration surface, the amount of rainfall storage that can be provided to temporarily hold water until it can infiltrate into the ground.

Assuming a single section area of 10.000 m², a rainfall capture target of 50 mm, 15% of impervious area on the single section with consideration of an average infiltration rate of 10^{-5} m/s and 10% infiltration from the collection basin per day, the total area needed for infiltration (bamboo surface infiltration) and the volume of the collection basin can be determined:

Volume of the collection basin $[V_c]$:

$10.000\ m^2 * 15\% * 50 * 10^{-3}\ m * 3\ days = 225\ m^3$

With consideration of 10% daily infiltration from the collection basin,

$[V_c] = 225\ m^3 – (10\% * 225 * 3\ days) = 160\ m^3$

If $[V_c]$ is to evacuate in a max. time of 3 days, the total bamboo surface infiltration bed $[S_b]$ is:

$[S_b] = 160\ m^3 / (10^{-5} m/s * 24 * 60 * 60s) * 3\ days = 560\ m^2$

Because there are 2 bamboo infiltration beds, each bed will be an equivalent of:

$560\ m^2 / 2 = 280\ m^2$ *(chosen dimensions: 10.00m width and 28.00m length)*

The spacing of bamboo in the infiltration bed is chosen 1.00m * 1.50m that is also the spacing suggested by Gielis (2000) during the trials in the framework of the project "Bamboo for Europe". With this spacing Gielis (2000) got good growth response of some bamboo species. The higher spacing density for Europe is comprehensible when consideration is made on the fact that bamboo is an exotic plant for Europe and therefore will grow relatively slowly compared to origin land where the spacing density is lower. Bamboo species to use for the infiltration bed will include Phyllostachys (P) species such as P. *aurea*, P. *nuda*, P. *aureosulcata 'spectabilis'* which showed good performance in growth in the trials of Gielis (2000). Other could be P. *viridiglaucescens* (the one used in this study) and P. *vivax* which produce bigger culms compared to the other species, although the last one in the study of Gielis did not perform as well as the others. All of them are running type of bamboos that possess a spreading growth pattern through the rhizome; they will be preferably used.

Advantages of the bamboo filter concept

The implementation of the bamboo filter concept in European settlements will provide many advantages. First of all the bamboo filter concept embedded on the diversion of stormwater for the purpose of safe infiltration of collected water into the groundwater is a contribution to water resources management. This basic role will

involved obviously the reduction of volume of water that flows to the WWTP and thus reducing and even avoiding flood risks if more and more units are implemented in a given entire catchment area. This will impact on the investment costs for WWTP that will drop down considerably. Additionally putting in place the bamboo filter concept will allow soil stabilization and therefore preserve fertile soil because the system favours infiltration as near as possible to the source, at the single section of the catchment area considered. Moreover running bamboos tend to spread laterally in the 50 cm of top soil rather than growing in depth. Environmentally speaking and when the bamboo filter is established (after 6 to 7 years) it will provide shadow and could be used as recreational area. After that period of time, it is expected to harvest first culms from the bamboo filter beds; these could be reused for several purposes.

Limitations of the bamboo filter concept

The bamboo filter intends not to be a solution for every single case rather a contribution wherever possible. The bamboo filter must be seen as an alternative among the possible solutions to remediate the question of flood risks in Europe. First of all the concept will require the provision of enough space. In the example above, approximately 600 m² are needed for the 6 house-block erected on roughly 1.00 ha. This might represent in some cases enormous piece of land, especially in the inner parts of cities where most land have been sealed with constructions and buildings. Provided that the space is not a limiting factor, there is the need of careful analyses of preparation steps prior to implementation. These relate: the provision of bamboo plants and related costs, the entire catchment area and its associated sewer system of RW in order to understand how it will be broken down into single sections, soil analyses where the bamboo filter concept will be erected. The bamboo filter concept must be planned for an entire region (corresponding to a given catchment area) in order to impact significantly on the risk of flood. Therefore as several units need to be installed the associated investment analyses must be run. Harvesting grown bamboo culms might be a problem in some cases where the use of it is irrelevant. Bamboo leaves must be removed periodically, especially in summer time. But this is also the case with other trees planted within the settlements near roads or on recreational areas.

Conclusion

Flood is more and more hitting many parts of the World and Europe is not at rest about it. This paper is a rapid investigation on the possible contribution of bamboo in terms of the bamboo filter concept (BPRWM) to reduce the risk of flood in European cities. The existing RW sewer system in most European cities is a good and precious starting point for diversion of RW as the BPRWM sectioned the main sewer into single sections to infiltrate the water as soon as it rains by reducing therefore the runoff. Provided that there is sufficient space and good analyses prior to the implementation is performed, the BPRWM can efficiently participate to flood risk avoidance. The efficiency of the BPRWM concept is at sight if planned for an entire catchment area of RW. A single unit will not impact on flood risk unless the system corresponds to the given catchment area. The BPRWM concept is also suitable in planned residential area; in this case diversion is directly done from each single catchment as no sewer system for RW is necessary to construct. The implementation of the BPRWM concept will automatically induce some further benefits for the sake of the environment including water resources management, soil stabilization. Furthermore recreational areas will be created within the settlements.

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Energy Crops in Western Europe: is Bamboo an Acceptable Alternative ?

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Abstract

Most attention in Western Europe goes to the classical bionergy crops poplar, willow and *Miscanthus*. However, several other plants are useful candidates to provide biomass for the production of electricity. Bamboo is among them. Pilot tests of bamboo growth in Ireland show that bamboo produces enough biomass, even under a rather adverse climate, to make the plant economically an equal investment as the classic crops. Moreover, bamboo tends to have a higher capacity for uptake of heavy metals than poplar and willow, offering possibilities for an efficient combination of biomass production and heavy metal phytoremediation.

Introduction

Given the ambition of the European Union to enhance the production and consumption of renewable energy types over the next decade (Commission of the European Communities 2006, 2008; Martinez de Alegria Mancisidor et al. 2009), as well as the current state in nearly every one of the Member States, a large effort will be needed to provide the means to make these plans come true. Second generation biomass products are currently most welcome as alternatives, albeit to be used in the future in combination with third generation fuels (transgenic carbon dioxide neutral crops) and fourth generation (transgenic carbon dioxide negative) fuels (Gressel 2008).

Currently, *Miscanthus*, *Salix* and *Populus* are best established as second generation biocrops for cultivation in Europe (Commission of the European Communities 2006, http://www.eubia.org/192.0.html and http://www.eubia.org/193.0.html). However, several other species might contribute to the production of biomass for fuel production. There is an emerging interest into oil from *Jatropha* (Achten et al. 2008) for the deciduous legume tree *Pongamia pinnata* (Mukta et al. 2009; Murugesan et al. 2009), or in the usage of waste material (Felizardo et al. 2006).

A source of biomass that should not be forgotten is bamboo (Scurlock et al. 2000; Atkinson 2009). Bamboo is one of the fastest growing sources of biomass on earth with an unsurpassed regeneration potential. In this paper,

we first analyse whether it is opportune to use bamboo as an energy crop in Europe, outside its native region. We will then compare bamboo with the three energy species that are best characterised (*Miscanthus*, willow and poplar) in terms of biomass production, energy production and phytoremediation potential.

Bamboo As An Energy Crop

Woody bamboos have usually been considered (Ohrnberger 1999) to belong to the tribe *Bambuseae* Kunth ex Nees within the *Bambusoideae,* a subfamily within the grass family *Poaceae*. This tribe contains 1200-1300 different species, divided over 130 genera of woody bamboos and 25 genera of herblike plants that function for the most part as undergrowth in forests. Bamboos are endemic to all continents, except for Europe. In Europe bamboo fossils dating back to the last Ice Age have been found and bamboos have been cultivated intensively for the last 150 years. The plants grow via a rhizome system from which hollow culms originate. Depending on the species, these culms can attain a diameter of up to 20 cm and a height of 10-30 m (El Bassam 1998; Scurlock et al. 2000).

Bamboo has several characteristics that might be useful for future energy plantations (Scurlock et al., 2000):

- As mentioned above, there is the high growth rate (Shanmughavel and Francis 2001; Scurlock et al. 2000 and references cited therein).
- Once properly set up, a bamboo plantation needs little care. Bamboo grows due to an extensive underground system of roots and rhizomes; this system not only procures a regular regeneration of the harvested parts above ground, but also protects scarcely vegetated soils from wind or water erosion (El Bassam et al. 2002; Scurlock et al. 2000).
- Bamboo can be used as a bio-fuel, short-circuiting the current CO_2 cycle, which draws on fossil fuels. This will offer an advantage in terms of greenhouse gas production.
- Bamboo does not need to grow on optimal agricultural land (which remains available for food crops), but can withstand a certain level of pollutants. It remains to be seen, however, to what extent.
- A bamboo plantation requires 5-7 years to achieve full maturity. Even during that time, though, management is quite inexpensive in terms of effort and costs. During the first two years, maintenance consists mainly of weed control, and possibly adding organic fertilisers. Once the plantation reaches maturity (after 5 years), it will maintain itself.
- Harvested bundles of bamboo can be kept for at least 3 months (Gielis 2000; Temmerman et al. 2005). Combined with an optimal harvesting season of 6 months (from October to March), this means that bamboo can be supplied as raw material to the industry for about 8-9 months per year, offering the possibility for a nearly year-round, rather steady supply of biomass for energy production.
- The preferred method of harvesting the bamboo plants depends on the intended use for the plants and on the available options for storage of the harvested biomaterial. Harvesting for future combustion occurs mechanically by use of a light-weight short rotation forestry harvester, which harvests the culms completely and chips them, if desired. This bamboo biomass can also be transformed into bricks or pellets, or be gazified.

These advantages notwithstanding, concerns have been raised that bamboo species are an exotic species in (Western) Europe. Failure to contain bamboo plants to the plantation areas (due to its spreading rhizomes) might therefore impact the development of nearby (natural) ecosystems, and past experiences with other exotic,

potentially invasive species, has provided plenty of reasons for a genuine concern. In the case of bamboo, however, spreading is easy to contain if taken into account from the start. With a few very simple solutions (such as the use of commercially available polyethylene sheets, to be put in the soil around the plantation at a depth of 50-70 cm), the rhizome outgrowth can be effectively blocked. Moreover, given the propensity of a bamboo stand to set flowers simultaneously throughout the entire stand (Janzen 1976), the formation of (limited) seed formation and dispersal can be avoided by harvesting the stand upon the onset of flowering.

Bamboo Yield In Europe

Bamboo growth has been studied with great care in India and the Eastern Asia. El Bassam (1998) mentions bamboo yields between 1.5 t ha^{-1} (for *Thyrostachys siamensis*, grown in Thailand) and 14 t ha^{-1} (for *Phyllostachys bambusoides* grown in Japan). The highest yield has been attained in a field test in India, focusing on *Dendrocalamus strictus*, leading to a production of 27 t ha^{-1} after 18 months at a density of 10000 plants per hectare. This test also demonstrated that bamboo produces most biomass when growing at a high density (albeit with smaller plants), whereas lower densities produced sturdier culms, but lower biomass yields. Lastly, in a study in India, optimal fertilization was determined to be 100 kg N, 50 kg K_2O and 50 kg P_2O_5 per hectare, resulting in a threefold yield (El Bassam 1998).

Little is known about the growth of bamboo in Western Europe. In 1990 the Federal Agricultural Research Center in Braunschweig, Germany, investigated the biomass production of 17 different bamboo genotypes. On the average, these plants produced 7 t dry matter (DM) ha^{-1} y^{-1}, attaining a shoot height of 3 m and around 200 shoots per clump. A plantation established in 1996 in Belgium of *Phyllostachys vivax, Phyllostachys aureosulcata* and *Phyllostachys praecox* was assessed to produce 10-13 DM ha^{-1} y^{-1} for *Phyllostachys vivax* and 4-5.5 ton DM ha^{-1} y^{-1} for the other two species (Temmerman et al. 2005).

While few, these studies indicate that bamboo offers some possibilities in terms of biomass production, even in Europe, a region without any endemic species. This has prompted more recent research into the possibility of growing bamboo in Western Europe. In May 2005, a 0.4 ha bamboo plantation (for research use) was set up in the Irish village of Ballyboughal (Co. Dublin, Ireland) on a field that had been used previously for vegetable growing. Four species were planted: *Phyllostachys humilis, Phyllostachys decora, Phyllostachys bissetii* and *Phyllostachys aurea*. The plants were planted at a density of 2500 plants per hectare. Before planting, the field was sprayed with glyphosate, and plowed both in February and April. No fertilizer was added given the high quality of the loam clay soil. A second herbicide treatment (Simazine) was performed right after planting ; three more treatments were exacted during the year 2006. Irrigation has been performed in the dry summer of 2005, but not in 2006. From 2007 onwards, no further actions were undertaken. As an aside, it should be noted that, although *Phyllostachys* sp. are known for their aggressive rhizome outgrowth, and although no rhizome fencing had been installed at the time of planting, no escaping bamboo plants have been noticed.

A manual harvest of a strip of 5 m wide, performed in April 2008, resulted in the yields given in table I. The plants were tied together before harvesting, cut at 10 cm above the soil and left in a nearby shed to dry for three months. For all species involved, this led to relative water contents between 20% and 27%. Extrapolated yields ranged from 7.7 t DW ha^{-1} (for *P. bissetii*) to 17.65 t DW ha^{-1} (for *P. humilis*).

Table I. Bamboo yield in a pilot plot in Ballyboughal, Co. Dublin, Ireland

	P. humilis	*P. decora*	*P. bissetii*	*P. aurea*
Area (m x m)	5 x 3	5 x 3	5 x 3	5 x 11
No. of plants	9	9	8	32
Fresh weight (kg)	34.56	21.53	9.86	61.1
Dry weight (kg)	26.47	17.22	7.7	44.57
Relative water content	23%	20%	22%	27%
Extrapolated yield (t DW ha^{-1})	17.65	11.48	5.13	8.10

For future economic implementation, bamboo should be harvested between growth seasons (October to March). During these months, other mechanical harvesters (corn harvesters, sugar cane harvesters, …) are usually not used for other crops. This offers the possibility of economizing the use of this expensive equipment – in autumn, corn can be harvested, while bamboo can be harvested during the winter. Moreover, the rhizome system can support the (considerable) loads of these harvesting machines. A tractor for chipping equipped with rubber tires exerts a load of 0.5 kg/cm². On the other hand, when one is reduced to use forestry harvesting machines, weighing up to 14 tonnes and exerting 1 kg/cm², this may lead to serious compaction and damage to the winter wet soils and the rhizome system, as shown in the EU-FAIR project "Bamboo for Europe" (Gielis 2000).

Bamboo Biomass Represents Energy Potential

The next question in this study focuses on the use of the produced bamboo biomass. It is evident that any new energy crop should guarantee a high level of energy production, whether it is a woody plant to be used for electricity generation, or for the distillation of bioethanol or biodiesel.

The physico-chemical characteristics of bamboo make it a good biomass fuel for classic combustion. It is composed of easily harvested woody tissues, containing cellulose, hemicelluloses and lignin, with an average calorific value of 18.3 MJ/kg, which falls within the range of wood species of 18.2 to 18.7 MJ/kg (Scurlock et al. 2000; El Bassam 1998). Bamboo is therefore a biofuel source similar to other woody fuels, with the exception of the mineral content, which is higher (2.5 % dry basis) for bamboo than for wood (1 % dry basis), although this was not confirmed in the Bamboo for Europe project. Bamboo wood thus is comparable to other woody plant material. On the other hand, Bamboos have a nitrogen and sulphur content that is lower than that of other potential bioenergy, leading to a smaller exhaust of the pollutants nitric oxide and sulphur dioxide (Scurlock et al. 2000).

El Bassam et al. (2002) reports the pyrolysis of bamboo biomass (90% stem and 10% leaves) at 487°C. Approximately 70% of the fed material was converted into pyrolysis oil (bio-oil) which can be used as a fuel. Bamboo is also an interesting material for producing charcoal. The calorific value of bamboo charcoal (31.66 MJ/kg) is equivalent to the calorific value of beech and poplar charcoals. The mass yield is higher (33 % on initial anhydrous mass) than for wood (29 % on initial anhydrous mass) carbonised in the same conditions of temperature, residence time and heating rate. The production of non-condensable gases is also higher (26.5 % vs. 18-20 %), while the tar production is lower (42 % vs. 50 %). Differences in volatile matter yield and composition are also noticed. These differences observed in bamboo carbonization result from the cutinized inner and outer layers of bamboo culms. This particular structure limits the gases outflows from the solid to the surrounding environment. This is favourable for the secondary pyrolysis reactions: cracking of heavy tars, recombination of volatile carbon with the fixed carbon structure.

As a final remark - the annular structure of bamboo culms makes it a very aerated and bulky fuel if used in rings or sticks. This means that bamboo would burn very quickly and would request bigger combustion or gasification chambers to obtain the same heating rate. However, if bamboo culms are chipped, these drawbacks are avoided. Bamboo chips are a suitable fuel for fluidized bed combustors and spreader stoker boilers. Bamboo can be adapted to briquette production and gasification using the same procedures as for as other species such as pine tree or eucalypts.

Economic comparison between willow, poplar, *Miscanthus* and bamboo

Based upon the energy content and the culture method for bamboo described in the previous paragraphs, as well as the culture methods described by El Bassam (1998) for *Miscanthus*, willow and poplar, we can now evaluate the different energy crops in terms of rentability. To this end, we will compare the classic biofuel crops for Western Europe with *Phyllostachys* sp., using the yield data from the preliminary trial in Ballyboughal (Table I), and using a cost structure which would be typical for our own region, Flanders (the northern part of Belgium). Given the fact that Flanders has a climate that is equal to or even milder than the climate in Eastern Ireland, bamboo yields can be expected to be equal as well.

The costs for initiating and maintaining an energy plantation are represented in table II.

Table II: Cost in €/ha of Agricultural activities for set-up and maintenance of bio-energy plantations in Flanders (Belgium).

Activity	cost (€/ha)	Reference
field preparation (plowing-harrowing)	225	[b]
mechanical weed removal	50	[b]
herbicides	50	[a]
fertiliser	50	[a]
planting willow	450	[a]
planting poplar	450	[a]
planting *Miscanthus*	450	[c]
planting bamboo	450	[c]
lease agricultural land	216	[b]
harvesting willow	850	[a]
harvesting poplar	850	[a]
harvesting *Miscanthus*	237	Styles et al. 2007
harvesting bamboo	250	[c]
storage and drying wood chips	110	Styles et al. 2007
removal willows	1850	[a]
removal poplar	1850	[a]
removal *Miscanthus*	207	Styles et al. 2007

Estimates are based upon data from [a] the Research Institute for Nature and Forest (INBO, Flanders, Belgium) (given in Meiresonne 2006), and from [b] the Department Agriculture and Fisheries of the Flemish regional government; through personal communications of [c] Dr Victor Brias of Oprins Plant NV, and the last author.

Willow and poplar cuttings were estimated to €0.08 apiece (Meiresonne, 2006). The cost for *Miscanthus* plants was derived from Styles et al. (2007) and set at €0.13 for a plant. Young bamboo plants (taken as rhizome cuttings) were estimated at €0.5 for a plant. The cost of leasing an area of agricultural land in Flanders was set at €216 (Department Agriculture and Fisheries of the Flemish regional government, 2008). It should be remarked, that this price may be lower if the plantation is set on marginal land. Chipping was estimated to cost €10/tonne DM ; the resulting chips were sold at an average price of €130 per tonne DM. Willow and poplar plantations can be harvested every three years. Miscanthus and bamboo can be harvested yearly. Finally, the Flemish government offers in addition a subsidy of €552 per ha for the production of biomass on agricultural soil (Department Agriculture and Fisheries of the Flemish regional government, 2008).

Estimates for the yield of a plantation were 6 t ha^{-1} y^{-1} for willow (averaged from Scholz and Ellerbrock 2002), 6.5 t ha^{-1} y^{-1} for poplar (averaged from Laureysens et al. 2004), 10 t ha^{-1} y^{-1} for *Miscanthus* (averaged from El Bassam (1998) and Boehmel et al. (2007), and corrected for the survival rate of less than 50%, as reported by Eppel-Hotz et al. (1998)). The yield of bamboo has been taken from table I (for *Phyllostachys humilis*) and corrected cautiously for what could be produced in one year. Willow and poplar were simulated for resp. 21 and 26 years, *Miscanthus* for 15 years (according to El Bassam 1998). Bamboo is not restricted by this life span, but the analysis was performed for 30 years.

All these data and considerations have lead to a general economic comparison between these different crops, as presented in Table III. Figure 1 gives the course of the net present value over the years. This is the value of the plantation and its products, corrected for the interests to be gained in a high risk investment such as an energy crop plantation. Based upon the fact that a bamboo plantation has the highest return on investment and the highest net present value after 30 years, bamboo can be considered at least equally useful as (and potentially more interesting than) the other three bio-energy species.

Table III. Economic comparison between willow, poplar, Miscanthus and bamboo upon production in Europe

	Willow	*Poplar*	Miscanthus	*Bamboo*
Survival	*97.6%*	*86.3%*	*49.7%*	*90%*
Yield (t ha^{-1} y^{-1})	*6*	*6.5*	*10*	*10*
1 ton pellets : cost (EUR)	*177*	*169*	*200*	*172*
Net present value (EUR)	*4083*	*5318*	*2886*	*7910*
Internal rate of return	*26%*	*30%*	*22%*	*29%*
Payback period (years)	*4.5*	*4.08*	*4.75*	*5.25*
Return on investment	*675%*	*965%*	*408%*	*1574%*

Bamboo Is Able To Decontaminate Polluted Land

A last topic to be discussed in this paper concerns the use of marginal soils for the production of biofuels. There are plenty of contaminated, previously industrial areas in Europe that are unfit for agriculture, because of the high levels of contamination in the soil. In spite of this pollution, however, these areas offer an enormous potential in terms of the growth of biofuels, linked to a simultaneous cleanup of the soil. To decontaminate large areas of land, several methods are available. Most of these methods are fast, but use a high level of technology and are very to extremely expensive. An alternative method, namely phytoremediation, is less expensive, but has as main disadvantage that it takes a long time before all contamination has been cleared. It should be noted, however, that with the correct choice of plants, the terrain could obtain an additional economic value. For example, when one wants to set up a large-scale phytoremediative effort, one could consider crop species as bioaccumulators of heavy metals; in fact, some of them can accumulate heavy metals while producing high biomass in response to established agricultural management (Ebbs and Kochian 1997).

This approach has been followed previously by different research teams. Huang et al. (1997) and Burke et al. (2000) worked on maize; Shahandeh and Hossner (2000) on sunflower, and Linger et al. (2002) on hemp. Other teams focused on fast growing trees such as *Salix* spp. (Punshon and Dickinson 1999; Mottier et al. 2000; Klang-Westin and Perttu 2002, Vandecasteele et al. 2005, Meers et al. 2007) and *Populus* spp. (Shannon et al. 1999, Banuelos et al. 1999, Vose et al. 2000, Laureysens et al. 2005). Marchiol et al. (2004) investigated the use of *Brassica napus* and *Raphanus sativus*. It remains to be seen if such an effort is possible based upon the use of bamboo as well.

To assess this possibility, our group has performed a preliminary test on the capacity of bamboo to retain heavy metals from the soil (data presented in Table IV). Bamboos were cultivated in pots in the local greenhouse and subjected to heavy metal concentrations of 0-8 mg kg^{-1} Cd, 0-1000 mg kg^{-1} Zn and 0-400 mg kg^{-1} Pb. Heavy metal contents were measured by atomic absorption spectroscopy (according to the methods of Blust et al. 1998). Table IV gives the ranges of uptake capacity in different species (*P. humilis, P. atrovaginata, P. bissettii, P. decora and P. aurea*) and after exposure to the abovementioned range of concentrations. Field data for willow and poplar (exposed in the same range, cfr. Vervaeke et al. (2003) and Laureysens et al. (2005)) were used as a comparison.

Table IV – Preliminary comparison of heavy metal uptake by different bio-energy crops

BAMBOO	*leaves*	*culms*	*rhizomes*
Zn (µg/g)	87-450	141-795	72-1900
Cd (µg/g)	8-27	7-27	5-50
Pb (µg/g)	33-60	33-61	32-260
WILLOW	*leaves*	*stem*	*roots*
Zn (µg/g)	411-695	24-40	ND
Cd (µg/g)	3.07-8.26	0.80-3.29	ND
POPLAR	*leaves*	*stem*	*roots*
Zn (µg/g)	362.5	146.1	243
Cd (µg/g)	4.3	3.6	3.2
Pb (µg/g)	2.9	12.7	17.7

The given range of values for bamboo was obtained in a pot/greenhouse experiment where 5 different *Phyllostachys* species were exposed to different concentrations of Pb, Cd and Zn, comparable to the concentrations of the field experiments with willow (Vervaeke et al. 2003) and poplar (Laureysens et al. 2005). ND : not determined

These data indicate that bamboo has an at least equal ability to take up heavy metals from contaminated soil. Moreover, given the fact that upon harvesting and drying, more than 90% of the leaf biomass stays attached to the culms, whereas the leaves of poplar and willow will generally fall off before the harvest starts, thereby either releasing the metal content of the leaves back into the soil, or requiring an extra effort to collect the fallen leaves. Bamboo will therefore be able to clean up a given soil faster than the other crops. On the other hand, an

advantage of poplar and willow is, that the plants are able to take up metals from much deeper in the soil, whereas the bamboo roots and rhizomes are confined to the upper 50-70 cm.

As an aside – the major technological problem in a system that combines biomass production and heavy metal cleanup is that any metal exhaust should be avoided during combustion. Also, in general, electricity producers are not quite keen on having to invest too much in modifications of their installation. It is therefore clear that this problem needs a proper sustainable solution, before this strategy can be put into practice.

Conclusion

The data presented here, preliminary as they sometimes are, indicate that bamboo is a useful species for eco-engineering applications in Western Europe that combine bio-energy production and heavy metal phytoremediation, equally valid to plant species that have been studied already in more detail. Moreover, knowledge about the behavior of bamboo (albeit under European climate conditions) offers possibilities about the application of bamboo in its native regions. What is needed, in order to make these eco-engineering methods more efficient, is a better knowledge of bamboo ecophysiology on marginal lands in order to be able to predict future yields and, evidently, future income. Also, there is a clear need for further technological advancement and management of the waste material after combustion. Given the fulfillment of these conditions, however, bamboos are sure to be of great service in energy production and pollution management, both in Europe, and in the rest of the world.

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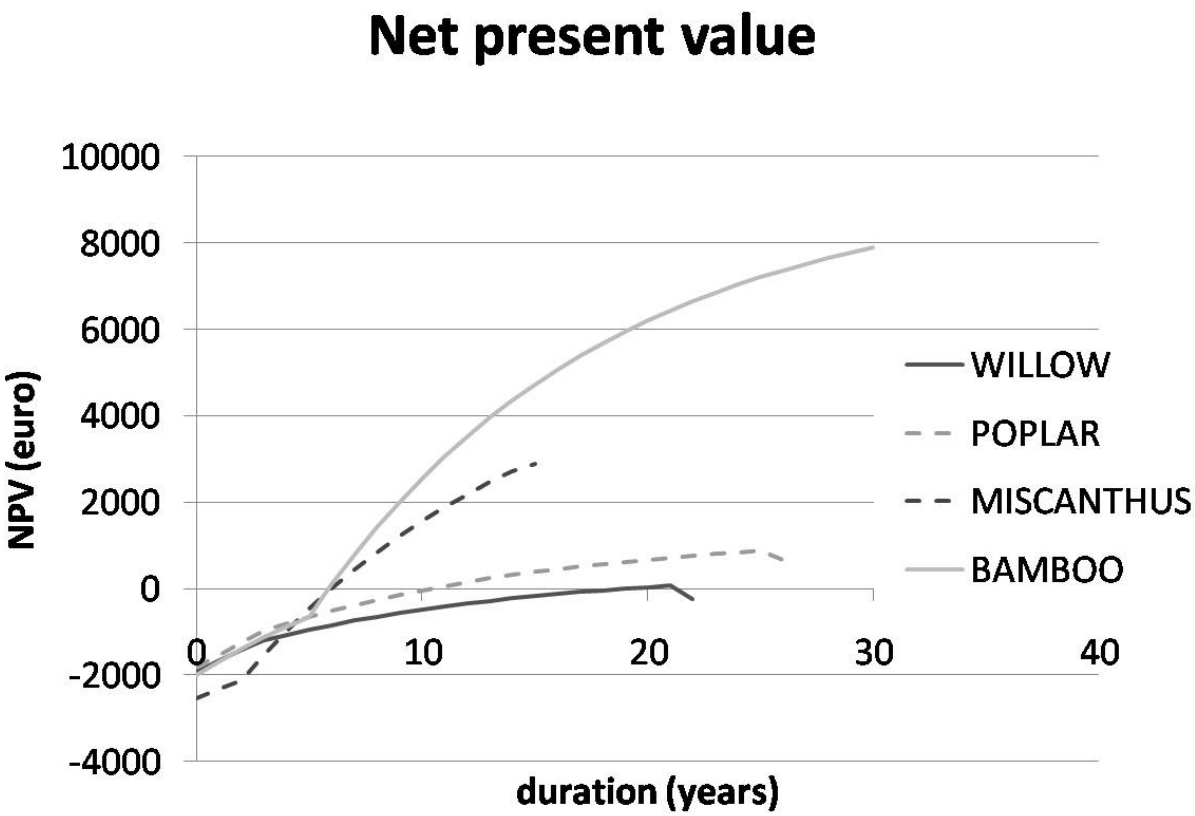

Figure 1. Net present value, calculated at an inflation level of 8% (to allow for comparison with a typical high risk investment) over the years for plantations of the different energy crop species.

Role of Bamboo in Conservation of Biodiversity and Promoting Ecotourism in Tripura, India

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Abstract

Almost 33% of the total geographical area and about 55% of the total forest area in Tripura is covered with 19 different species of bamboo. This proverbial 'poor man's timber' is used extensively by almost cent percent people in the state for various purposes. Presence of 19 different tribal communities mandates use of bamboo practically for everything they do in their day to day life. Moreover, practice of shifting cultivation (jhooming) by these tribal communities across the State has led to more and more use of bamboo rich areas for ease in working and yielding more output per unit as compared to output from jhooming over dense forest areas. Of late, industrial and commercial values of this grass species has been appreciated as a substitute to the wood based products leading to enhanced use of bamboo at all fronts. Tripura is an integral part of one of the two hot spots in the country. The state located at 9B NE Hills Oriental Zoogeographical region is very rich in her floral and faunal diversity and exhibits close affinity with flora & fauna of Indo-Malayan and Indo-Chinese sub-regions. The linkage between bamboo and biodiversity both of which are in abundance and complements and supplements each other is yet to be objectively appreciated. An attempt has been made through this paper to study this relationship and explore ways and means to make it an integral part of existing policies and schemes on biodiversity conservation, with special reference to the participatory approach. The paper also highlights at the possible conflicts in interests while putting to use this unassuming grass species for socio-economic development of the people (yielding tangible, commercial and industrial benefits) vis-à-vis its use for biodiversity conservation (yielding intangible and ecosystem benefits).

Introduction

The bamboo is a large woody grass belonging to the sub-family Bambusoideae and its ca 1250 species from 75 genera are distributed mostly in tropics besides occurring naturally in subtropical and temperate zones of all continents except Europe. Bamboo is an important resource in the Indian socio-economic-cultural-ecological-climatic-functional context with about 1500 recorded uses. India having ca 9 million hectare area under bamboo growth supporting ca 130 million tons of resources with annual harvest of 12.5 MT places, is second only to

China in bamboo resources. Bangladesh, Indonesia and Thailand are other nations with substantially high bamboo resources. However, this grass species has yet to come out of its current status as 'poor man's timber', by which it is known for many centuries in the past.

In India, a total of 140 wild and cultivated species of bamboo from 19 genera are spread over about 96,000 sq km of the total geographical area except in Kashmir valley. Compared to China with only about 3% of the total forest area under bamboo growth, India has ca 13% of the total forest area covered with bamboo. All the seven northeastern states together contributing ca 66% bamboo resource in quantity and 28% in terms of area coverage under bamboo growth make up for largest bamboo resources in India. Region wise distribution of bamboo resources in India suggests maximum number of species/genera is recorded in Eastern India (63/16), followed by Peninsular India (24/8), Western Himalayas (14/5), Indo-Gangetic Plains (8/4) and Andaman & Nicobar Islands (7/6).

Although, there are multifarious commercial and domestic uses of bamboo varying from its use as constructional material, handicrafts, agriculture, paper and pulp, textiles, wood substitute and meeting subsistence economy of poor people, yet, its importance and role for conservation of biodiversity, howsoever inconspicuous it may appear in comparison to the tangible commercial uses, are too vital to be ignored. The intangible benefits contribute directly to the survival of the human kind through biodiversity conservation and thus raise the status of bamboo as a very important commodity in this field. Unfortunately, in spite of this direct relationship between bamboo and human survival through multifarious uses from 'cradle to coffin', its status has not gone up from what it is known for ages as a 'poor man's timber'. The tangible uses of bamboo, though, have attracted attention of commercial entrepreneurs, yet, the role of bamboo in meeting objectives of biodiversity conservation through its ecological-economical-social-cultural mix is yet to be properly discerned and understood. This paper addresses the importance of bamboo for conservation of biodiversity and ecotourism in Tripura and attempts at setting up linkages between these two concepts.

Bamboo and Biodiversity Conservation

Conservation refers mainly to the protection of natural resources and their sustainable use for the benefit of dependent (directly and/or indirectly) stakeholders. Protection (of wildlife species and other resources on which those species depend) and participation (of local human communities in conservation processes in lieu of usufruct sharing for their socio-economic-cultural well being) have been identified as two main approaches towards biodiversity conservation. Protection leads to viable population growth and survival of all wild flora and fauna, while participation allows survival of dependent human populations through sustainable utilization of natural resources (resulting from protection approach). In Tripura, bamboo plays a very crucial role in implementation of both above approaches.

Protection approach

In the past extraction of natural resources was within the sustainable limits (within the carrying capacity of the given resource base) as there were fewer dependent people compared with the available natural resource, and hard-core protection to the habitat and all its varied elements worked as the only means of conservation strategy

of the forest department. This protection measure was also in total agreement with the biological and ecological needs of different dependent wildlife species. A *habitat* is a place where given species gets required mix of food, cover, water and other resources to fulfill its biological needs. The stability, increase or decline of wildlife species and their populations depend directly on the extent of available habitat. Such habitats also play a vital role in meeting the subsistence needs of dependent human populations inhabiting biodiversity-rich areas.

Bamboo, covering almost 13% of the total forest area of the country, as a rich habitat provides a direct link with biodiversity conservation. In more than 88% of the total protected areas in the country different bamboo species act as rich habitats for innumerable number of wildlife species from avifauna to large mammalian species. Due to high adaptability, versatility and ability to improve soil conditions facilitating fast and diverse growth of bamboo even on degraded areas, make it a preferred species for restoration of degraded wildlife habitats across the length and breadth of the country. This characteristic of bamboo is of utmost importance in the north-eastern state, including Tripura, where wildlife habitats are degraded following *jhooming.* On an average Ca 50000 to 60000 hectare of rich forested area gets affected due to *jhooming* every year resulting into large-scale soil-erosion and landslides. Besides, repeated *jhooming* over a given piece of land for consecutive 2-3 years renders the soil impoverished in its nutrient contents unable to support the luxuriant growth of high forest species. Under such conditions, the fast-growing bamboo species provides much needed green cover to the naked soil within shortest possible time period thus protecting it from the vagaries of intensive rainfall in the entire region. The treatment of fallow land (deserted jhoom plots) is very crucial from biodiversity conservation view point and here too fast and luxuriant growth of bamboo facilitates faster uptake and storage of essential nutrients and quicker turnover to supplement soil flux and provides stability to the fallow land. The fast growth of bamboo groves across every possible soil-types (organically poor to mineral rich soil) and moisture regimes (rich leaf-litter of bamboo increases soil porosity thus raising the soil moisture retention capacity) act as one of the most important habitat components providing refuge to varied faunal and floral species. Extensive root system and vast underground rhizome network almost covering ca 100 m^2 area around bamboo clumps strongly hold and bind the soil and make the bamboo growth capable of tolerating the onslaughts of landslides, floods, hurricanes and quacks (Varshney, 2004).

In both the biodiversity hot-spots in India, namely, the Western Ghats and Eastern Himalayas (including all the seven northeastern states) the bamboo is present in its densest and most diverse forms and support some of the highly endangered and endemic faunal species. The bamboo shoots and other parts of culms provide a rich, nutritious and unlimited source of food to many animal species. Similarly, dense growth of bamboo culms and their canopy contiguity in association with high forests impart protection, breeding cover and connectivity for uninterrupted ranging to the animals. Bamboo growth on degraded lands provides a very crucial habitat element to wildlife who is able to tolerate some degree of habitat disturbances. This is more evident in jhoom fallows where bamboo covers as early and the only secondary growth act as a life-supporting micro-habitat for the conservation of many species ranging from insects to even some of the largest mammalian species (elephant, primates, gaur, etc.). Therefore, management of bamboo growth may also be equated by and large with the management of biodiversity rich areas in India leading to biodiversity conservation, which in final analysis leads to poverty alleviation, especially of those living below poverty line (BPL). The above account substantiates existence of an intimate and very important direct link between bamboo management and biodiversity conservation through protection measures.

Participatory approach

Over the last few decades, unsustainable utilization of natural resources by ever increasing population of stakeholders has led to the decimation of the habitat at a much faster rate than expected and within the limits of restoration. The 'Protection' strategy, in absence of sufficient man-power to impart protection to each and every important habitat and species, also fell far short in curbing this onslaught. This scenario forced policy makers to introduce new policy initiatives at the National level for management of forests and wildlife (Anonymous, 1998) and thin turn underlined a necessity for a 'participatory' approach for management of natural resources. In 1991, the Ministry of Environment & Forests brought about a Resolution on Joint Forest Management (JFM) in the territorial forest areas and within a span of 2 to 3 years practically all the states adopted this approach. In protected areas, this participatory approach was known as Eco-development. This approach entails people's involvement in the decision-making and execution of various conservation related measures and in lieu of participation the local communities get the usufruct benefits from the harvested natural forestry resources and/or alternative means of earning their livelihood mostly based on non-forestry resources with the sole aim of reducing the dependency of local people over natural resources. This ultimately aims at restoring and maintaining the balance between the availability, extraction, and exploitation of the natural resources within the sustainable limits.

The role of bamboo and its products is again very important and crucial in meeting the subsistence needs of most of the dependent local human populations. This intimate relationship is much more evident in northeastern states having ca 66% and 28% of the total bamboo resources in India in terms of production and cover and finds its utility in socio-economic-cultural domain of various communities practically for all their needs. The bamboo and its products are very intimately linked with successful implementation of the participatory approach for biodiversity conservation.

Development of Bamboo Resources and Wildlife Conservation Strategies in Tripura

Tripura is a small, land–locked hilly state situated in the north–eastern part of India. The state has a total geographical area of 10,492 sq. km. accounting for barely 0.342 per cent of the total area of the country. In terms of area, it is the third smallest state in the country, after Goa and Sikkim. The state lies between latitudes $22^0$56' N and $24^0$32' N are longitudes $91^0$09' E and $92^0$20' E. The total length of its international borders is 1018 km but it is bound by Bangladesh on three sides covering 856 km. of its total border. It is connected with the remaining part of India through Assam, via a small strip of border of 53 km – the Siliguri neck. The state is predominantly hilly and is dissected by six low ranges of hills running north–west to south–east. The state is located in bio-geographic zone of 9B- North-East hills with a rich diversity of resources. There are six important rivers but none is perennial. According to provisional estimates of 2001 census, the state's population stood at 31.91 lakh, with a population density of 304 persons per sq. km. The birth rate in the state is 16.5 per thousand which is lowest in north–east region much lower than the national average of 25.8. Again its death rate is 5.4 per thousand which is much below than the all India level of 8.5. Of the states in the North East, Tripura is the second most populated state after Assam, though in terms of area it is also the second smallest state. There are 19 sub–tribes among the scheduled tribes in the state with their own cultural diversity. Magority of the

population depend on agriculture and allied activities. The productivity of main agricultural crops and plantation crops like rubber has been found higher than the national average. The state is predominantly rural, accounting for 82.91 per cent of population in rural areas. About 58 per cent of the area of the state is under different categories of forests, and land suitable to normal agricultural operation is relatively scarce. In fact, the net sown area is only 26.5 per cent of Tripura's land mass and average size of operational holdings is 0.97 hectare, which is below the national average. Only about 20 per cent of gross cropped area is irrigated and agriculture is mainly rain–fed. The crop intensity is 176 per cent, which is higher in the land situated in the valley. The major part of the land of the state is dry, consisting of laterite soils suitable for some selected crops only. Important crops in the state are rice, wheat, potato, pulses and vegetables. Cash crops like jute, mista, cotton, tea, rubber and plantation crops are also produced in the state. Tripura, with about 6500 hectares of tea plantation, 28000 hectares of rubber plantation (assessed potential for rubber plantation of 1,00,000 hectares), is rich in plantation crops like rubber, tea, pineapple, orange, litchi, banana and lemon. Nearly 67 percent populations are below the poverty level.

Tripura is called the 'home' of bamboo. The wonder plant is intimately interwoven in the socio-cultural fabric of the State. Bamboo based economic activities are an intrinsic part of life; the importance of the resource in the State's predominantly agrarian economy is well recognised. Bamboo finds many uses, and is a major source of income and employment as well. It is estimated that 2.46 lakh families in the State are engaged in bamboo related vocations. The average productivity of the resource for forests and farm areas is estimated to be 0.73 MT/ha/annum, which is higher than all India average of 0.51 MT/ha/annum but compares very poorly with productivity level of 3.79 MT/ha/annum in China. There are 19 species of bamboo found in Tripura. Out of the 19 species of bamboo muli bamboo is found extensively all over the State and is the most important species from ecological and economical view point.

Protection Strategy : Current status of bamboo as Habitat

In Tripura, the area under bamboo cover in the protected areas is generally managed as a routine alongside other habitats, of which, bamboo habitat may form just a small part. In none of the four protected areas in the state, the areas under bamboo are treated as specific wildlife habitat. Very rarely, do we come across any case related to a protected area where the bamboo as a habitat has been given a very specific and special attention. The only few instances are probably found in those protected areas where the gregarious flowering of bamboo has either taken place or is in the offing in the near future. In fact, in most cases the wildlife management strategies that are adopted and practiced are solely dependent more on the kind of major/important/flagship wildlife species inhabiting a given protected area. and, any kind of apparent management of bamboo areas found in and around any given protected area happens to be just incidental. In no way the management of bamboo habitats in the protected areas wherever found is in commensurate with the vast potential that the bamboo as a habitat possess and that can be harnessed for the protection and conservation of many a key endangered and endemic species of flora and fauna.

Protection of Bamboo as Habitat: Future suggestive measures

Considering the importance of bamboo as a habitat for many wildlife species, more proactive measures are needed to make bamboo habitat contributing much more effectively in addressing the direct protection approach towards wildlife conservation. Some of the suggestive measures that can be adopted in this regard could be the following:

1. The wildlife habitat can be enriched both in quality and quantity by proper selection and scientific propagation and establishment of suitable bamboo species. The suitability of a given groups of bamboo species can be determined based on the ecological and biological needs of key and flagship wildlife species. This tool can also be very effectively used to address man-animal conflict problems in many a cases depending upon the need of the wildlife species by making food and cover available to the animal species in conflict with humans in required quantities and quality (e.g., suitable bamboo species could be very important in competing with the more palatable and nutritious domestic grass species (maize etc.) that are more preferred by elephants leading to man-wildlife conflict situation).
2. It may be difficult to increase the net area under bamboo cultivation in a given protected area due to other priorities and needs of different user groups. But, the productivity and value of the existing growing stock of bamboo within the given area can be enhanced in much higher proportions by using genetically improved planting stocks. New technologies using tissue culture are now available to improve the genetic viability of the bamboo stock this adding to its existing productivity and value in a given unit area of consideration.
3. Making use of the property of most of the bamboo species to very quickly allow soil-binding facilitating soil conservation process, the degraded and soil erosion prone areas can be immediately planted with bamboo, even though it could be a stop-gap arrangement before the same degraded land is reclaimed raising other plant species.
4. As mentioned earlier, the northeastern states are facing one major habitat destruction problem through the practice of non-traditional shifting cultivation. Thousands of hectares of areas in all the seven northeastern states are laying fallow and unproductive following *jhooming*. In such cases too, the raising of bamboo plantations using commercially important species could lead to meeting two fold benefits: one, restoring and reclaiming the degraded fallow land, and two, increasing the economy of the local people by planting commercially important bamboo species in some cases and also by raising cash crop plantations of rubber, tea, orange, etc. on the restored and reclaimed jhum fallow areas of the yesteryears.
5. Most of the bamboo species can come up in combination with many other tree species of definite importance to many wildlife species. This unique property of bamboo species may further allow the managers to grow bamboo groves with suitable tree species mixtures. This will support more diversity of wildlife species and may also add to the ecotourism as well.
6. Few bamboo species act as a major source of food and cover for some of the highly endangered and endemic primate species (Hoolock gibbon, slender and slow loris, lion-tailed macaque, Nilgiri langur, Golden langur, Phayre's langur, and capped langur) in the northeastern states and the Western Ghats, especially during the pinch period when the food productivity of other plant species

is either very low or altogether nil. In all such areas, special emphasis on the species-specific plantations and management of bamboo growths will help in the long term protection and conservation of all those primate species.

Participatory Strategy : Current status of use of Bamboo in Participatory strategy

The participatory approach to forestry and wildlife conservation is mainly addressed through three distinct processes, namely, the Joint Forestry Management (JFM), the Eco-development (ED) and the Joint Protected Area Management (JPAM). The JFM was started in the country following the new National Forest Policy of 1988, which recognized the symbiotic relationship between the (tribal) people and forests and stated that a primary task of all agencies responsible for forest management including the forest development corporations should be to associate the (tribal) people closely in the protection, regeneration and development of forests as well as to provide gainful employment to people living in and around the forests. The policy further observes that the "Forests should not be looked upon as a source of revenue, but as a National asset to be protected and enhanced for the well being of the people and the nation" and the current approach of 'Protect from the people' should be changed to 'Protect through the people'. This policy decision led to the issuance of Joint Forest Management Guidelines by the Ministry of Environment and Forests in the year 1991 to all the State Forest Departments. Over the years, these guidelines have been modified to accommodate the changes in the external environment, the latest being the Guidelines of 2000 and the latest decision to constitute Forest Development Agencies where all the forestry related works have to have the participatory component as a must. Similarly, in the field of wildlife management too, the Ministry of Environment & Forests had come up with a special Central Sponsored Scheme (Eco-development around National Parks and Wildlife Sanctuaries) in 1991 in which the funds were placed with the States/UTs for undertaking participatory approach towards wildlife management for the following main activities:

- Biomass regeneration
- Soil and Water Conservation
- Use of alternative sources of energy to replace non-renewable natural forestry and wildlife resources
- To undertake necessary health measures both for Humans and their livestock
- To initiate and establish welfare measures for the people at the cottage (small) industry level.
- Research and monitoring to gauge the progress of this process to fine tune it according to the site and issue specificity.

Over the years, the eco-development has been made a mandatory instrument of wildlife management, it is the Wildlife Conservation Strategy of GOI, National Wildlife Action Plan (2002-15), or the schemes under the auspices of Directorate of Project Tiger, Directorate of Project Elephant, other Centrally Sponsored Schemes, and Schemes of States/Us forest department.

The eco-development aims to conserve biodiversity by addressing both the impact of local people on the protected areas and the impact of the protected areas on local people. The eco-development is defined as a site specific package of measures, developed through people's participation, with the objective of promoting sustainable use of land and other resources, as well as on-farm and off-farm income-generating activities which are not deleterious to PA values. The eco-development is also referred to as a limited rural development designed with the participation of local people, for the purpose of reconciling genuine human needs with specific aims of Protected Area management.

The two main elements of eco-development approach are (1) Habitat Improvement and Management addressing directly at the level of the Biodiversity Conservation, and (2) the Village eco-development looking at the Resource Sustainability aspect to ensure that equitable resource allocation is done for viable survival and growth of each of the stakeholders of biodiversity conservation. Based on these two basic premises, the major specific activities being undertaken for eco-development could be as follows (this list is not exhaustive as at many places new innovations are made in the process and techniques to best suite the given site):

1. Improved collection and use of non-wood products.
2. Improved dry farming techniques
3. Efficacious water harvesting
4. Soil conservation measures
5. Preferences to cash crops (pulses, oil seeds, spices, cotton, medicinal plants, commercial bamboo plantations)
6. Agro-forestry
7. Sericulture, horticulture and Apiculture.
8. Development of Minor Irrigation measures
9. Animal husbandry, dairying and wool crafts
10. Fisheries
11. Ecotourism
12. Development of Infrastructure
13. Cottage industry and Handicrafts

Among the various potential activities listed as above for undertaking participatory eco-development approach, the use of bamboo can be very conveniently and justifiably defined in most of these listed activities. The bamboo and its products, both in its raw and in value added form, can contribute substantially in meeting the targets of various participatory activities for providing alternate use of livelihood options as listed above at the serial numbers 1, 2, 3, 4, 5, 6, 7, 11, 12 and 13.

Both eco-development and the Joint Forest Management for biodiversity conservation are performed through the specifically constituted Committees for this purpose, called eco-development Committees (EDCs) and Village Forest Committees or JFM Committees (JFMCs)

Therefore, as described in the preceding paragraphs, the bamboo along with its varied and diverse products has strong (direct and indirect) linkages with the conservation of biodiversity in general and wildlife in particular.

Use of Bamboo in Participatory Approach: Future Suggestive Measures

However, in spite of the fact that the bamboo and its products can contribute substantially in achieving the targets of participatory wildlife conservation, not much systematic attempts have been taken to make use of highly valuable properties of bamboo and its products at the advanced technical and scientific levels. The main reason for this neglect has been more due to ignorance about the multitude properties of bamboo and its products and their importance for multi-facet integrated development through its use as:

- As a bio-energy crop
- As food crop
- For environmental amelioration
- As a substitute of wood
- As a material for infrastructural development
- As environment friendly housing and building material
- As a renewable energy and fuel source
- As herbal medicinal plant
- As a controller of ecosystem damages and
- For overall integrated development (Rao *et. al*. 2004 and Varshney 2004)

Therefore, ample scope still exists to fully exploit the untapped potential of the vast bamboo resources across its range in the country (with bamboo plantations over about 8.96 mha roughly equivalent to 130MT in quantity yielding an annual harvest of roughly 14.5MT).

Bamboo as an Alternative Resource for the Participatory Approach to Biodiversity Conservation: A Suggestive Model

In order to fully utilize the strong direct and indirect linkages of bamboo as a habitat and its importance as a potential resource for undertaking measures for providing alternate means of livelihood options within the ambit of eco-development planning, I propose a Model. This Model looks at the utility of bamboo and its products at two very distinct levels:

(1) at the level of domestic usages, and

(2) at the level of commercial and industrial usages.

At the level of domestic usage

Given the distribution range of bamboo coinciding mainly with areas of high population density of tribal and aboriginal communities mostly in and around the protected areas, the bamboo is used by those communities in practically every activity performed as daily chores. The domestic uses of bamboo and its products relate mostly to as construction material, as utensils, as decorative items, as food (shoots), as raw material for various cottage and handicraft items, as an important species in various social-religious functions, etc. The nick name of bamboo as a 'poor man's timber' denotes its utility for those communities from 'cradle to coffin'. But, unfortunately, the traditional methods of propagation, exploitation and usage of bamboo as adopted by these communities over the past many years are still in use. Those traditional methods might have been in conformity at the level of sustainable management of bamboo resources at that time, but due to drastic changes in the demographic patterns and other external environment as a result of changes in the development paradigm, those methods now do not yield desired benefits anymore. Moreover, it is now understood that most of the traditional methods do not help in upgrading the bamboo to its fullest potential to what it is worth of, thus leading to much more per capita consumption for the similar amount of benefits/yields that can be achieved from much less per capita consumption using advanced scientific and technical know how. Therefore, it is very important to reassess the feasibility and applicability of many traditional methods and to upgrade those, if need be, by integrating those methods with the advanced technical and scientific methods. Presently, in absence of any improvements in the shelf life and strength of bamboo, its per capita consumption as food and for other purposes is very high. With the use of advanced scientific methods, the shelf life and strength of bamboo and its products can be increased to reduce the quantity required for per capita consumption. This savings in the bamboo resources without compromising in its usage patterns shall add to its conservation value for wildlife and this saved bamboo resource can also be made available for its increased alternative usages.

The EDCs and JFMCs have to come up with definite plans to ensure that in all those areas where the bamboo and its products contribute substantially in meeting the sustenance needs of the local communities, the traditional methods are integrated with advanced methods so that per capita income from bamboo and its products could be increased in leaps and bounds, as ample scope do exist for this change over. If this approach is institutionalized and practiced as an accepted norms and policy, has the potential of fulfilling the objectives of participatory approach without much bothering for bringing in the alien methods and resources as substitutes to the other forestry and wildlife resources being used currently. One biggest advantage of bamboo-based eco-development measures would be the recognition of bamboo and its products by the targeted communities and their preliminary knowledge on the cultivation, exploitation and utilization of bamboo and its products.

The EDCs and JFMCs can also take up the programmes for imparting proper training to the users both at the individual and group levels to build up on their existing capacity enabling them to use bamboo and its products in much more scientifically and technically advanced form. The National Mission on Bamboo Application and

many other similar institutions can be roped in for this purpose of integrating the local traditional knowledge of user groups with the advanced scientific and technical aspects of this species.

At the level of Commercial/Industrial usages

The use of bamboo at the commercial and industrial level is practically limited right now only to the extent that local people harvest bamboos and sell it in raw or semi-processed form in the local markets or to some select co-operatives. The income from this transaction is just not sufficient to meet their subsistence economy. Moreover, the major benefit of their labour and time spent in these activities goes to the middle men, who by taking advantage of poor transportation, processing and marketing facilities at the disposal of the local people, exploit this situation at the detriment of the local beneficiaries.

However, vast potential does exist in this field for local people to raise their economy by utilizing the bamboo and its products for many different types of commercial and industrial activities. In this aspect too, the role of EDCs and JFMCs is very important and crucial in that these bodies can associate themselves with different industries and institutions involved in the technically and scientifically advanced commercial and industrial usage of bamboo and its products.

The Model that I propose is based on the cottage industry concept of the past where the individual families are provided scope to set up their kind of small scale industry for bringing out marketable products both in raw and value added processed form for domestic and commercial/industrial uses. The end products of such cottage industry will constitute the raw material for larger commercial and industrial units located elsewhere. The transportation and marketing of raw material to the big and commercial industrial units will form an integral part of this Model. The following steps may be taken to make this Model run successfully:

1. Bamboo based small scale cottage industries can be set up at individual beneficiary and/or at the level of entire Eco-development and Joint Forest Management Committees.
2. These cottage industries should act as feeder channel for providing the raw and semi-processed and value added raw material for bigger bamboo based industries for various products (paper and pulp; construction materials; food processing; handicrafts; bamboo furniture; bamboo plywood; bamboo flooring; bamboo grids; bamboo as wood substitutes; and for variety of miscellaneous industries for agarbatti sticks, ice-cream sticks, fire cracker, lathis, ladders, etc.). This direct linkage between the beneficiary-run cottage industry and large scale commercial industries shall ensure that the total sale of processed raw material fetches the appropriate market price without the involvement of middle men who do not allow the real benefit flow to the actual beneficiaries. This institutionalized arrangement shall help raise the economy of the local people based on the same resources that they are familiar with and recognise it in their day to day activities. This linkage between the cottage industry (bamboo based) and the bigger industries shall also help sustain the concerned EDCs and JFMCs financially in the long run. Currently, most of the Committees survive only till the external funding is able to support their existence. The much desired transport and marketing facilities for the individual local level beneficiaries will also be developed through this means, which would also help in the marketing of other non-bamboo based products of those Committees to further boost the economy of the Committee members.

3. The required value addition to bamboo and its products at both the domestic and commercial scale can be done through capacity building of local artisans and local people; with the use of advanced scientific technologies and as highlighted time and again in the preceding paragraphs, the integration of advanced technical and scientific know-how with the traditional knowledge of different user groups.
4. This bamboo-based Model is best suited to achieve the desired objectives of biodiversity conservation through participatory approach under the auspices of EDCs and JFMCs because of the following properties of bamboo:
    a. Its immediate acceptability among the beneficiaries both economically and culturally.
    b. As stated earlier, the cultures and traditions of many communities inhabiting areas of bamboo abundance are closely interwoven and integrated with bamboo and its varied usages for meeting many a daily needs. Therefore, alternative programmes based on bamboo shall be immediately acceptable to them (in fact in many cases various alternatives suggested for economic upliftment of local communities have failed as those alternatives were not in consonance with the local traditions and culture and the communities found it difficult to identify themselves with those alternative measures).
    c. Another positive aspect associated with the use of bamboo is its bio-degradable nature. Although, the bamboo and its products find their use in many activities that the people perform during the day, yet, there is no danger of ecological hazard, which is associated with the use of plastics. This eco-friendly nature of bamboo makes it one of the most favorite as an alternative for other natural resources.
    d. The bamboo and its products can be used for various commercial and industrial products that would prove ideal for raising the economy of the local people without making any compromise to their other social-cultural-traditional needs and aspiration. Some of the important industrial usage of bamboo could be the following:
        i. Industry: Wood substitute (laminates, flooring, panels, particle boards, roofing, false ceiling, insulation material, chipboard, wafer board, bamboo ply, veneer); Building, Construction and Structural Application Industrial Products (shelter, community building, earthquake resistant construction, scaffolding and ladders, road enforcement grids, embankment and slope protection, check dams and bridges, truck bodies, activated carbon); Specialized Bamboo Processing Machinery and Process Technology (dyes and modules, development of special purpose resin, etc.).
        ii. Food and Agro-Processing: Bamboo shoots, props for horticulture crops, sericulture, drip irrigation, cultivation and propagation.
        iii. Product Application – small scale Enterprise: Bamboo furniture, kiosks, woven bamboo application, stick making, pencil, safety matches and other consumer applications.
    e. Increased use of bamboo and its products for meeting various needs will also help in protection of the habitat from wanton destruction through felling of hardwood trees. Protection of habitat will directly contribute to the conservation of biodiversity.

Bamboo and Ecotourism: The Link

Ecotourism is an amalgamation of three basic ethos, namely, the conservation ethos ensuring conservation of resources on which the ecotourism is based; meaningful community participation ethos ensuring that the benefits of ecotourism does flow to the local communities residing in and around the areas of ecotourism sites; and economic consideration ethos ensuring that the ecotourism venture is profitable and self-sustaining. The ecotourism is considered another form of participatory approach towards biodiversity conservation as a strategy linking conservation with development in ecologically rich areas. In this terminology, the word 'eco' means ecological benefits to the ecosystems and economic benefits to the local communities. The National Policy on Ecotourism (Anonymous, 1998) mandates that the ecotourism should be made a grassroots, community based movement through awareness, education and training of local communities as guides and interpreters. It further calls for involvement of local communities for overall economic development of the area and further stipulates that the ecotourism development type and scale should be compatible with the environment and socio-cultural characteristics of the local communities. The Wildlife Conservation Strategy, 2002 prescribes that the revenue earned from increased tourism should be used entirely to augment available resources for conservation. World over, the ecotourism has also been defined as an environmentally friendly travel to relatively undisturbed natural areas in order to appreciate nature that promote conservation and provides for beneficially active socio-economic involvement of local human populations.

Bamboo and its products with eco-friendly nature and vast potential to increase community based income generation programmes, can also contribute substantially in undertaking and promoting ecotourism in areas clothed with bamboo growth. The following features of bamboo may help develop a link between bamboo and ecotourism:

1. The ecotourism based on visits to natural wilderness areas can be promoted in areas with dense bamboo covers, which, as one key habitat element, support diverse flora and fauna.
2. The facilities for tourists inside the tourism zones can be made eco-friendly with the use of bamboo and its products. The current concrete structures as tourist lodges, visitation centers, cafeterias, hotels/motels, interpretation centers, etc. can be very conveniently replaced with bamboo based structures using value added features of bamboo and its products. Use of bamboo in these cases will protect the nature and add to the natural beauty of the given areas.
3. The above mentioned tourist facilities can be created through the EDCs to provide the alternative means of livelihood to the local people that too based on resources that can be handled by them more conveniently and dexterously.
4. Bamboo made souvenir and handicraft items through the involvement of local people from different JFMCs and EDCs will also help them earn their sustenance livelihood. The concerned Committee officials have to facilitate the transportation and marketing of those products so that appropriate pricing is received by the people through the sale of such items.
5. At many nature based tourist sites, the water rafting and house-boats constitute an integral part of tourist facilities. Here too, use of bamboo and its products can be ensured through the Committees, which will earn the local people their livelihood.

6. The ecotourism, as one of the participatory approach towards biodiversity conservation, is very closely linked with eco-development and joint forest management. Therefore, usefulness of bamboo and its products towards eco-development and joint forest management also contribute in the field of ecotourism.

Implementation of the Model

As described in few preceding paragraphs, various Policies and Schemes of Government of India and States/UTs make it mandatory to have participatory approach towards biodiversity conservation. To enable it to happen, necessary changes in the National Forest Policy and National Wildlife Action Plan have already been incorporated. Recent amendments (in the year 2002 and 2003) in the Wildlife (Protection) Act, 1972 mandates to have two more categories of protected areas, namely the Conservation Reserves and Community Reserves. In both these categories strong emphasis will be to accommodate the sustenance needs of the local communities based on traditional resource through value addition and their capacity building of the local people alongside the conservation of wildlife and their habitat. All these changes in the policy and the legislation fit well in the scheme of Model proposed above.

However, at the implementation level, there are many steps that are yet to be integrated with the current working schemes. Currently, the working of the territorial forests and the protected areas is governed by the Working Plan prepared for each forest division and Management Plan for a given protected areas. Both these documents are revised every ten years to incorporate new changes for better management of forests and wildlife under the changed conditions, if any. With the practice of participatory approach to biodiversity conservation, now the scope exists to prepare Annual Micro-plans for each forest division and given protected area to incorporate all those measures associated with the effective implementation of various programmes and schemes of participatory approach. It would be of utmost importance to bring in enabling changes in the Annual Micro-Plans to include the requirement of the above described Model so that the policies are translated into action in the field to yield desired outputs.

This Model, as proposed above may appear utopian in this era of globalization where more and more emphasis is being paid to boost the economy by opening the seams that have been hitherto binding the trade and commerce within the confines of a country or at the most a region. However, this approach alone could facilitate and ensure integration of commercial interests (based on bamboo) with the sustenance-level-livelihood earning interests of scores of those people for whom an only industrial usage of bamboo and its products may not bring in desired level of economy for them to survive. The technical, industrial and commercial usages of bamboo and its products, will definitely boost the economy in leaps and bounds for various industrial and commercial units based on this species. What, of course, is required to be understood very clearly is that the bamboo as a species is very intimately associated with various ecosystems that help preserve and conserve biodiversity across the globe, and especially in areas which are referred to as ‘hot spots’. The complete and total commercialization and industrialization of this species at the cost of not allowing it to meet the demands for biodiversity conservation through intangible benefits (that can not be weighed in terms of hard cash), would definitely be suicidal. After all, not very long ago, even the high forests were sacrificed (and this trend still continues albeit at a much faster pace) to meet the industrial and commercial needs of only few elite section of the society. And we all are now

paying a very heavy price of this short sightedness, with global warming challenging the very survival of human kind. Therefore, in this perspective, the small cottage-industry-level Model may prove quite appropriate that will not only ensure that the local people who are now partnered for biodiversity conservation continue to draw the benefits at the sustenance level, but also become an active partner in becoming the supplier of raw materials for industrial and commercial units. Once it is ensured, the bamboo and its products will truly justifying their very intimate association with the poverty alleviation in general and the biodiversity conservation in particular.

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Chemistries of Throughfall and Stemflow in Two Bamboo Forests and a Japanese Cedar Forest in Japan

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Abstract

Comparative studies on the chemistries of throughfall and stemflow in three forests were conducted in the southern region of Japan. Precipitation, throughfall, and stemflow were collected from the middle of June 2006 to the end of September 2006 in three adjacent forests: madake bamboo (*Phyllostachys bambusoides Sieb*), moso bamboo (*Phyllostachys pubescens Mazel*), and Japanese cedar (*Cryptomeria japonica*). The volume-weighted mean pH of precipitation was 4.7 with a range of 4.2 to 4.9 and acid rain fell over the forest. Throughfall pH values for madake bamboo, moso bamboo, and Japanese cedar were 5.3, 5.2, and 5.3, respectively. Throughfall pH values for the three forests were higher than precipitation pH. This suggests that pH buffering mechanisms occur in the forest canopy, probably due to neutralization of cations derived from dry basic deposits and basic leachates derived from plant materials. In the bamboo forests, the relative contribution of K^+ cations to the total cations in throughfall was high—29% in madake bamboo and 42% in moso bamboo. Further, these relative contributions showed seasonal trends with a high value during the first half of the observation period, when bamboo undergoes growth and other changes. K^+ is a major contributor to the basicity of throughfall and may be strongly associated with the neutralization of acid rain. Ca^{2+}derived from leaves and NH_4^+ derived from air were major contributors to the basicity of the Japanese cedar. They may be strongly associated with the neutralization of acid rain. Stemflow pH values for madake bamboo, moso bamboo, and Japanese cedar were 5.0, 4.9, and 4.1, respectively; that is, the stemflow pH values for the bamboo forests were higher than that for the Japanese cedar. In the Japanese cedar, excess SO_4^{2-} derived from air may mainly cause soil acidification. Soil under bamboo faces a small risk of soil acidification.

Introduction

Over the last 20 years, numerous studies on acid rain have been conducted worldwide. The relationships between acid rain and forest damage have been studied in Japan. Only a few studies have discussed chemistries of throughfall and stemflow in bamboo forests. Furthermore, in recent years, the encroachment of bamboo on forest areas has become a serious problem in Japan, and there is great concern for environmentally negative effects of bamboo encroachment. Previous report have shown that in the encroached area of bamboo on the Japanese cypress(Chamaecyparis obtuse□, 90% of trees were dead , and soil moisture contents of surface soil were lower than that of the pure Japanese cypress stand (Yokoo et al.2005). Furthermore we suggested that the

bamboo could neutralize the pH of surface soil as result of the higher soil pH in bamboo forest than that of Japanese cypress forest.

For these reasons, in this study, we investigated the chemistries of throughfall and stemflow in a bamboo forest. In this paper, we discuss the chemistries of throughfall and stemflow in a bamboo forest in comparison with those in a Japanese cedar, which is a typical tree species used for afforestation in Japan.

Material and Methods

Study site

The experimental site (33°02′ N, 130°36′ E), which is located in a private forest at Nagomi Town in Kumamoto Prefecture in southern Japan, as shown in Figure 1, was used for monitoring purposes. This site is situated in a rural area. The annual mean of air temperature at this site is 17.0°C. In 2006, the annual precipitation amount at the Kahoku aerial observing station (33°07′ N, 130°42′ E), nearest to this site, was 2663 mm.

Three adjacent forest stands were selected: madake bamboo (*Phyllostachys bambusoides Sieb*), moso bamboo (*P. pubescens Mazel*), and Japanese cedar (*Cryptomeria japonica*). Experimental plots for obtaining tree census in the two bamboo forests were set in areas of 5 m × 5 m each, and that in the Japanese cedar stand was set in an area of 10 m × 10 m. In each bamboo forest, 9 sample trees of different sizes were cut down, and the culm height and the diameter at breast height (DBH) of sample trees were measured in June 2007. There was a good relationship between the culm height and DBH each bamboo forest, which described as follows:

In madake bamboo forest, $H = 1.44 \times DBH + 4.27$ $R2=0.969$

In Moso bamboo forest, $H = 0.60 \times DBH + 7.93$ $R2=0.925$

Where H and DBH are the culm height and the diameter at breast height.

The overall height of culms were calculated by DBH using the equation mentioned above. In Japanese cedar, the height of all trees were measured by using the ultrasonic hypsometer(Vertex).

Further details on each stand are provided in Table 1.

Sample Collection and Period

Bulk precipitation (hereafter referred to as precipitation) was collected in open areas adjacent to the forests, using one polyethylene funnel collector (diameter: 300 mm). Throughfall was collected by placing one polyethylene funnel collector (diameter: 300 mm) beneath the forest canopy at a height of approximately 1.5 m above the ground of each plot, as shown in Photo 1. Stemflow was collected from one tree with uretan collars placing around a trunk of tree and led into each polyethylene bottle as shown in Photo 1. The number of sampling events was 10 for a period of 3.5 months from June 16, 2006 to September 25, 2006.

Chemical Analysis

Rainwater samples were brought to the laboratory on the day of collection itself, and their pH values and electrical conductivity (EC) were immediately measured using a pH meter (Horiba, F-22) and a EC meter (Toa, CM-40S), respectively. The samples were then filtered using a cellulose acetate filter and stored at 2°C. The cations Ca^{2+} and Mg^{2+} in the filtered samples were analyzed using an atomic absorption spectrophotometer (Hitachi, Z-6100). The other cations Na^+, K^+, and NH_4^+ and the anions Cl^-, NO_2^-, PO_3^{3-}, NO_3^-, and SO_4^{2-} were analyzed using an ion chromatograph (Dionex, DX-500).

Results and Discussion

The volume-weighted mean pH of precipitation was 4.7 with a range of 4.2 to 4.9 and acid rain fell over the forest (Table 2). This value of precipitation pH is the same as the annual mean volume-weighted pH of precipitation in Japan (Tamaki et al. 1991). Table 3 shows the ionic concentration (in μequiv./L) of cations and anions and ionic balance in precipitation. In order to verify the quality of data obtained by chemical analyses, quality control was carried out by achieving ion balance and by drawing a comparison between measured and calculated conductances. The charges of cations and anions in precipitation were almost in balance.

At sampling event no. 10, highest concentrations of Na^+ and Cl^- were observed—251 μequiv./L, 214 μequiv/L, respectively (Table 3). The collected precipitation was significantly affected by sea salt derived from seawater attributed to Typhoon no. 13 that attacked this area on September 17, 2006. In this study, an analysis of all data except for data in the special case of sampling event no. 10 was carried out for discussion purposes.

As shown in Table 2, the throughfall pH values for madake bamboo, moso bamboo, and Japanese cedar were 5.3, 5.2, and 5.3, respectively. Throughfall pH values for the three forests were significantly higher than the precipitation pH ($p < 0.05$), probably due to the neutralization of cations by dry deposits and basic leachates from leaves, branches, and barks. When precipitation falls through forests in the form of throughfall and stemflow, its quality changes, and usually, many kinds of soluble elements are added to the precipitation.

According to Terashima et al. (2004), elements Si, K, Ca, and Mg are predominant in the culm of bamboo, and Ca is a dominant element in the leaves and bark of the Japanese cedar. Furthermore, in a bamboo forest, leaching of K^+ and Cl^- from leaves and culm has been suspected to occur, on the basis of results of comparisons among the chemistries of precipitation, throughfall, and stemflow (Sakai et al.1996; Takenaka et al.1995 & 1996; Tazaki et al.2004).

Table 4 shows the relative contributions of anions or cations to the sum of ions. K^+ cations in the precipitation, throughfall in madake bamboo, throughfall in moso bamboo, and throughfall in the Japanese cedar accounted for 1%, 29%, 42%, and 10%, respectively, of the total cations. In bamboo forests, K^+ is a major contributor to the basicity of the throughfall. As is the case with throughfall, the relative contribution of K^+ in the stemflow in madake bamboo and moso bamboo to the total cations was high—21% and 27%, respectively. Similar patterns of higher relative contribution of K^+ to the total cations in the first half of the observation period, i.e., from mid-June to mid-August, were clearly observed in the case of K^+ in the throughfall and stemflow of bamboo forests

(Figure 2). During this period of the year, bamboo undergoes growth and other changes. For example, this period witnesses the sprouting of bamboo shoots and shedding of bamboo leaves. In our study, these phenomena were expected to affect the enhancement of K^+ in the throughfall and stemflow of bamboo.

On the other hand, in the Japanese cedar, NH_4^+ and Ca^{2+} are major contributors to the basicity of throughfall, and together, they accounted for 62% of the total cations. These results coincide with those of studies cited above (Sakai 1997; Sakai et al.1996; Takenaka et al.1995 & 1996; Tazaki et al.2004).

Cl^- anions in the precipitation, throughfall in madake bamboo, throughfall in moso bamboo, and throughfall in the Japanese cedar accounted for 13%, 49%, 58%, and 18%, respectively, of the total anions (Table 4). In bamboo forests, Cl^- is a major contributor to the acidity of both the stemflow and throughfall. Further, Cl^- in the stemflow in madake bamboo and moso bamboo accounted for 46% and 56%, respectively, of the total anions. Thus, high values of both Cl^- and K^+ in the throughfall and stemflow in bamboo suggest that the leaching as the composition of KCl occurred.

As shown in Table 2, differences were observed between the stemflow pH values for bamboo forests and Japanese cedar. Stemflow pH values for madake bamboo, moso bamboo, and Japanese cedar were 5.0, 4.9, and 4.1, respectively. That is, the stemflow pH value for the Japanese cedar was lower than those for the bamboo forests. Furthermore, the stemflow pH value for the Japanese cedar was lower than the precipitation pH value. Because SO_4^{2-} is a major contributor to the acidity of stemflow (Table 4), this lower stemflow pH is assumed to cause soil acidification due to excess SO_4^{2-} derived from air. Several previous studies have reported the acidification of soil near the trunk of the Japanese cedar (Matsuura 1992; Sakai 1997). On the other hand, soil under bamboo faces a smaller risk of soil acidification, because the pH values of throughfall and stemflow in bamboo forests are higher than the precipitation pH value.

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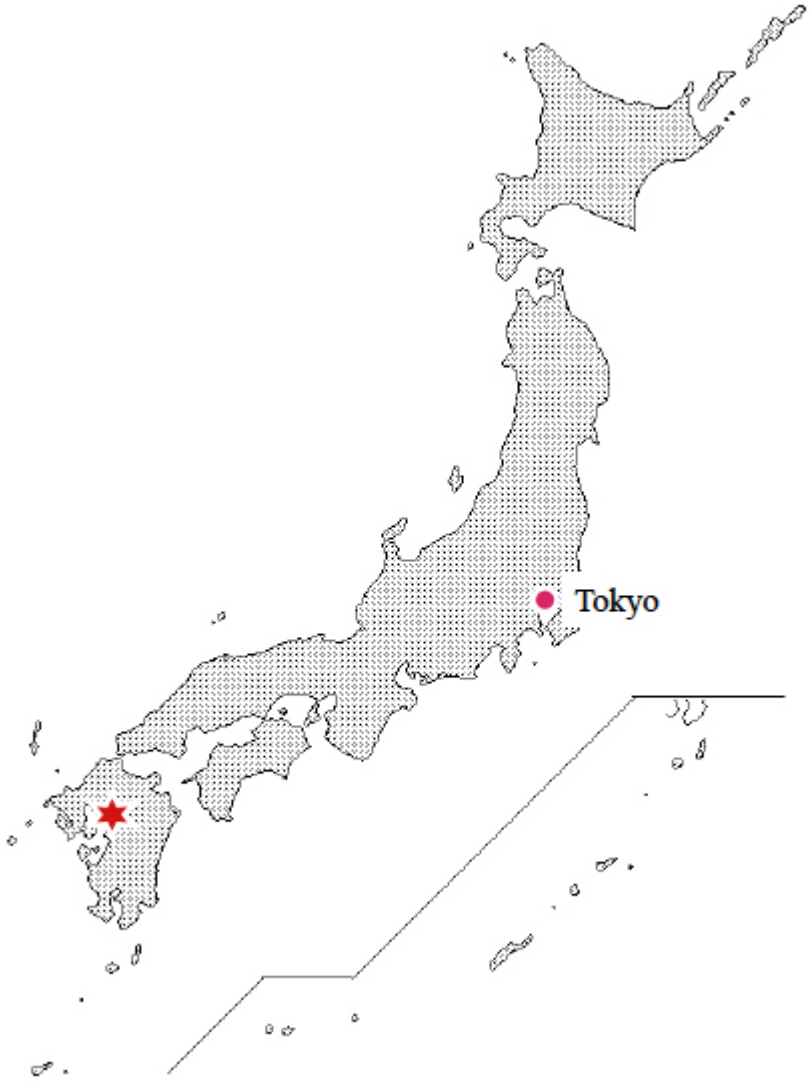

Figure 1 A location of Nagomi experimental site in Japan (*)

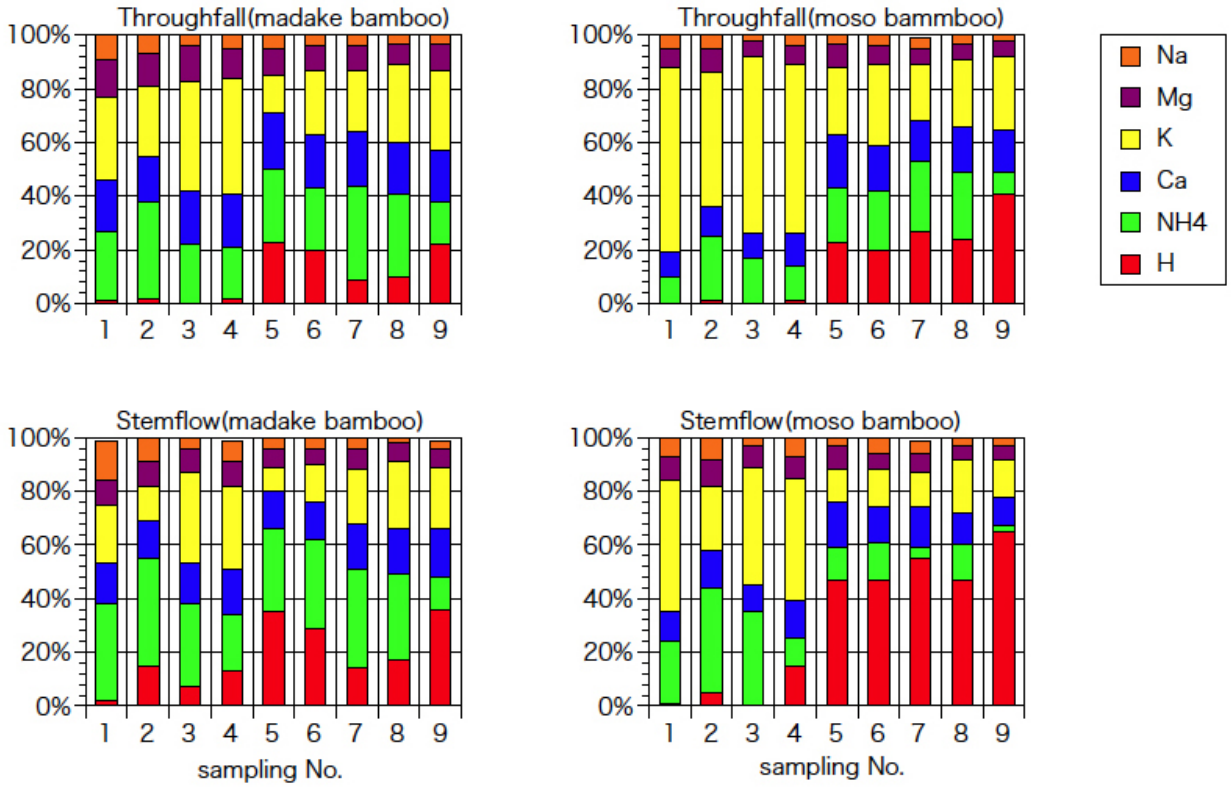

Figure 2 Relative contributions of cation to the sum of catios each sampling event

Photo 1 Collectors for throughfall and stemflow

Table 1 Site description of three forest stands

Stand name	Forest type	Age (years)	Mean DBH (cm)	Mean Tree Height (m)	stand density (No.of Stem/ha)	Direction	Inclination	Altitude (m)	Species
Madake	Bamboo	-	7.3	14.8	24800	SW	5	105	*Phyllostachys bambusoides Sieb*
Moso	Bamboo	-	9.3	13.5	12800	SW	16	100	*P.pubescens Mazel*
Japanese cedar	conifer	30	21.8	21.2	1900	SW	18	100	*Cryptomeria japonica*

A measurement date : November 2006

DBH: a diameter of tree at breast height.

Table 2 The volume-weighted mean pH and electric conductivity(EC)

		pH	EC (μS/cm)
	Precipitation	4.7	13.8
Madake bamboo	Throughfall	5.3	21.3
	Stemflow	5.0	19.8
Moso bamboo	Throughfall	5.2	30.3
	Stemflow	4.9	22.9
Japanese cedar	Throughfall	5.3	13.4
	Stemflow	4.1	42.2

Table 3 The values of pH,electric conductivity(μS/cm), and ionic concentration(μequiv./L) of precipitation

sampling No.	sampling date	days	an amount of precipitation (mm)	pH	EC	Cl^-	NO_3^-	SO_4^{2-}	Na^+	NH_4^+	K^+	Mg^{2+}	Ca^{2+}	Σcations	Σanions	ionic balance
1	12/Jul/06	26	738	4.7	15.4	13.8	13.1	32.7	13.0	20.0	0.8	3.3	4.0	62.759	59.573	1.05
2	31/Jul/06	19	568	4.8	9.2	5.1	8.1	22.3	5.2	10.5	0.8	2.5	3.5	37.154	35.419	1.05
3	04/Aug/06	4	31	4.7	25.5	11.6	39.0	78.7	9.1	68.7	4.6	12.3	25.9	140.557	129.292	1.09
4	21/Aug/06	17	229	4.9	8.9	6.2	9.4	18.7	5.2	8.9	1.0	2.5	7.5	38.448	34.298	1.12
5	25/Aug/06	4	67	4.4	22.8	4.5	28.4	43.5	3.9	25.5	0.8	2.5	5.0	77.134	76.410	1.01
6	29/Aug/06	4	64	4.6	15.0	5.6	17.3	26.4	4.3	17.2	0.5	1.6	3.0	54.008	49.339	1.09
7	04/Sep/06	6	37	4.4	20.6	8.5	22.3	45.6	6.1	28.8	0.5	2.5	4.0	78.745	76.314	1.03
8	11/Sep/06	7	39	4.2	32.0	10.2	21.3	68.9	4.3	22.7	1.0	2.5	5.0	104.192	100.357	1.04
9	15/Sep/06	4	32	4.2	30.0	8.2	13.4	62.5	3.0	8.3	0.5	2.5	3.5	88.065	84.026	1.05
10	25/Sep/06	10	35	4.8	43.2	251.3	7.9	48.5	214.0	0.0	9.7	46.1	25.0	310.470	307.753	1.01

ionic balance:Σcations/Σanions

Table 4 Relative contributions of cations or anions to the sum of ions (%)

			madake bamboo		moso bamboo		Japanese cedar	
		precipitation	throughfall	stemflow	throughfall	stemflow	throughfall	stemflow
Cations	H^+	46	10	19	15	31	10	58
	Na^+	9	5	6	4	5	10	10
	NH_4^+	29	26	30	18	17	37	8
	K^+	1	29	21	42	27	10	4
	Mg^{2+}	5	11	8	7	7	8	5
	Ca^{2+}	10	19	16	14	13	25	15
	total	100	100	100	100	100	100	100
Anions	Cl^-	13	49	46	58	56	18	25
	NO_3^-	27	16	19	12	13	29	22
	SO_4^{2-}	60	35	35	30	31	53	54
	total	100	100	100	100	100	100	101

Guadua angustifolia Forestry nucleus in Colombia: Contribution to Environmental Preservation and to Local Social Development

Ximena Londoño
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Abstract

The Nucleo Forestal de Guadua La Esmeralda – NFGLE (La Esmeralda Guadua Forestry Nucleus) was established in 2007 in the coffee growing region of Colombia. It is operated by the Colombian Bamboo Society and has the following objectives: a) to integrate the area planted in guadua that had different owners under one same figure; b) order and improve the forestry quality of the plantations; c) ensure a better quality and better price for the raw material; d) guarantee protection of the water resources and biodiversity; e) generate employment; f) provide support and incentives for the research processes; and g) strengthen the social and entrepreneurial organizations existing in the region. NFGLE is formed by 11 farms, having a total area of 315,7 hectares, out of which 27,74 ha (8,8 %) are planted in *Guadua angustifolia* Kunth. With this organizational scheme we expect to guarantee the sustainability of the resource, do a friendly management of the environment, and achieve greater profitability for the owners.

Resumen

En la región cafetera de Colombia se conformó en el año 2007 el Núcleo Forestal de Guadua La Esmeralda, operado por la Sociedad Colombiana del Bambú, cuyos objetivos son: a) integrar área de *guaduales* de diferentes propietarios bajo una misma figura; b) ordenar y mejorar la calidad forestal de estos rodales; c) asegurar un mejor precio y calidad de la materia prima; d) garantizar la protección del recurso hídrico y de la biodiversidad; e) generar empleo; f) apoyar e incentivar los procesos de investigación; y g) fortalecer los procesos de organización social y empresarial que existan en la región. El NFGLE está conformado por 11 predios que cuentan con un área total de 315,7 ha de las cuales 27,74 ha (8,8%) están cubiertas por *Guadua angustifolia* Kunth. Con este esquema organizacional se espera garantizar la sostenibilidad del recurso, realizar un manejo amigable con el medioambiente y lograr una mayor rentabilidad para el propietario.

Introduction

La Esmeralda Guadua Forestry Nucleus - NGFLE was established in March 2007 having as its main objective: a) to integrate the area planted in guadua having different owners under one same figure; b) order and improve the forestry quality of the plantations; c) ensure a better quality and better price for the raw material; d)

guarantee protection of the water resources and biodiversity; e) generate employment; f) provide support and incentives for the research processes; and g) strengthen the social and entrepreneurial organizations existing in the region.

NFGLE is located in the Province of Quindío, Colombia, in the Municipalities of Montenegro and Armenia, on the western side of the Cordillera Central (Central Mountain range), at an elevation of 1200 to 1250 meters above sea level, and with a rainfall regime of approximately 1800-2500 millimeters per year. In the location of the Nucleus there is guadua of good quality and a very good size and an adequate infrastructure of roads, electrical networks, and rural aqueduct which are basic conditions to exploit and commercialize guadua culms, and to establish a primary transformation center in the future.

NFGLE is made up by 11 farms having a small to medium size, with a total area of 315, 7 hectares, of which 27, 74 ha (8.8 %) are covered by the American native bamboo *Guadua angustifolia Kunth* (see Table 1). The area in *guaduales* represents very low economic profits for the farms, while the plantain, coffee, banana, tropical flowers, cassava and grass crops generate the greatest income.

Three main aspects have contributed towards the reduction of the agricultural vocation of guadua in this zone, and to the reduction of the area planted in guadua: 1) The large and medium sized properties have been divided due to inheritance processes and have become smaller farms with areas between 1 and 9 hectares; 2) the change of land ownership, whereby the new owners have a different culture, eradicating traditional crops, and planting grass and other foreign products requiring less labor, contributing significantly to damage the soil and its agricultural potential; 3) The increase of atypical climatic phenomena, represented by wind storms with wind speeds over 150 km/h that seriously affect the crops and the watersheds of rivers and creeks.

Given this situation, CBS has promoted the integration of medium and small sized farmers in forestry management activities related to improve the environmental, social and economic quality of the community.

Guadua represents a low income in the total economics of the farm owner, who has not yet identified the great business opportunities that exist in relation to guadua, thus the farmers don't have great interest in this crop and devote most of their efforts to crops that are 30% more profitable, such as plantain and coffee.

According to Botero et al. (2006) "10% of the total cost of guadua in a lumber yard corresponds to the value of the standing raw material, that is, what the farm owner receives; 43% of the total cost corresponds to labor intensive tasks that take place in the stand and inside farm (eliminating weeds, harvesting and transportation by technical assistants and forestry operators); 38% corresponds to land transportation, where there is only one actor; and 9% corresponds to commercialization".

Creating and operating NFGLE successfully has required quite a bit of organizational work with the farm owners, the local environmental authorities, the forestry operators, transporters, and dealers, the companies interested in this raw material, and the academia, with the objective of integrating the different actors of the Guadua chain.

Table 1. Area of the farms, area in guadua and percentage of the *guaduales* in NFGLE.

Property (Farm)	Farm Area (ha)	Area (ha) of the Guadua Plantation		Percentage of the area in *Guaduales* (%)
		Natural	Cultivated	
Guadualito	37,15	2,0	0	5
La Esmeralda	3,75	0,5	0	13
La Manuela	31,61	0,5	0	2
El Guatín	16,78	2,2	0	13
El Bambusal	16,78	0,6	0,8	4
La Negrita	4,48	0,01	0	0,2
La Elena	23,56	4,09	0	17
La Manila	28,65	2,15	0	8
El Volga	41,8	1,45	0	4
La Balsora	108,9	12,8	0	12
El Jardín	2,24	0,64	0	29
TOTAL	315,7	26,94	0,8	8,8

What is a Guadua Forestry Nucleus?

A Guadua Forestry Nucleus is the forestry organization of the guadua plantations into an area united by homogeneous characteristics or by geographical factors (watersheds, micro watersheds, mountain systems, valleys, etc), where the silvicultural activities concentrate using a criteria of sustainable practices that aim to improve supply and generate social and economic benefits (Botero et al. 2006; Castaño & Moreno 2004; Moreno 2007).

Organizational Structure of NFGLE

The land owners who form part of the NFGLE assign their right to exploit their guadua plantations to the Colombian Bamboo Society - CBS, which in turn, commits to manage the guadua resource with a dual purpose: guaranteeing an environmentally friendly management and achieving greater profits for the owner (Diagram 1).

To operate the NFGLE, the Colombian Bamboo Society has a group of 5 workers: 1 forestry operator, 2 harvesters, and 2 guadua loaders who extract and transport the raw materials from the stand to a storage area. This personnel is properly trained and must wear personal protection elements (helmet, leg protection, goggles, thick books – with a leather sole and steel structure to prevent perforations), ear plugs (only for work done with a chain saw), and a raincoat. To commercialize the products of the NFGLE, commercial agreements have been entered into with local and national dealers and members of the CBS in order to supply them with high quality guadua and to guarantee the custody chain in the certification processes.

To participate in the legalization projects of the forestry sector, NFGLE forms part of the Forestry project FLEGT- Colombia (2007-2010) sponsored by the European Community, which promotes the improvement of forestry legalization and governance, and the increase of legal production and commercialization of forestry resources in Colombia. In 2005, illegal operations in the forestry sector of Colombia were estimated to be 35%. This represents illegal transportation and transformation of over 1,5 millions of cubic meters of timber (Ecoforest 2009). Through this project, NFGLE has received equipment donations that make the forestry operation more efficient (brush cutters, chain saws) as well as training and assistance on the concept of voluntary forestry certification and legal timber.

With the local environmental authority a cooperation agreement was drawn with the objective of joining efforts and resources that lead to inter-institutional support in the areas of research, promotion, cultivation, forestry management, and sustainable exploitation of native bamboos and of bamboos introduced into the zone of their jurisdiction.

Since 2003, NFGLE has worked together with the Instituto Colombiano de Normas Técnicas - ICONTEC (Colombian Standards Authority) and with the Technical Committee 178 Bamboo-Guadua on the drafting of the guadua standards to establish basic quality, security, health and environmental protection requirements for guadua related products, services, processes and systems. Seven standards have been published during these 6 years of work (2003-2009): NTC 5300, NTC 5301, NTC 5407, NTC5405, NTC 5458, NTC5525, and Pre-NTC 209-08 (see References). They are not mandatory, but contribute to standardize and homogenize the quality of the products and processes. CBS has conducted training workshops to generate awareness about these standards among NFGLE members and the different actors involved in the Guadua chain of Colombia.

In the social aspect, a cooperation agreement was drawn with the principal authority of the Pueblo Tapao Township, in the Municipality of Montenegro, to promote the creation of a handcraft center for women-bread providers (head of the household). NFGLE provides the raw materials and the government, through SENA (the national training services) provides the training. A total of 12 women have become involved in this project.

In Research aspects, the CBS has worked since 2002 with various universities and research centers of the region (Cenicafé, Universidad Tecnológica de Pereira and Universidad Nacional de Colombia), making NFGLE available to them and providing financial and logistic support to undergraduate students. The resulting research work contributes to the sustainable management of the guadua stands and to improve the quality of the guadua products extracted.

Objectives for success when establishing the nucleus

1. Environmental objectives: a) Assemble and educate farm owners so they value the environmental benefits of the guadua ecosystem; b) Preserve and reforest the watersheds in the area of the NFGLE with guadua plantations; c) Minimize environmental impacts during the exploitation process; d) Establish new areas planted in guadua to develop soil and watershed recovery projects with the objective of having a compensation for environmental services in the future; e) Identify and protect the habitats of the different fauna and flora registered in the area.

2. Social objectives: a) Generate employment sources in the zone; b) Improve the environmental and touristic offer in the zone; c) Strengthen the principle of association among the members of NFGLE to carry out other activities that contribute to the improvement of the nucleus and of the township; d) Exchange knowledge and contribute with the research being done on guadua at different universities of the country; e) Train the communities neighboring NFGLE in the sustainable management of the guadua stands and in the handling of the raw materials to stimulate the establishment of business that help dynamize NFGLE.

3. Economic objectives: a) Perform productive activities related to the guadua stand that generate aggregate value, b) Provide guadua stands that yield higher productivity and profitability to the farm owners; c) Guarantee the supply of guadua through time, being able to supply high quality raw materials suitable for the different processes of transformation and industrialization; d) Supply quality guadua to the Guadua chain; e) Open and consolidate new domestic and foreign markets.

Activities carried out within the NFGLE

To begin any activity within the NFGLE a forestry exploitation plan must be prepared. This is a requirement of the local environmental authority, who must grant an exploitation permit by means of an official resolution. This plan consists of a study done by a forestry professional, whereby he determines the area of the native guadua stand, the number of culms in the stand, and their corresponding status of health and maturity. He defines the number of culms that can be harvested; taking into consideration the harvesting intensity, i.e. the number of culms harvested can't exceed 38% of the mature culms counted, without including sick, warped or dead culms.

After the local authority approves the plan, the following activities begin:

Weed control: It consists of eliminating weeds that prevent access and movement through the guadua stand. This activity must be carried out before extraction of the guadua to facilitate guadua cutting and transportation activities. Trees over 10 cm in diameter must not be cut down (NTC5300). Vines must be cut at least two weeks before harvesting the culms to facilitate harvesting and extraction. For this task, a machete and a "garabato" or hook are used in addition to the personal security equipment (helms, gloves, goggles, leather leggings).

Eliminating branches with thorns: In its morphology guadua develops thorns on the lower third portion of the culm (the first 2-3 meters of the culm). These branches are cut off taking care not to wound the culm with the machete. For this task, a machete, pole pruners, and a "garabato" or hook are used in addition to the personal security equipment.

Extraction and elimination of low quality culms: The dead, low quality or sick culms of guadua segments must be cut into small pieces to contribute to organize the guadua stand, facilitate circulation, and promote the birth of new shoots. The segments might be arranged as a barrier in the perimeter of the guadua stand or in existing gaps, so that the direct action of the sun and water may accelerate the decomposition process. For this task machetes, chain saw, and "garabatos" or hooks are used in addition to the personal security equipment.

Marking: Consists of marking the number of mature culms (5-6 years old) to be extracted according to the harvesting intensity recommended in the harvesting plan. This task is done by an experienced person, in a subjective manner, because to date, no quantitative method has been found to establish the culm's age. After the culms are marked, the cutting team proceeds to harvest them. This activity aims to prevent the cutting of immature culms and an excessive exploitation of the stand. The exploitation of immature culms is a serious problem for any transformation process, to overcome it, the new shoots are marked in the NFGLE placing the year of the new shoot eruption using a permanent ink marker.

Harvesting plan: It consists of quantifying the mature culms harvested so as not to surpass the volume of culms to be extracted as authorized by the regional environmental authority. The sustainability and productivity of the guadua stand will depend on a good harvesting plan.

Harvesting of the culms: The cuts are done above the first node of the culm, avoiding the rupture of the node's membrane and the accumulation of water in the internodes. The harvest of the culms is distributed in a uniform manner, trying to avoid the forming of gaps or an excessive exploitation of the guadua stand. When the cutting of the culm is taking place, it is important to direct its fall and avoid hitting the new shoots or other immature guadua stems that remain standing. Experienced people are required for this task, and they must use security equipment.

Correcting culms that don't have a good cut: After the harvesting plan is carried out, the old imperfect cuts from earlier harvests or caused by climatic phenomena such as the wind must be corrected by making a new cut at the base of the node. This task is made easier using a chain saw. The culm segments and the branches that remain in the stand after the harvest and which at that time are not of commercial interest, must be cut into small pieces and arranged in small piles inside the stand.

Transportation and storage: After the harvest, the culms are transported by workers to the border of the guadua stand, and from there they are transported with beasts of burden (horses or mules), taken to the collection area where the truck arrives, and sent on to their final destination. The storage of the cut culms is done in an open yard because we don't have a warehouse to store them yet.

The culms are stored horizontally, avoiding piles or laying them in tiers not higher than 3 meters and keeping the tiers in layers, separated by uniform wedges placed crosswise (NTC 5300). Storage is also done vertically. In this case the culms are leaned on a frame, with space between them, or leaned on trees; because of the strong winds in the area of the NFGLE, some of the culms must be tied to the frame to prevent them from slipping off.

Commercialization: The products from the NFGLE are mainly sold to dealers from Bogotá and Armenia. They collect the guadua in the storage yard. The unit of sale is the linear meter, and the price per linear meter is $700 pesos (0.35USD) for culms having a height of 4, 5 or 6 meters, or $500 pesos per linear meter (0.25USD) for the 4 meter *esterilla* (culm that is split and forms a mat). The products that are being offered at present are pre-dried in the open yard and are not preserved or immunized. For the members of the CBS there is a 5% discount over the sales price, and the farm owners who are members of the NFGLE are only charged for the labor costs.

Conclusions

1. After 2 years, the NFGLE associative project was able to achieve profitable productive scales, giving *Guadua angustifolia* culms a higher aggregate value, and giving the guadua stand owner a higher percentage of the profits, increasing their participation in the final price from 10% to 37%.

2. By increasing the productivity and supply availability both in quantity and quality at the NFGLE, competitivity in the local and national markets is improved, and the planting of new areas of guadua inside the nucleus is stimulated.

3. This associative scheme facilitates the transfer of science and technology, makes improvements of the plantations possible, increases the volume supplied and lowers the cost for negotiation and thus increases competitiveness.

4. The permanent availability of guadua culms for the NFGLE members has stimulated the use of this raw material in the various agricultural and livestock tasks, and in the construction of rural infrastructure at the farms, contributing to rescue the traditional use of guadua in Colombia's coffee growing region.

5. The water volume of the Tres Palitos and La Esmeralda creeks, affected by deforestation in the headwaters and by the urbanization process of the area, has increased with the improvement of the guadua stands in the NFGLE.

6. The establishment of the NFGLE has given permanent jobs to 5 people in the area, and the process of entrepreneurial association of the group of women who are the heads of their household (bread winners) at the Pueblo Tapao Township has been strengthened.

7. The supply by NFGLE of quality raw materials has contributed to the improvement of all the transformation processes in the guadua supply chain.

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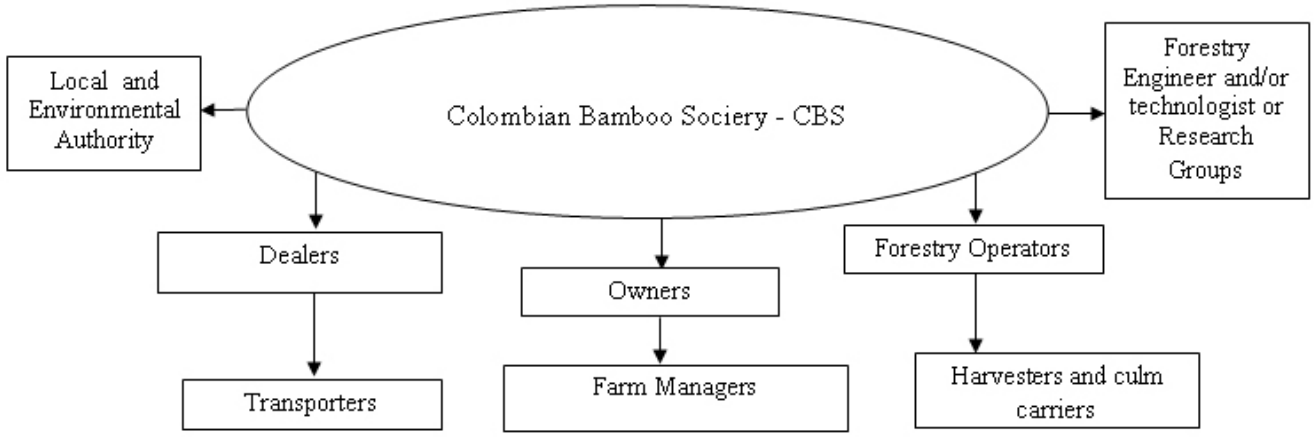

Diagram 1. Organizational Chart of the NFGLE

Oxygen Oasis

Tim Fisher
FisherGreen Communications

Imagine importing rich, life sustaining oxygen into your local community to combat high concentrations of air pollution from traffic clogged streets, backed up highways, multiple train lines and airplanes flying overhead.

Introducing OXYGEN OASIS – a completely new, innovative way to increase oxygen emission by 35 percent and help to combat pulmonary disorders such as asthma. OXYGEN OASIS is a simple and economical project designed to bring lush, green environments to abandoned urban lots.

Properties of Bamboo

1. emits 35 percent more oxygen than other plants
2. a renewable plant resource –
3. replicates quickly – a grove can mature in as little as three to five years
4. has minimal water requirements
5. grows in sun or light shade
6. thrives in temperate zones and can stay green year round

Benefits of an OXYGEN OASIS

Bamboo has superior properties that set it apart from other plants (shade trees and perennials) that would typically be used to green an urban environment:.

1. increased oxygen emissions
2. sequesters carbon
3. reclaims toxic soil and brownfields
4. controls soil erosion
5. green garden spaces:
    a. beautify and vitalize a neighborhood
    b. strengthen community bonds
    c. improve quality of life
    d. provide recreation, exercise, learning, therapeutic experiences
    e. cut heat absorption
    f. help to foster economic development

Getting OXYGEN OASIS in the Ground

In order to bring an OXYGEN OASIS to your community, the following requirements are needed:

1. empty dirt lot (brownstone size and above) with sun exposure
2. neighborhood site manager and community gardeners
3. debris removal and soil amendment
4. security fence
5. landscape design
6. bamboo plants
7. watering, maintenance
8. event planning and site administration

Bamboo as Carbon-Sink - Fact or Fiction?

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Abstract

Bamboo is often considered as a plant with an extraordinary potential for carbon sequestration and therefore for mitigating climatic change. This paper argues that bamboo is not likely to be significantly better than trees, and that much more research is needed to establish the true potential of bamboo for carbon sequestration.

For example, the assumption of bamboo's high sequestration potential is derived mainly from the fast growth of the individual culm during its expansion phase. However, the impressive biomass of such a young culm does not originate from its own photosynthesis, but derives from the energy produced by older culms in previous years and stored as carbohydrates in their culms and rhizome system. At the beginning of the growth season this energy will be mobilized and transported to the growing culm.

The individual culm has a limited lifetime of 7-10 years, and thereafter its biomass and the carbon contained will be deteriorated biologically into its origins, among them also CO_2, released into the atmosphere. Furthermore, the gregarious flowering of some species, often world-wide and followed by their death, can constitute a massive CO_2 production. On the other hand, prolonged sequestration of carbon is provided through the great variety of bamboo products that range from the manifold constructions to pulp; many of these uses serve the daily needs of over 1.5 billion people.

Although the carbon sequestration of bamboo forests is not likely to influence the mitigation of global warming as much as some protagonists have been arguing, the importance of bamboo forests and plantations for an environment-friendly and sustainable production of food, fibre and energy, and their environmental services including soil stability and waste-water management, important for adaption to climate change are undisputed.

Keywords: bamboo, CO_2 sequestration, biomass, carbon, life cycle, bamboo products

Introduction

Global warming, its causes and possible counter-measures are a major global concern and numerous international conferences and initiatives, both in research and politics, strive to identify viable approaches to mitigation and adaptation. Among these approaches the „carbon, capture, storage (ccs)“ idea is considered, where plant communities sequester carbon dioxide by their assimilation and transform the gas into their biomass for longer storage. Bamboo is certainly among the plants that are to be considered in that context, and this is also indicated by the title of our Conference „Bamboo, the Environment and Climate Change“.

The impressively fast growth of a bamboo culm and the annual re-growth of new culms point to a sustainable high biomass production and thus carbon sequestration. This is also expressed by numerous statements in public media like „Trees absorb the carbon we generate rapidly by photosynthesis, but bamboo does this five times faster than the others“(Times of India 4.08.2008). The internet-forum „bamboo-plantations“ provides statements like „ if we plant new forest and especially new bamboo plantations, we could cool the planet by purpose“(26.01.09).A National Workshop in Kerala, India, discussed in January 2009 as urgent topic „Bamboo - a global cooling agent“. To mention are also considerations to include bamboo plantation projects and the sustainable management of bamboo forests as eligible CDM projects for the post-Kyoto period.

Although a bamboo plant is biologically a grass and not a tree, a bamboo forest is considered a forest by UN-FAO definition (FAO 2004); there it reads: “forest includes areas with bamboo and palms provided that height and canopy cover criteria are met” (Fig. 1). Bamboo forests are able to store large amount of carbon which is later released by its natural biological deterioration. The discussions about relevance of forests in the context of global warming are mainly about the tree-forest and ecosystems, not about specific plants or (agro-)forestry species, such as for example at a recent conference in Copenhagen on “Climatic Change-Global Risks, Challenges and Decisions” (10-12 March 2009), with 2.500 delegates from nearly 80 countries, where no specific discussions were devoted to the (potential) role of bamboo.

In principle, of course, a bamboo forest has relevant characteristics like a tree forest regarding its role in carbon sequestration, but many questions are still open regarding the carbon dynamics in bamboo forests.

On the past VIIth World Bamboo Congress 27th February- 4th March 2004 in New Delhi, Session 23 “Carbon Sequestration and Trading” discussed in four papers mainly the issues of biomass production and carbon sequestration (Singh and Dadlani 2004). This paper follows with some biological aspects of the bamboo life cycle which are relevant for determining the storage of its biomass. Corresponding considerations and conclusions were published recently in a German Journal (Liese and Düking 2009).

The Growth of a Bamboo Culm

In order to consider bamboo as an extraordinary carbon-sink influencing atmospheric conditions, the carbon dioxide used for photosynthesis would have to be captured as biomass for a longer period than the period for comparable trees in the ecosystem under consideration. But what are the biological facts, which were apparently not much considered so far?

The bamboo culm impresses by its fast growth within a short time of only 3-4 months. Its daily growth amounts in a sub-tropical, temperate climate (*Phyllostachys, Pleioblastus*) on average to 20-30 cm and for tropical genera (*Bambus, Dendrocalamus, Guadua)* about 40-60 cm, depending on species and the environmental conditions; measurements of a daily growth of 100 cm are reported - but are not common. During its expansion the young culm is protected by culms sheaths, which fall of with time. Leptomorph (sub-tropical) genera reach a length of about 5-15 m and tropical, mostly pachymorph genera about 20-30m (max. 35m) with a diameter of up to 30 cm (Fig. 2).

The considerable amount of carbohydrates needed for the expanding culm cannot be produced by the culm itself. This is quite contrary to a germinating tree seed, which produces with the little energy of the seed first germination leaves as its own power plant- but admittingly also grows much less during its seedling year than bamboo. A bamboo culm, however, can grow so fast, because it is connected by its rhizome system with its older culms. Consequently, the energy for the culm shoot originates from the carbohydrates of previous years stored in their culms and rhizome. By the well-known photosynthesis process the leaves produce carbohydrates by uptake of CO_2 and release of oxygen. The resulting soluble sugars (saccharose, glucose, fructose) are transported in the phloem of the vascular bundles from the leaves to the culm and further down to the rhizome and roots. They diffuse in the surrounding parenchyma (about 50% of the tissue) and are mostly transformed into compact starch globules (Fig.3). The starch content varies with species, site conditions and age; it may be up to 10% of the biomass. Only few investigations exist so far about the molecular and physiological processes during culm growth. Observations on *Sasa palmata* (Magel et al. 2006) have shown that at early development stages the starch content in the rhizome and in older culms is much reduced, transformed into soluble sugars and transported to the expanding culm. In its early phase an older culm contains about 120nmol saccharose/mg dry weight which is reduced to 10 nmol during expansion. The hydrolysis of the carbon hydrates leads to a 50 times increased sugar concentration, so that due to the high osmotic pressure the cells expand and consequently growth results.

At a later stage of culm expansion the sheaths fall off and the epidermis appears often greenish coloured by their chloroplasts. In how far these chloroplasts contribute by photosynthesis to the culm tissue below has hardly been investigated (Poudyal 2006). It is one of the many questions for research on bamboo growth and the photosynthesis and respiration of the developed culm.

After the few months of expansion the fully elongated culm has all cells and tissues developed to be functional. However, the fibres of the vascular bundles contain still a small cell wall of few layers (Fig.4). Since the fibres amount to about 40% of the total tissue, young culms are called “immature” and may break easier, e.g. by storm. During the following years their wall will be strengthened by formation of additional lamella. Also the wall of the parenchyma cells will be thickened (Liese and Weiner 1996). It can be assumed, that this additional biomass stems from the culms ongoing photosynthesis.

The production of total biomass/ha/a is not to be addressed within this paper. Data about the biomass are found in a number reports, such as Scurlock et al. (2000), Kleinhenz and Midmore (2001) and Hunter and Wu Junqi (2002).Like trees, it varies in a wide range, depending on species and site conditions, for bamboo between about 50 t/ha/a and 4 t/ha/a, with a considerable biomass also below ground. The carbon content amounts to about 45-50 % of the total dry biomass, equivalent to trees.

Life Cycle of a Bamboo Culm and Stand

A managed bamboo forest gives the impression of a continuous production of biomass. The “mature” culms harvested commonly after 3-5 years are replaced by the young culms, so that the bamboo stand appears to be in biological balance. With such a regular management hardly any older culms are left, the more as their outer appearance makes them unfavourable for use. Significant is the fact, that a bamboo culm has a limited life span

of only 7-10 years, which will hardly be recognized in a managed forest. An old culm looses its leaves, dries up and breaks down after a while. Its biomass will de decomposed then by micro-organisms and insects into its origins with an uptake of oxygen and a release of the captured carbon back into the atmosphere. The biochemical and structural modifications at the culms natural death are still unknown and need to be analysed urgently; another research question in the context of bamboo stand dynamics.

An unmanaged, naturally regenerated bamboo forest, however, contains culms of all ages, including a great many dying and dead ones (Fig.5). Also the connected rhizome system appears to become deteriorated, equivalent to trees. Such forest is often situated far from human settlements and poorly described. It may be assumed, that most of the 37 millions ha bamboo forest are not utilized, so that their biomass will follow the biological cycle between growth and deterioration. According to FAO (2007), in Asia about 30 % of bamboo are planted, but 70% naturally re-generated.

Consequently, the additional storage of CO_2 by a bamboo ecosystem due to early fast growth may be quite limited because also in a relatively short time period such forest reaches an age when old culms start to die of and when the CO_2 captured by photosynthesis equals its release through biological deterioration.

Such calculation assumes a complete biological deterioration, so that no un-rotten material remains on the ground to form thicker humus or even coal layers, as often postulated for the tree forest. This situation has still to be clarified. Also recent reports from Australia about the formation of long lasting phytoliths with a high carbon content in old bamboo stands merit further investigations (ABC 2008).

The Flowering of Bamboo

The apparent continuous growth of a managed resp. natural bamboo stand with a replacement of the harvested resp. dying culms by young ones can end abruptly by a gregarious flowering. Quite a few bamboo species flower in regular intervals, often with a cycle of 30-50 years. The flowering occurs worldwide for all individuals of the given species and is regularly followed by the death of culms (Fig. 6).The common species for northeast India *Melocanna baccifera* has flowered in recent years in the Mizoram region, but also in Colombia (Fig.7).The phenomenon was already observed 1969 in Bangladesh, confirming the cycle of 45-50 years registered since 200 years (Liese 2008, Shibata et al. 2008). In Europe the common *Fargesia murieliae*, although not really a high biomass producer, has flowered around 2006 followed by a general dye-off. However, for the widely distributed *Bambusa vulgaris* no flowering was seen since 1810. Other species do not exhibit the natural property of gregarious flowering, but show spontaneous flowering of individual plants or culms, followed often by the death of the culm or group of culms that flowered.

After flowering the culms and most of the rhizome die off, they become brittle, collapse and decompose biologically. Consequently the stored carbohydrates will be released into the atmosphere as a big CO_2 eruption. Also the fire of a bamboo forest can produce large amounts of CO_2, as it also occurs for the trees by fire, insect calamities or windbreak.

The occurrence of a coming flowering is indicated by smaller and lesser foliage, so that the culms might be harvested in time by clearing and storing for the material requirements in coming years. However, the strength

of the dying culms becomes much reduced; details of these changes in the culm structure are yet to be researched.

It might be noted, that reforesting a new bamboo stand on a large area either by seed or with a plantation program will take about 4 - 6 years until the regenerated culms reach their final productivity and dimensions; harvesting of mature culms will then take another 2-3 years. While this is usually quicker than for a tree plantation, the manpower for planting and maintenance as also the energy input through fertilization and watering during establishment should be taken into consideration when calculating the carbon sequestration balance of bamboo- and of trees or other carbon sequestration crops for hat matter.

Bamboo Products for CO_2- storage

The natural carbon cycle in bamboo is being interrupted by the utilization of mature culms as products. There are about 1.500 kinds of products for manifold purposes. These products store the carbon until the product is either biological deteriorated or burnt. The commercial bamboo utilization is estimated to about 20 million tons/year, but much more can be assumed to be consumed by rural life, not being accounted for in national statistics (Scurlock et. al. 2000). Bamboo contributes between 4-7% of the total tropical and subtropical timber trade (Jiang 2007). During the last decade, production, utilization and trade of bamboo have increased considerably, mostly due to improved and new products, but also by the higher esteem for bamboo products as part of the natural scenery (Zhang Qisheng et al. 2001; van der Lugt et al. 2009).

Construction is the main field for bamboo use. In rural areas bamboo is often the only material readily available. It is estimated that at least 1 billion people live in bamboo houses of different kinds and quality. Prefabricated elements and international programs have fostered the construction of modern house-types, as in Costa Rica by UNHABITAT. The slogan “bamboo is the poor men’s timber” embraces both the fact that bamboo is a good replacement for wood and cement available to the poorest in society, as well as the unfortunate fact that poor people do not have access and the financial means in invest in appropriate preservation technology and that therefore their bamboo constructions often face deterioration by fungi and insects. Adequate constructions will be helped by chemical protection, although with its potential significant side-effects (Liese and Kumar 2003).With the present status of bamboo preservation technology use in bamboo constructions the storage time of CO_2 should be considered limited and is estimated to be in the order no more then 15-20 years.

Furniture products from round or split bamboo are much appreciated; some are designer pieces for long lasting use, but mostly bamboo is used for daily life products in the bamboo-countries often with a limited use time. In compact flat packs they are increasingly exported to North-America and Europe in spite of various obstacles regarding production, transport and commercialization (van der Lugt and Janssen, 2008).

Bamboo-based panels and boards of about 25 types are produced for an expanding large market (Ganapathy et al. 1999). China produces around 1 million cbm boards in about 200 factories for manifold applications. Their service life may be in the range of decades. Also bamboo flooring should be mentioned with a production of 17.5 million m^2 2004 in China.

Pulp and paper are big consumers of bamboo (and wood), but do not have great value for carbon sequestration. Their production in large mills requires a steady and huge amount of raw material. In a few cases an over-cutting of bamboo stands has led to a shortage and therefore a change of the material source, or even to the closure of these factories. Also imports became partly necessary. The use of bamboo for cardboard or paper is short term use, and most of the products if not recycled will rapidly deteriorate and return to the atmosphere as CO_2.

Pulp mills require a continuous intake of raw material. Bamboo however can be harvested in most regions only during about 6 months due to the sprouting season and weather conditions. Consequently large amounts of culms have to be stored at least for several months. Often fungal infections and borer attack occur which can reduce considerable the pulp quality and also quantity (Fig. 8).The loss of biomass during storage and the corresponding immediate carbon release is an additional factor determining the limited carbon sequestration value of most pulp/paper products made out from bamboo.

As an **energy resource** bamboo has a most important function. In rural areas bamboo is often the only material for cooking and heating, especially where firewood is not available. Also the bamboo waste from processing often serves as energy. A large amount of bamboo biomass is being used this way, often replacing wood because of bamboo's high potential regrowth after cutting, which can help to prevent deforestation. The potential of bamboo biofuels is intensively investigated (El Bassam et al. 2002)

Another way for using bamboo biomass is the production of bamboo charcoal. This process leads to products with a better heating quality. Bamboo charcoal is lighter, can be stored and transported easily and they is absorbent and not susceptible to insects and fungi. A recent project by INBAR and the EU for Ethiopia and Ghana sees plans for a total of about 1.000 production centres for bamboo charcoal to meet the energy demand of 30.000 families on a sustainable basis.

Its biological resistance also promotes intentions to use bamboo charcoal for long lasting improvements of degraded soil.

For wood a permanent carbon dioxide sequestration by a burial process was recently proposed by Scholz and Hasse (2008) and also considered for long time storage of bamboo. However for an operational application severe restrictions exist (Köhl and Frühwald 2008).

Conclusions

The fast growth rate of bamboo culm and the apparent sustainability of its forests favours considerations about a very high potential as a carbon sink with potential beneficial impact on global warming. However, a closer look indicates that there are no reasons to assume that bamboo would outperform trees in carbon sequestration. For example, the impressive production of biomass during the growth phase is based on carbohydrates produced in prior growing seasons. Since a bamboo culm has a lifetime of only 7-10 years, the biomass accumulated through assimilation will relatively rapidly start to degrade into its origins. Thus, a natural bamboo forest in biological balance is not likely to be an exceptional CO_2-sink. Also the gregarious worldwide flowering rhythm of decades of some species, followed by their death is likely to lead to a massive sudden carbon release.

A prolonged capture of carbon in bamboo is possible whenever the culms are processed into products with long life cycles, such as construction material, panel products and furniture; also the use as an energy resource and as activated charcoal - reducing resources of fire-wood - may contribute to a sink effect of bamboo stands or may help halting deforestation and its related release of captured carbon. However, it must be noted that the lifespan of bamboo products rarely exceeds decades.

Consequently and despite other expectations, it does not appear justified to consider bamboo forests` capabilities as a carbon sink to be any more relevant than those of tree forests regarding their role in halting global warming. Fact is though because of bamboo´s high level of re-growth promoting increased usage of bamboo forests reduces the pressure on other forest resources, and thus protects and maintains the carbon sink function of ordinary tree forests.

Bamboo forests have many positive environmental effects: They stabilize steep slopes and water ways, prevent soil erosion and contribute to waste-water management (Ndzana and Otterpohl 2009). Bamboo as a plant and as a basis for thousands of uses does indeed secure the existence of more then a billion people on this planet. Bamboo plays a great role as an environmental friendly way to produce food (bamboo shoots), it is essential for the construction of houses as scaffolding as well as building material mostly in rural areas. Also bamboo is increasingly used as raw material for the production of countless articles and as an energy source for cooking and heating, where there is no alternative thus making it a frequent substitute for wood (Hunter 2002).

The facts presented in this paper are well known; it is clear that a lot of knowledge is still missing when analysing the potential role of bamboo for carbon sequestration.

Acknowledgement

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Figure 1. Bamboo forest in Colombia, *Guadua angustifolia*

Figure 2. Expanding culms, *Guadua angustifolia*

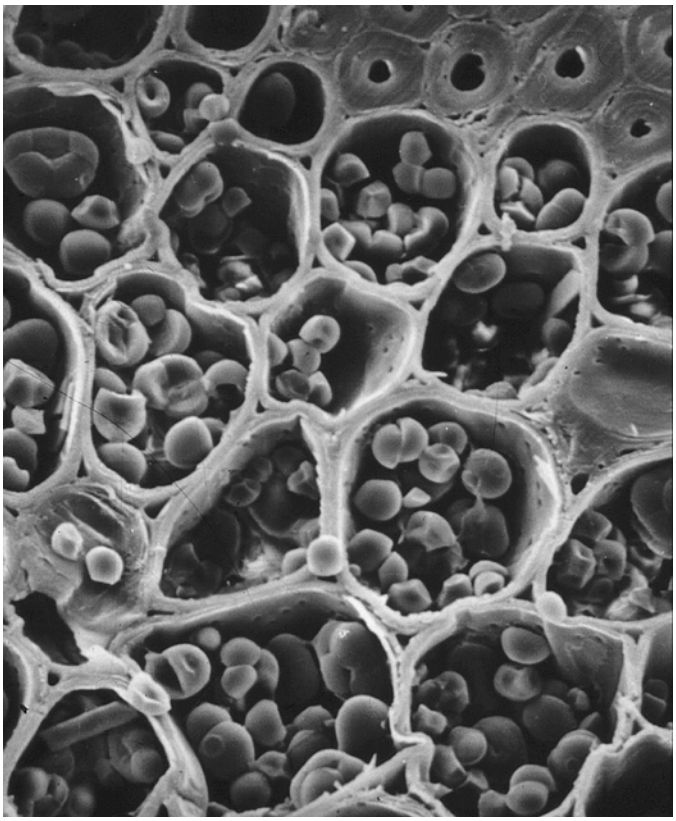

Figure 3. Starch granules in parenchyma cells store growth energy

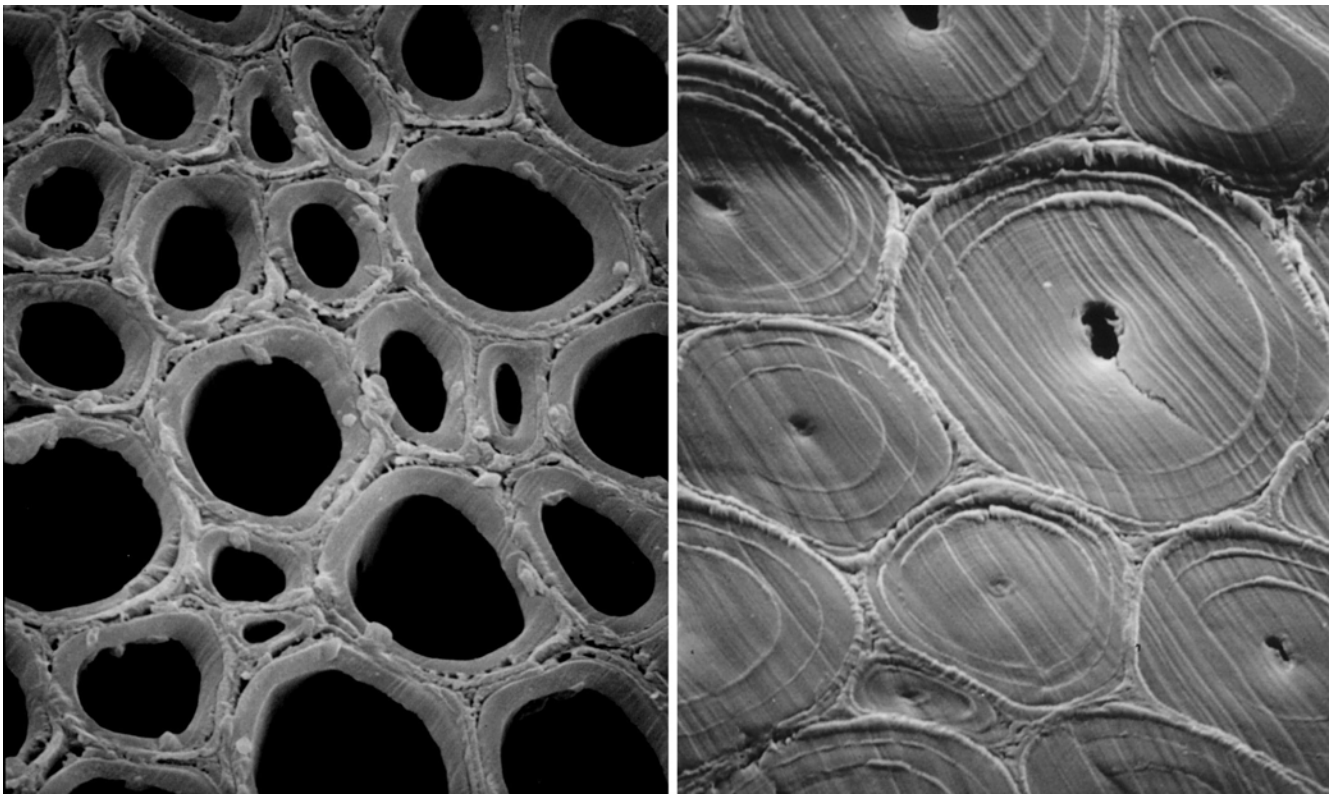

Figure 4. Cell wall of fibres, one and four years

Figure 5. Bamboo stand in balance between growing and dying culms.

Figure 6. Flowering and death of a bamboo clump.

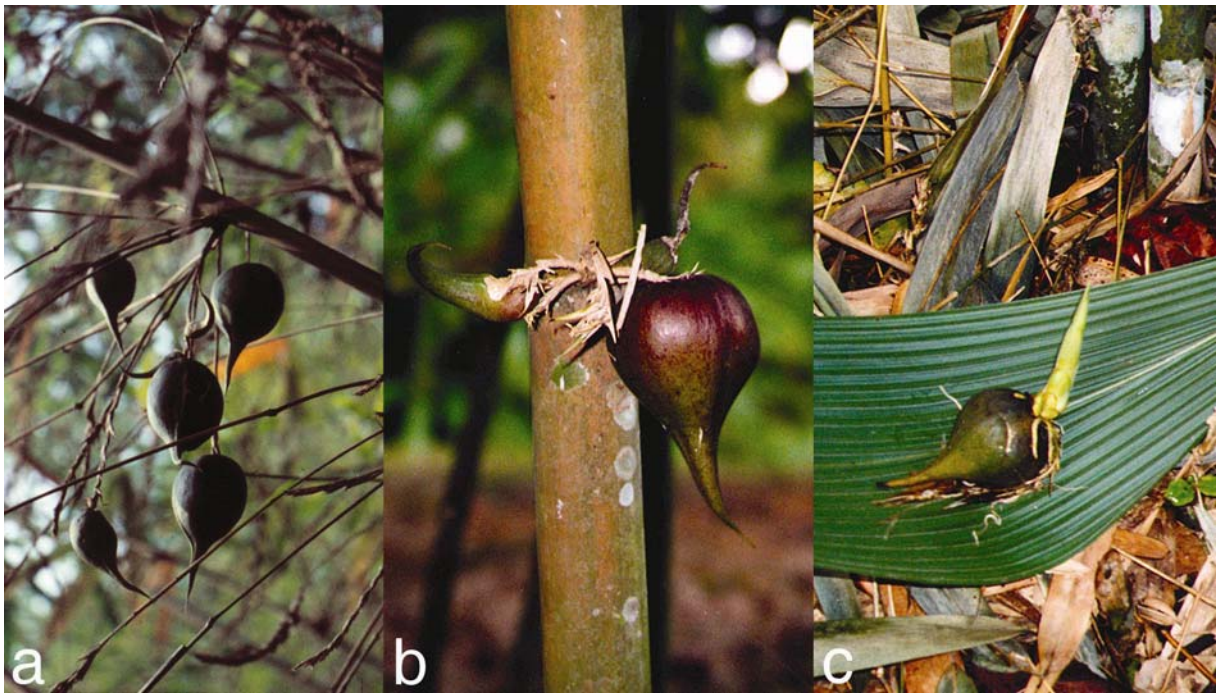

Figure 7. Fruiting cycle of *Melocanna baccifera* . 1969 Bangladesh, 2004 Colombia, India.

Figure 8. Fungal deterioration of a bamboo pile at a pulp mill.

Bio-sequestration of Carbon within the Phytoliths of Economic Bamboo Species

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Abstract

The rates of carbon bio-sequestration within silica phytoliths of the leaf-litter of ten economically-important bamboo species indicates that a) there is considerable variation in the phytolith occluded carbon (PhytOC) content of the leaves between different bamboo species, b) this variation does not appear to be directly related to the quantity of silica in the plant but rather the efficiency of carbon encapsulation by the silica. The PhytOC content of the species under the experimental conditions ranged from 1.6% and 4% of the leaf silica weight. The potential phytolith carbon bio-sequestration rates in the leaf litter component for the bamboos ranged up to 0.709 tonne e-CO_2 $ha^{-1}y^{-1}$ for these species. The data indicates that the management of bamboo forests to maximise the production of PhytOC has the potential to result in considerable quantities of securely bio-sequestered carbon per annum.

Keywords: Soil Organic Carbon; Phytoliths; PhytOC; Terrestrial Carbon Sequestration; Occluded carbon; Organic Matter Decomposition

Introduction

The world's soil carbon stocks have previously been estimated to accumulate at ~ 2.4 g C m^{-2} yr^{-1} (Schlesinger, 1990). However, quantifying soil carbon changes is difficult due to differences in methodologies currently employed and rates of decomposition resulting in both spatial and temporal variability (McKenzie et al., 2000; Skjemstad et al., 2000; García-Oliva and Masera, 2004). Current methods of carbon quantification in soil include determination of total carbon (TC). Total carbon measures all carbon fractions and is unable to distinguish between the more volatile soil carbon fractions and the stable soil carbon forms.

One inert form of organic carbon that is biosequestered within plants (and hence can be measured whilst in standing vegetation) and that accumulates in soil after the decomposition of that vegetation is the phytolith occluded carbon (PhytOC) fraction (Parr and Sullivan, 2005). Phytoliths are found in many plants species but are particularly prolific in grasses such as bamboo species. Also referred to as 'plantstones' or 'plant opal', phytoliths are silicified epidermal cell structures that occlude carbon (Wilding et al., 1967). The silicified epidermal cells of the leaf and stem within all grasses are particularly good at occluding carbon (Parr and Sullivan, 2005). This carbon fraction is likely made up of the internal cytoplasmic organic cellular material

(Wilding et al., 1967). Upon maturity the leaf material is deposited onto the soil surface: phytoliths later become incorporated into the soil matrix during decomposition of this organic material.

The occlusion of carbon within phytoliths has been demonstrated to be an important long-term terrestrial carbon fraction (Parr and Sullivan, 2005) representing up to 82% of soil carbon in some buried topsoils after 2000 years of in situ decomposition depending on the overlying vegetation type and drainage regime. Moreover, it has been demonstrated that relative to the other soil organic carbon fractions that decompose over a much shorter time scale, the carbon occluded in phytoliths is highly resistant against decomposition (Wilding et al., 1967; Wilding and Drees, 1974; Mulholland and Prior, 1993; Parr and Sullivan, 2005). Our research has demonstrated (using radiocarbon dating of the phytoliths themselves) that phytoliths extracted from palaeosols and peat sediments reach ages of at least 8000 years BP (Parr and Sullivan, 2005) and in another study a date of 13,300 ± 450 BP was acquired (Wilding, 1967). While under some circumstances bioturbation may move them up or down a soil profile, or erosion and dust storms may transport phytolith assemblages over some distance, or they may be burnt in a grass fire, or pass through the digestive system of an animal, the durability and persistence of phytoliths against such processes has been well documented (Baker, 1959; Baker, 1961; Baker et al., 1961; Bowdery, 2007; Hart and Humphreys, 1997; Humphreys, 1994; Jones and Handreck, 1967; Jones and Milne, 1963; Parr, 2006; Pearsall, 1989; Piperno, 1988; Rovner, 1986; Sangster and Parry, 1981; Wilding, 1967; Wilding et al., 1967). Moreover, the ability to radiocarbon date the phytoliths themselves demonstrates that they can remain stable sequesters of carbon over millennia despite being subject to the above circumstances.

Bamboo is known to be particularly proficient silica accumulators and hence also at the production of phytoliths (Drees et al 1989). Bamboo forests cover approximately 22 million ha worldwide and at least 7.2 million ha are currently growing in China (Jiang, 2004). There has been a significant increase in the use of bamboos for economic purposes such as crafts, charcoal and gas (for fuel), human consumption, housing construction including flooring, panelling, roofing and veneers as well as paper, oil and the production of textiles for the clothing industry which will result in an increase in demand for bamboo plantations (Lobovikov et al., 2007). While the culms are harvested for these various applications the leaf litter is often overlooked in carbon inventories (Zhou et al., 2008). In this study we examine the PhytOC content in the leaf litter fraction of ten economically-important clumping bamboo species in China. While PhytOC has been shown to be an important long-term soil carbon fraction (Parr and Sullivan, 2005), the potential of bamboo, a known silica accumulator plant, to securely biosequestrate carbon through this process has not been examined previously.

Materials and methods

Plant material

In this study bamboo species were used to examine the variability of the yields of plant silica and PhytOC within ten economically important species and to examine the relationship between these two characteristics. The importance of variability of PhytOC content within different cultivars of the same species is that such variability would allow, by the selection of a high PhytOC yielding species or cultivars over a lower yielding species or cultivars, to increase the rate of terrestrial carbon securely sequestered in PhytOC (Parr et al 2009).

Living leaf samples were collected from ten different sympodial (clumping) bamboo species of economic importance that had been established for approximately eight years.

Sampling of plant material

In most commercial bamboo applications the shoots and culms are harvested for consumption, the production of building materials or textiles. The leaf litter from new growth and the harvested culms generally is returned to the soil. In this study we have focused on the PhytOC component contained within the leaf litter. The accumulation of silica has been found to be greater in plants at maturity than in juvenile plants (Motomura et al., 2002; Norris and Hackney, 1999; Parr and Kerr, 2007), so to ensure valid comparison and to gain maximum accumulation contents, only the mature leaf samples from each bamboo species were collected and analysed (Table 1). Soil under each species were acidic (pH 4.0 to 5.5).

Phytolith occluded carbon analysis

The method used in this study for the isolation of phytoliths from duplicate leaf samples is a microwave digestion process described in (Parr et al., 2001). The basic method adopted here is a modified version of a stepped microwave digestion process (Parr et al., 2001) for plants and for soil samples (Parr, 2002) this process was followed by a Walkley-Black type digest (Walkley and Black, 1934) to ensure extraneous organic materials in the samples were removed. The absence of extraneous organic materials in the samples was checked by optical microscopic examination. This is a similar method to that used in the preparation of phytoliths for radiocarbon dating (Parr and Sullivan, 2005; Wilding, 1967). The phytolith isolates were then dried and weighed to obtain plant silica yields. The phytolith isolates were then combusted in an Elementar CNS analyser to determine carbon contents. The PhytOC results for duplicate leaf samples were combined and the mean percentage calculated.

Annual leaf litter deposition rates were not available for the study sites. Published data describing typical yields of two of the bamboo species were used in conjunction with the relative PhytOC yields (% biomass by weight) to provide estimates of the potential annual PhytOC yields in tonnes e-CO_2 ha^{-1}. Published data of annual leaf litter deposition rates for the remaining bamboo species consist of highly variable leaf litter accumulation rates for different geographical locations and species. Estimates of leaf litter accumulation rates in mature bamboo stands range from 1 to 37 t/ha (Kleinhenz and Midmore, 2001; Peng et al. 2002; He et al. 2003). Using the published data for two species and the potential range based on the above leaf litter accumulation rates, the PhytOC percentages per hectare were then quantified and compared (Parr and Sullivan, 2004).

Results

The phytolith extraction methods used in this study are designed to completely remove all organic material from the leaf-litter of each bamboo species and all available organic material from soils apart from that within the phytolith fraction give (Parr, 2002; Parr et al., 2001; Walkley and Black, 1934). Both the silica content and the PhytOC content of leaf-litter show significant variation between species (Table 2). The phytolith content for the ten bamboo species varied from between 8% and 28% of the original mass of leaf-litter material (Table 2).

There was considerable variation in the phytolith carbon contents of leaf-litter material for each bamboo species, ranging between of 1.60% and 4.02% (Table 2).

The total carbon (TC) content of soil samples taken from the base of each bamboo species ranged from 0.26% to 6.80% and the PhytOC content of the soil samples ranged from 4% to 100% of the total soil carbon content (Table 3).

Discussion

Both the silica content and the PhytOC content of the leaf-litter show significant variation and there was a relatively strong negative correlation between the two variables (Figure 1). These results suggest that it is the efficiency by which carbon is encapsulation within the phytoliths rather than the quantity of silica uptake by the plant that determines the relative PhytOC yield.

The high variability of PhytOC content for the different species used in this study provides some opportunity to increase the amount of bio-sequestered carbon. For example, the PhytOC content of leaf-litter for the lowest yielding species contained 1.60% and the highest yielding species 4.02%, a relative difference of 251% (Table 2). For the two species of which the leaf-litter data per hectare have been determined in a study, *Dendrocalamus latiflorus* and *Phyllostachys pubescens* the PhytOC accumulation rates were 0.030 t-e-CO2 ha-y^{-1} and 0.102 t-e-CO2 ha-y^{-1}, respectively, a relative difference of 340%. These data indicate that if 1) high PhytOC yielding bamboo species are grown over lower PhytOC yielding bamboo species under 2) conditions that are conducive to the production of biomass, then the amount of carbon being securely bio-sequestered (in phyoliths) could be substantially increased.

There are several factors a land manager would need to take into account (e.g. location, disease resistance, yield and the end use or application of the bamboo etc) prior to planting a bamboo plantation. If for example a land-manager chose to grow *Phyllostachys pubescens* over *Dendrocalamus latiflorus* there would, assuming the published leaf litter deposition rates apply, be as a direct result of that decision, an increase of 0.072 t-e-CO2 ha^{-1} of additional securely sequestered carbon in phytoliths each and every year for that plantation.

The ability to isolate and accurately quantify this carbon fraction for each bamboo species prior to its incorporation into soils is a distinct advantage for carbon accounting purposes because it bypasses many of the potential problems discussed earlier that are associated with the measurement of soil carbon (García-Oliva and Masera, 2004; McKenzie et al., 2000; Skjemstad et al., 2000).

In this paper we have 1) discussed methods of plant and soil carbon quantification and 2) demonstrated that the ability to accurately quantify the PhytOC carbon fraction in the leaf litter fraction for each bamboo species prior to incorporation into soils is possible. This latter point provides a distinct advantage for bamboo plantation and/or land managers wishing to quantify and trade in soil carbon. The results also show that the quantity of carbon occluded in phytoliths varies considerably between different bamboo species. This indicates that substantial quantities of carbon could be sequestered securely by choosing to grow bamboo species that have high PhytOC yields over those that have low PhytOC yields as well as by maximising biomass production. For example, if a land-manager chose to grow *Phyllostachys pubescens* over *Dendrocalamus latiflorus* (assuming

the published leaf litter deposition rates apply), an increase of 0.072 t-e-CO2 ha^{-1} of additional securely sequestered carbon in phytoliths could be achieved annually. Thus the selection of specific species of bamboo with high phytolith occluded carbon levels and/or the appropriate management of that bamboo to maximise biomass production, could substantially increase the terrestrial sequestration of carbon .

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Table 1. Corresponding sample number for each bamboo species and sample collected at the Fuzhou City, Fujian China site.

Sample	Scientific name
1	*Dendrocalamopsis basihirsuta* (McClure) Keng f. et W. T. Lin
2	*Bambusa pervariabilis* McClure
3	*Bambusoideae cerosissima* McClure
4	*Thyrsostachys siamensis* (Kurz ex Munro) Gamble
5	*Bambusa ienta* Chia
6	*Phyllostachys pubescens* Mazel ex H. de Lehaie
7	*Dendrocalamus latiflorus* Munro
8	*Dendrocalamus minor* var. *amoenus* (Q.H.Dai et C.F.Huang) Hsueh et D.Z.Li)
9	*Bambusa multiplex* cv. *fernleaf* R.A.Young
10	*Bambusa vulg*aris var. *striata* Gamble

Table 2. Bamboo species, percentage of silica (Si) post-digestion to original plant sample dry weight and percentage of phytolith occluded carbon (PhytOC) post-digestion.

Bamboo species	**Si** (%)	**PhytOC/Si (%)**
Dendrocalamopsis basihirsuta	21.27	2.40
Bambusa pervariabilis	28.03	1.60
Bambusoideae cerosissima	9.34	4.02
Thyrsostachys siamensis	21.56	1.83
Bambusa ienta	13.71	3.82
Phyllostachys pubescens	15.82	3.00
Dendrocalamus latiflorus	8.15	2.99
Dendrocalamus minor var. *amoenus*	13.01	3.18
Bambusa multiplex cv. *fernleaf*	13.19	3.35
*Bambusa vulg*aris var. *striata*	11.33	3.39

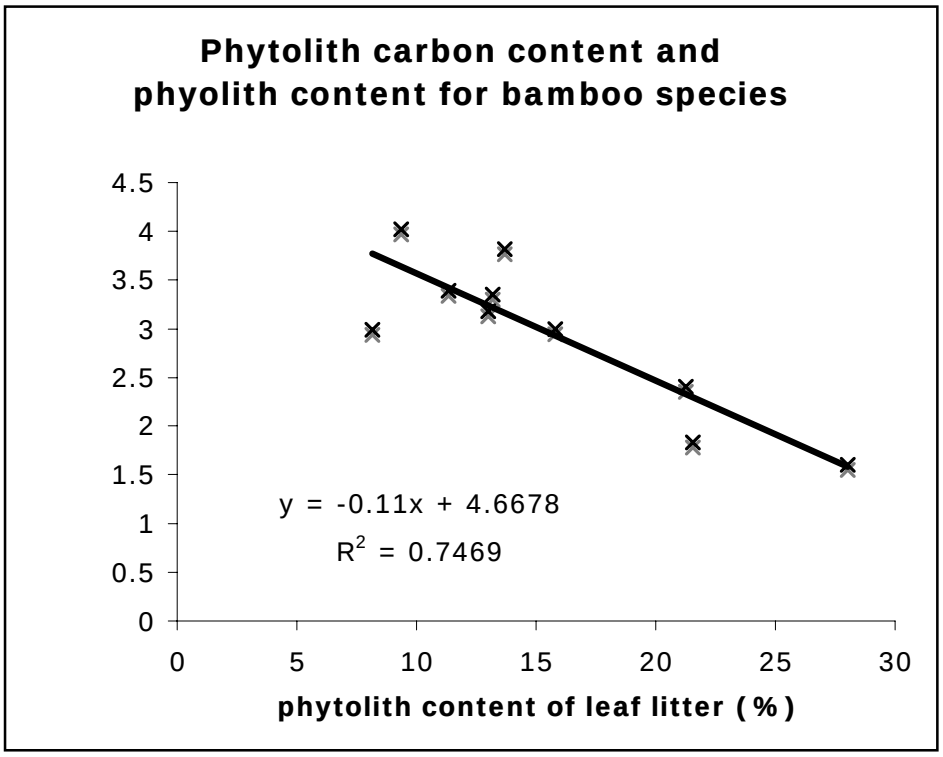

Figure 1. Phytolith carbon content and phytolith content.

VOLUME 4

Resources – Forestry, Plantations and Conservation

Table of Contents

Preface

This session covers forestry and conservation activities in South America, Australia, China, Japan, South East Asia, India, and Africa. The importance of silvicultural management and genetic improvement for enhancing the quality and yield of bamboo are highlighted. Innovative strategies for preserving natural stands are demonstrated, and the impact of bamboo flowering on forests and land use is thoroughly analyzed. Problems and potential solutions related to the protection and enrichment of the resource base are discussed in detail by several speakers. The challenges that face bamboo resources on the policy level are addressed. Likewise, the issue of financing bamboo plantation development, particularly by small landholders, is tackled constructively. The benefits that bamboo forests and plantations provide to the environment is a theme that underlies the presentations of this session.

The session is chaired by Victor Brias and co-chaired by Inder Dev Arya.

Victor Brias is known in the bamboo world as the founder of the popular Bamboo-Plantations Discussion Group (www.bamboo-plantations.com). He has an international background; he is a Spaniard who was born in the Philippines, where he lived for 25 years. He lives in Belgium where he is employed as the Project Development Manager for Oprins Plant N.V. (www.oprins.com), a company in the province of Antwerp that is specialized in bamboo. He is a consultant to the United Nations Industrial Development Organization and has been involved in bamboo projects around the world for many years. His academic background is neither in agronomy nor forestry. He holds a Ph.D. is in philosophy and a Masters degree in Finance. In his own words: "What I know about bamboo and forestry, I have learned through reading, professional experience, and networking. I love bamboo, and work with it every day!"

Inder Dev Arya holds a Ph.D. in Genetics. He currently heads the Forest Genetics & Tree Breeding Division at the Arid Forest Research Institute (www.afri.res.in) at Jodhpur, India, where he is working on the genetic improvement and mass propagation of bamboo using tissue culture techniques. He has been devoted to bamboo research for the last 2 decades. Under his leadership, his research group has developed tissue culture protocols for 7 bamboo species, 3 of which have been extensively used for mass propagation. Dr. Inder Arya is popularly known for the development and establishment of edible bamboo *Dendrocalamus asper* in India. Thanks to his efforts, this edible bamboo species has been established in many parts of India and is being multiplied in millions by commercial companies, NGOs and research institutes.

Planning, Designing and Implementing a Jati Bamboo (*Bambusa tulda*) Plantation Scheme through Bank Credit on Small Landholder's Revenue Wastelands in Assam, India for Sustainable Livelihood

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Abstract

National Bank for Agriculture and Rural Development (NABARD) is a developmental bank and provides credit for promoting sustainable agriculture including bamboo cultivation.Hindustan Paper Corporation in Assam uses bamboo as raw materials but faces difficulties in procuring bamboo from forests due to inaccessibility, hence desired seedling based bamboo cultivation under farm forestry and approached NABARD for suitable credit schemes for small land holders. Accordingly it prepared a scheme for raising seedling based ***Dendrocalamus strictus*** plantations. However, the farmers were not interested to raise bamboo through seedlings, rather they requested NABARD for ***Bambusa tulda*** cultivation scheme through rhizomes. After undertaking field visits, holding workshops with NGOs, farmers and bankers, a rhizome based scheme for intensive cultivation of bamboo was formulated for the districts of Assam. The scheme was exclusively designed for farmers who could spare at least one bigha (1 / 3 acre) of wastelands and the cost of cultivation was Rs. 9050 over a period of 4 years (1 US$=INR 50). 85 bamboo rhizomes were planted per bigha with spacing of 4 m x 4 m and in every alternate year 40 clumps would be harvested annually from 5th year onwards. Based on an average price of Rs. 20 per bamboo, income would be Rs. 6400 in 5th year, reaching to Rs. 16,000 in 10th year on retail sale . The interest charged on loan by bank was 8% per annum and IRR of the scheme was 37%. Implementation of the scheme started during 2006-07 and more than 100 farmers were provided loans by Assam Gramin Vikas Bank. Repayment of loan with interest would be completed within 8 years. The financial outlay of the scheme was Rs. 48.86 million for developing 1800 acres of small farmer's wastelands. The scheme can be replicated in other districts of Assam.

Keywords: Bamboo, small landholders, credit, sustainable livelihood

Introduction

NABARD is a national level institution for providing and regulating credit and other facilities for the promotion and development of agriculture, small scale industries, cottage and village industries, handicrafts and other allied economic activities in rural areas. It is responsible for supervision of rural co-operative credit structure

and regional rural banks in the country. It also provides refinance to these institutions for their lending activity in rural areas and gives loans to state government for creation of rural infrastructure.Although Forest Departments and Forest Development Corporations (FDCs) have traditionally raised bamboo on degraded forest lands, farmers have also started raising bamboo on farmlands, however, scientific and systematic cultivation of bamboo is a recent trend. In fact bamboos are known in India more for utilization rather than cultivation. Traditionally, bamboos have been used as raw materials by the paper making industries. But as little importance was given for raising plantations, bamboo became already scarce and the industry had to augment bamboo supply with alternative sources of raw materials such as fast growing trees like ***Eucalyptus sp., Acacia sp., Casuarina sp., Leucaena s****p*. etc. In spite of this, for producing quality paper, certain percentage of bamboo mix in the raw material is considered essential, thus compelling the industry to procure bamboos from far-flung places, which has become rather uneconomical due to transportation costs. This has necessitated raising of bamboo plantations on farm lands under Farm forestry and Agroforestry.

Potential for Bamboo

India is one of the richest countries in bamboo population with about 75 genera and 136 species, out of the total 1250 species of bamboo found in the world. The North Eastern Region alone hosts about 90 species under 13 genera (Bhuyan, 2003). Bamboo development is viewed as a program for eco-restoration, economic development, employment generation and livelihood security. These multipurpose species have enormous potential which have only been partly harnessed. There are at least 1500 recorded uses of bamboo. The important usages are mainly in paper industry, building material, tiny and cottage industries, handicrafts, medicinal products, edible shoots and new generation products such as wood substitutes, truck bodies, railway carriages, bamboo boards, tiles etc. In Assam the major traditional industrial use of bamboo is for paper manufacture by Hindustan Paper Corporation Ltd. which functions through its units in Panchgram and Nagaon. It is now increasing its capacity to 800,000 tones p.a. from the present level of 320, 113 tones. Despite its versatile utilities, bamboo in India is currently faced with a number of problems, especially within forest area, such as poor management, low productivity (about 1-2 tonnes per hectare), over exploitation of the available stock, gregarious flowering etc. There is also increasing pressure on forest areas for procurement of bamboo as raw material for industrial uses. These problems invite attention for organised cultivation of bamboo both inside and outside forest areas. In Assam, there is practically no organised cultivation of bamboo. Most of the requirements of raw materials are met through procurement from forests and the bamboos cultivated by farmers on their homestead lands are mainly for their own personal use and consumption.

The Planning Commission, Govt.of India, in the report of the National Mission on Bamboo Technology and Trade Development (2003) suggested raising 2 million ha bamboo plantation during the Xth Five Year Plan and 4 million ha in XI five Year Plan period and had estimated fund requirements of Rs.26,080 millions for the Xth Five Year Plan (2006-07) period. The estimated demand is 26.69 million ton against the supply of 13.47 million ton. A two pronged strategy was suggested to meet the gap i.e. proper harvesting from forest areas and fresh plantations in 6 m ha of degraded forest lands / wastelands. Later in 2006, Indian Govt. approved National Bamboo Mission which recommended to raise 88,000 ha bamboo plantations each in forest and non-forest areas through a centrally sponsored scheme.

As indicated earlier, the major industrial use of bamboo in the country is paper manufacturing. The paper industry requires about 6 million tons of bamboo for improving its installed manufacturing capacity utilization. Non availability of bamboo is the main reason for low consumption which offers scope for increased utilization of bamboo by paper mills which are currently operating at 41% of installed capacity. Paper mills should therefore enter into buy-back arrangements with bamboo growers outside forest areas to ensure sustained supply of raw material. It is significant to note that the import of pulp costs about Rs. 38000 million annually (1US$ = INR 50).One of the characteristic features of bamboo is its suitability for cultivation in wastelands. Farming in Assam is mostly rainfed and the farmers are not technologically well -equipped. Also input application is minimal. Bamboo, with its wide adaptability, hardy nature, therefore, best suits cultivation in this situation. The project being implemented in the districts of Nagaon, Morigaon and Kamrup have available wastelands of more than 20,000 hectares; hence bamboo development in 1800 acres will not pose any problem so far as availability of land is concerned.

The project

It envisages commercial cultivation of bamboo in about 5400 bighas (1800 acre) of wastelands in Nagaon, Morigaon and Kamrup districts of Assam, through financial support from 3 Banks viz. Assam Gramin Vikas Bank, United Bank of India, and State Bank of India in these districts through their branches in the respective blocks. The total financial outlay of the project is Rs.46.20 million involving a bank loan of Rs.41.58 million. The purpose of bamboo cultivation is to utilize the wastelands in the districts for increasing productivity which are not put to use by farmers. Further, there has been no or negligible credit flow to the Forestry sector in the State for want of viable and bankable projects. The project therefore envisages extension of technology besides financial assistance by Banks. There is a big local market for bamboo in the districts. In fact the Nagaon Paper Mill is located nearby. Besides, new industries like Koson's Forest Products has come up in Amingao near Guwahati which requires large number of desired variety of bamboos. Thus marketing will not be any problem for the bamboo produced under the project, especially because the project will produce Jati bamboo (***Bambusa tulda***) which is not only favored by the farmers but also by the industries.

The project objectives are :

I. To encourage bamboo cultivation in small holder's waste lands in possession of farmers in three districts of Assam viz. Nagaon, Morigaon and Kamrup for ecorestoration, economic development, employment generation and livelihood security.

II. To encourage flow of bank finance to the hitherto neglected but potential sector of forestry in Assam

III. To augment raw material requirements of new generation bamboo based industries.

IV. To increase green forests in the non-forest areas of the state

The partners

The implementation of the project involves the active participation of the farmers, banks and NABARD. These agencies are expected to work in close coordination for effective implementation of the project. The responsibilities of each of these agencies are explained in the following paragraphs.

Farmers:

The number of farmers identified under the project is approximately 2500 to cover an area of 5400 bighas (1800 acres, 1 bigha = 1/3 acre) in three years. The land holding of these farmers ranges from 1 bigha to 10 bighas. However, for the project, a minimum unit of one bigha wasteland is required for raising bamboo. As it will be too ambitious to convert agricultural lands for bamboo cultivation due to food security concerns, available waste lands in possession of the farmers only were selected. The obligations on the part of the farmers are : (i) agree to raise bamboo in his plot with rhizomes which are available in plenty in the locality,(ii) the farmers agree to meet necessary input costs of labour, manures, fertilizers, insecticides, fencing etc on his own through bank loan and (iii) repay the bank loan after moratorium period. A few progressive bamboo farmers were identified to arrange for supply of healthy rhizomes for selected farmers of the project.

Banks :

The major banks i.e Assam Gramin Vikas Bank (AGVB), State Bank of India (SBI) and United Bank of India (UBI) were considered under the project although other banks could participate if they are interested in the project. This was done after undertaking field visits with the bank officials in all the three districts. The obligation on the part of the bank will be to encourage the farmers to take up bamboo plantations, extend financial assistance to the identified borrowers and ensure repayment through the proceeds of sale of bamboo by proper vigil from time to time. However, only Assam Gramin Vikas Bank participated in funding the scheme.

NABARD:

It identified wasteland development as a thrust area for rural development. NABARD, as an apex institution in rural credit structure will act as a facilitator for credit flow by way of preparation of project, educating the bankers for bamboo plantations by arranging workshops, advising the bankers for extending finance for bamboo cultivation and creating awareness among all concerned. Apart from the above promotional activity, NABARD will extend refinance support to banks at 100% of bank loan at 6.5 to 7.0 % rate of interest.

Technical aspects

Climate :

A majority of the bamboo thrive at temperature ranging from 8 to 36^0C. Rainfall is an important factor and the minimum threshold precipitation required is 1200 per annum. The rainfall range for bamboo cultivation is very wide ranging from 1200 to 4050 mm per annum. Assam is a high rainfall zone with normal rainfall being more than 1772 mm per annum, hence is suitable for commercial cultivation of bamboos.

Soil :

Most bamboos are found in sandy loam to loamy clay soil, derived form river alluvium or underlying rock. Although bamboo, like other commercial crops prefer a well drained soil, it is observed even in swampy soils and wet stream beds. The soils of the districts vary from clay to clay loam to sandy loam and soil reaction is acidic with pH of 4.5 to 7.0. A luxurious growth of bamboo is a common feature in the districts and therefore the soil and climatic conditions are best suited for cultivation of bamboo.

Species:

Among many indigenous bamboo species growing in Assam, only 2 species are cultivated by farmers viz, ***B. tulda*** and ***B. balcooa***. However, the most common bamboo available in the districts and most favored by the farmers is jati bamboo ***B. tulda***. So it is proposed to plant only jati bamboo for the present project.

Planting Material:

There are various methods of propagating bamboo viz. through seed and vegetative methods including tissue culture. The vegetative method i.e mainly rhizomes have been considered under the project because this is not only the traditional method of bamboo cultivation, but also most favored by the farmers because of quick yields. Besides, the progressive bamboo farmers have been identified for supplying rhizomes to the farmers. It has also been observed that plenty of rhizomes are available in the project areas.

Raising of the plantations:

The planting will be taken up during the period January to March. Pits of 60 cm3 will be dug and FYM will be put inside the pits before the Rhizomes are planted at a spacing of 4m x 4 m. The number of plants per bigha is estimated at 85. A provision has been made for casualty replacement in the second year to the extent of 10%.

Fencing :

Live hedge fencing has been recommended as it is essential to protect Bamboos in initial years from grazing by stray cows and goats, because bamboo leaves are fodder and voraciously eaten by the animals.

Fertilization :

Bamboo is a heavy feeder and therefore, even rich soils might becomes depleted after a few years if no fertilizer is added. Although fertilizers may be applied at any time in the year, it is preferred to apply fertilizer after harvest and before irrigation. It should be noted that rhizomes continue to be active (growing) except during the coldest part of the year. It is therefore proper to apply small quantities of fertilizer round the year rather than in one/two large doses. Bamboo responds well to nitrogen and potassium which are found in compost, green manure, wood ash and chemical fertilizers. Lime is often applied to neutralise soil acidity.

Irrigation :

The area receives adequate precipitation for successful bamboo plantation hence no irrigation is proposed except protective irrigation during the dry months in initial years. It would be desirable if irrigation is given at least once in a month during dry period.

Plant protection :

Bamboo is generally free from pest and diseases, however, diseases such as rhizome rot, bamboo blister, shoot and culm borer, are observed sporadically. Timely application of systemic fungicides and pesticides will control the problems.

Weeding :

Bamboo plantations receive more sun because of the relatively wide separation of the culms. Sunlight encourages the growth of weeds which consume nutrients intended for bamboo and shade the ground, lower the soil temperature and thus retard shoot emergence. Regular weeding during the 1st three years is a necessity for vigorous growth of bamboo.

Pruning :

Bamboo grows vigorously and many branches develop on the culms along with thorns. It is therefore necessary to prune the undesirable branches to maintain the healthy growth of the harvestable culms.

Intercropping :

The gestation period in bamboo plantation (through rhizome) is 4 years. During the first two to three years, it is possible to cultivate intercrops such as turmeric, ginger, chilli etc.

Harvesting and yield :

The annual yield of a bamboo clump depends on the number of new culms produced each year. This in turn is related to the production of young rhizomes. Culms mature after two to three years. To maximise production some shoots must be left each year to develop into leafy young culms. On an average bamboo produces 10-20 culms in a year under good growing conditions. Considering a 30 year life cycle, one clump may produce 300-600 culms.

The harvesting can be done from the fourth year onwards, however, for commercial production, harvesting will start from the fifth year under the project on a rotational basis every alternate year from each clump. So in the 5th year it is proposed to harvest bamboos from 40 clumps and the remaining 40 clumps will be harvested next year. In the first year of harvest i.e., fifth year, 8 culms per clump will be harvested followed by 10 culms in sixth year, 12 in seventh year, 15 in eighth year, 18 in the ninth year followed by 20 culms from tenth year onwards.

Financial aspects:

Unit cost-

The unit cost for raising small holder's bamboo plantation (1 bigha) is Rs.9,050 spread over a period of four years. The various assumptions for arriving at the unit cost are given in Table no. 1.

Table-1: Unit cost for intensive cultivation of bamboo in one bigha (1/3 acre) wastelands of Assam

Sl. No.	Particulars of Work	Unit	Cost (Rs.) in Years			
			1	2	3	4
1	Clearing of Jungle, land preparation etc. (MDs)	10	600	-	-	-
2	Digging of Pits (60 cm3) MDs	10	600	-	-	-
3	Live hedge fencing including maintenance	Lumpsum	300	100	100	100
4	Application of Organic manure and Fertiliser	Lumpsum	250	250	250	250
5	Cost of Rhizome including transport (85+10)	Rs.30	2550	300	-	-
6	Cost of Planting rhizome (MDs)	5	300	-	-	-
7	Weeding cum Soil Working (MDs)	6	360	360	300	300
8	Protective Irrigation	Lumpsum	250	250	-	-
9	Plant protection measures	Lumpsum	100	100	100	100
10	Prunning-tending/cleaning (MDs)	2	120	120	120	120
11	Cost of intercropping	Lumpsum	200	200	-	-
	Total		5630	1680	870	870
	Unit Cost	9050				

Labour rate = Rs.60 per MD Espacement = 4m X4 m = 85 rhizomes / unit

Survival = 80 rhizomes / unit of 1 bigha Cost of rhizome= Rs. 30

Income: Harvesting commences from the 5th year onwards which will be done every alternate year with 50% survival of clumps i.e. 40 clumps per year. The sale price per bamboo is considered at Rs. 20 which is a conservative estimate. The income details are given in the Table no.2

Table-2: Income estimates for intensive bamboo cultivation in one bigha(1/3 acre) wastelands of Assam

Year	No of harvestable culm /clump	Total culms per bigha	Income @ Rs. 20 per culm	Yield in ADMT(@15 kg/culm)	Income @ Rs 1200/ADMT)
V	8	320	6,400	4.8	5,760
VI	10	400	8,000	6	7,200
VII	12	480	9,600	7.2	8,640
VIII	15	600	12,000	9	10,800
IX	18	720	14,400	10.8	12,960
X onwards	20	800	16,000	12	14,400

Financial analysis

The project is technically feasible and financially viable with the above cultivation practices, expenditure and income levels. The financial indicators for one bigha bamboo plantation are provided in Table no.3

Table-3: Economics / Financial Analysis for intensive cultivation of bamboo in one bigha (1/3 acre) wastelands of Assam

Yeas	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Total Income	0	0	0	0	6400	8000	9600	12000	14400	16000
Total Cost	5630	1680	870	870	870	870	870	870	870	870
Net Income	-5630	-1680	-870	-870	5530	7130	8730	11130	13530	15130

Financial Indicators

Discount Factor	15%
NPV of Cost	9118
NPV of benefits	22221
NPV of net benefits	13103
BCR	2044
IRR	37%

Repayment period

The bank loan was considered at 90% of the unit cost i.e. Rs. 8,145/-. Income generation from the activity will commence from the 5th year onwards. The interest accrued during the gestation period will be deferred. The repayment of principal with deferred interest will be for four years i.e., 5-8th year of plantation, the details are provided in Table no.4

Table-4: Amount of Bank loan and Repayment schedule for intensive cultivation of bamboo in one bigha (1/3 acre) wastelands of Assam

Years	Unit Cost	Bank Loan @ 90%	Rate of Interest
1	5630	5067	8 %
2	1680	1512	
3	870	783	
4	870	783	
	9050	**8145**	

Years	Loan disbursed during the year	Total loan outstanding at the end of the year	Interest accrued during the year	Cumulative interest	Loan repayment				Income	Surplus
					Principal	Accrued interest	Interest	Total		
1	5067	5067	507	507	0			0		
2	1512	6579	658	1165	0			0		
3	783	7362	736	1901	0			0		
4	783	8145	815	2715	0			0		
5		8145	815	3530	1500	882	815	2315	5530	3216
6		6645	665	2647	2000	882	665	3547	7130	3583
7		4645	465	1765	2500	882	465	3847	8730	4883
8		2145	215	882	2145	882	215	3242	11130	7888
	8145				**8145**					

Discussion

Because of their very fast growth, bamboos fit well in the bank's lending systems. Returns on bamboo investments are comparable with any other method of farming systems. Annual income from bamboos after a short period of gestation, makes them suited for Farm / agroforestry on small land holdings of small and marginal farmers. Within such bamboo plantations, intercrops like soybean, zinger, turmeric, mustard & various medicinal plants can be successfully cultivated at least for two years, which also gives substantial income to the farmers. In fact, with ***Bambusa vulgaris***, a family continues to get a steady annual income for several decades (Chaturvedi 1986). With little planning and efforts, the bamboo poles can be converted into several bamboo products, fetching better price, thus assisting the poor families in improving their economic status. The present scheme promoted by NABARD aims at commercialization of Bamboo in an area where, so far, no commercial Forestry projects have been successful. As there is a demand for bamboo among farmers and paper mills, the project showed positive results. Bamboo in India is not cultivated under any organised system and sometimes farmers face difficulty in marketing; on the other hand, the artisans face problems in procuring bamboo easily. These aspects have been taken into consideration in the scheme. Overall, there is a good scope of raising bamboo through institutional credit in India **(**Haque 1997, 2002; Karmakar and Haque 2004). The bamboo plantation technology is now well established, therefore, the introduction and cultivation of desired bamboo species in the pattern of agroforestry is the need of the hour. *Bamboo - the poor man's timber,* has the capacity to improve the economic condition of vast members of the rural poor of India **(** Haque 2004). As the supply diminishes, there is a need for a major thrust to restore and enlarge the production base **(**Karki "et. al" 1997). During the past 50 years of India's independence, bamboo received little attention compared to other timber yielding trees **(**Biswas 1997).Hopefully, the potential of bamboo in poverty alleviation is being reassessed and its cultivation and proper utilization can make rural communities of India and the country self sufficient and economically strong on wood front, as it has been achieved on the food front with the Green Revolution.It has been observed that bamboo based agroforestry models provide economic returns much faster and higher than Poplar ***(Populus sp***.) and ***Eucalyptus sp***. **(**Rawat "et al" 2002***).*** In addition, it provides ancillary benefits due to improvement of environment, flood control, soil and water conservation etc.

The Planning Commission, Govt.of India (2001) had identified Bamboo as one of the 6 species for agroforestry plantations. It advocated the use of Clonally Propagated Cutting (CPC) of ***D. strictus***, ***B. tulda*** and ***B. vulgaris*** besides those of ***B. nutans*** for cultivation. It also recommended the research work for selection of plus culms for quality pulp, early and every year flowering, good height and diameter growth including high biomass production per unit basis. The National Mission on Bamboo Technology and Trade Developmentnt (2002) had also recommended identification of potential bamboo for plantation in different agroecological regions, technology upgradation including mass production by tissue culture, plantation technology standardization for afforestation of wastelands, and establishment of primary and secondary processing units of bamboo for value addition, employment generation and poverty alleviation. NABARD supports all bamboo based activities that improve the economic condition of the rural poor in the North Eastern Regions (Haque 2004).The North East has a special significance with respect to bamboo, as about 60% of the bamboo resources of India and 20% of the world are available in the region **(** Salam 2006). Victor Brias (2005) had recommended that since North East India has the highest concentration of bamboo in the world, by blending modern technology and by cutting across boundaries, bamboo can be used as a universal assets. NABARD is also exploring the possibilities of

promoting new bamboo projects through Forest Development Corporations(FDC) .It has already sanctioned a major bamboo project to the Andhra Pradesh FDC for raising bamboo plantations on 5400 ha degraded forest lands. The major problem faced by NABARD in this venture is the non-availability of quality planting stocks. Bachpai (2005) undertook growth studies on 15 clones of ***B. tulda*** selected from Assam and Meghalaya States. It was indicated that there were significant differences among genotypes for all the parameters viz. height, diameter at breast height (dbh) and age. The authors concluded that there is an opportunity to select the best plus clumps for further production of improved planting stocks for afforestation and other plantation programmes.

Conclusion:

The scheme faced difficulties in implementation stage, because Govt. of India announced simultaneously a subsidy based bamboo plantation scheme on farmer's land under National Bamboo Mission (NBM), which remained a total non-starter for non-forest land development. Because of wide variations in costs of cultivation in NBM scheme, the author and his team prepared three models and sent to NBM for implementation (Karmakar, Haque and Kumar, 2008). The present paper proved beyond doubt that there are possibilities of channeling credit to small farmers for intensive bamboo cultivation under homestead farming system.

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Genetic Improvement and Conservation of Bamboos in India

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Abstract

Bamboo is woody grass belonging to the sub-family *Bambusoideae* of the family *Poacae*. There are more than 1,250 species under 75 genera of bamboo worldwide, which are unevenly distributed in the various parts of the humid tropical, sub-tropical and temperate regions of the earth. India has the largest area and the second largest reserve of bamboo in the world today. There are 124 indigenous and exotic species, under 23 genera, found naturally and/or under cultivation. In spite of rich diversity, the productivity of bamboo forests in India is very low i.e. 4.5 million tones per year. Bamboo today is a major non-wood forest product and wood substitute and also important from socioeconomic and cultural point of view. Quickly changing its image from the "poor man's tree" to a high-tech industrial raw material and wood substitute, bamboo is globally recognized now as an increasingly important economic asset in poverty eradication and economic & environmental development. The ever-increasing demand for bamboo due to various reasons is not commensurate with the current demand of bamboo materials. The main reasons for the gap are: low productivity of bamboo forests and plantations, inadequate supply of quality planting stock and lack of scientific advancement in plantation technology. Hitherto there is a need of raising improved bamboo planting stock to enhance the productivity of the species for which a systematic approach for bamboo improvement starting from exploration, collection, preservation and evaluation of the germ-plasm is essential. A bamboo improvement programme consisting of selection of bamboo plus clumps, collection and conservation of plus clumps in germ-plasm bank, standardization of mass multiplication techniques of improved propagules, standardization of silvicultural & plantation management practices, and multi-location trial of the selected germ-plasm to test the genetic worth of superior bamboo germ-plasm are in progress at various research Institutes all over India to meet the ever increasing demand of bamboo raw material. The results of the bamboo improvement programme are very encouraging, however, results of multi-location trials are still awaited, the outcome of which can be used in further deployment of productive clones in specific areas of the country.

Introduction

Bamboo is woody grass belonging to the sub-family *Bambusoideae* of the family *Poacae*. There are more than 1,250 species under 75 genera of bamboo worldwide, which are unevenly distributed in the various parts of the humid tropical, sub-tropical and temperate regions of the earth. 'Bamboo' the poor man's timber is one of the most important forestry species with wide distribution throughout the India. India has the largest area and the second largest reserve of bamboo in the world today. A very large standing resource is found mostly in moist and deciduous forests in all the states except Jammu & Kashmir. Of India's total forest area of 67.7 million

hectares; bamboo (both natural and planted) occupies around 11.4 million hectares. This represents 16.7 percent of the total forest area of the country and 3.4 percent of the total geographical are (329 million hectares) of India (FSI 2003). Bamboo constitutes important species occurring widely in the Indian forests and forms the under-storey in the natural forests. It is found to grow practically all over the country, particularly in the tropical, sub-tropical and temperate regions where the annual rainfall ranges between 1,200 mm to 4,000 mm and the temperature varies between 16°C and 38°C. The most suitable conditions for the occurrence of bamboo are found in between 770-1,080 meter above sea level. However, two-thirds of the growing stock of bamboo in the country is available in the north-eastern states. Bamboo forms a part of a wide variety of forest types in Indian forests. It may constitute a separate forest type or sub-type or occur as brakes. The forest types/sub types in India are listed in Table 1 (Champion and Seth 1968).

Table 1. Distribution of Bamboo in different Forest types

S.N.	Forest Type No.	Forest type/Sub type	Dominant Species
1.	1/E2	West Bamboo Brakes	*Ochlandra sp*, *Bambusa sp*.
2.	2/E2	West Bamboo Brakes	*Ochlandra sp*, *Bambusa sp*.
3.	3/E2	Moist Bamboo Brakes	*Bambusa bambos, Schizostachyum kurzii.*
4.	3/2S1	Dry Bamboo Brakes	*Dendrocalamus strictus.*
5.	5/E9	Dry Bamboo Brakes	*Dendrocalamus strictus.*
6.	8/E1	Reed Brakes	*Ochlandra sp.*
7.	12/DS1	Montane Bamboo Brakes	*Sinarundinaria sp*.

There are 124 indigenous and exotic species under 23 genera, found naturally and/or under cultivation (Naithani 1993). Clump forming bamboo constitute over 67% of the total growing stock, of which *Dendrocalamus strictus* is 45%, *Bambusa bambos* 13%, *D. hamiltonii* 7%, *B. tulda* 5% and *B. pallida* 4%. All other species put together are 6%. *Melocanna baccifera*, a non-clump forming bamboo, accounts for 20% of the growing stock and is found in the north-eastern states of India. Bamboo falls into two main categories according to growth pattern, (i) sympodial or clump forming, (ii) monopodial or non-clump forming, runner bamboo. North-east India supports about 50% of the total genetic resources followed by peninsular India (Eastern & Western Ghats), which accounts for about 23% of the genetic resources occurring naturally. North-western India, Indo-Gangetic plains and the Andaman & Nicobar Islands account for the remaining bamboo diversity in India.

Bamboo today is a major non-wood forest product and wood substitute and also important from socioeconomic & cultural point of view. Quickly changing its image from the “poor man’s tree” to a high-tech industrial raw material and wood substitute, bamboo is globally recognized now as an increasingly important economic asset in poverty eradication and economic & environmental development. Bamboo has always played an important economic and cultural role across Asia and its usage is growing rapidly in Latin America and Africa as well. Since the beginning of civilization bamboo has played an important part in daily lives of people in India. Bamboo craft is one of the oldest cottage industries primarily due to versatility, strength, lightness, easy

workability of bamboo with simple hand tools. Bamboo has been put to use for various applications ranging from construction to household utilities and have more than 1,000 documented uses including an important use in paper and pulp manufacturing (Anon 2008). It is an important species for landscape as it provides shade and acts as windbreak & acoustical barrier (INBAR 1997). Bamboo grows fast and matures early; the output of bamboo plantation is great and the use of bamboo stem is wide. Once successfully planted, bamboo plants keep on rhizoming, shooting and maturing every year. The annual selective cutting and sustainable utilization can be implemented without damaging ecological environment (Singh 2008).

The ever-increasing demand for bamboo due to various reasons is not commensurate with the current demand of bamboo materials. The main reasons for the gap are: low productivity of bamboo forests and plantations, inadequate supply of quality planting stock and lack of scientific advancement in plantation technology. In spite of rich diversity, the productivity of bamboo forests in India is very low i.e. 4.5 million tones per year because of many factors mentioned above and for this reason, various research institutes including National Bamboo Mission (NBM) are engaged to remove multiple constraints in bamboo sector. The shortfall in requirements can be met by improving the productivity of plantations using genetic improvement programmes and scientific management of natural bamboo growing areas & plantations. Though, research work on collection and evaluation of genetic resources of bamboos started way back during 1970's in India, but the pace of work was rather slow. A provenance trial on *Dendrocalamus strictus* was laid at Forest Research Institute, Dehra Dun. This was followed by the work on selection, evaluation and *ex-situ* conservation of several economically important bamboos of north-eastern region at State Forest Research Institute, Itanagar in the state of Arunachal Pradesh. In the era of bamboo development there is a need for raising improved bamboo planting stock to enhance productivity for which country wide bamboo improvement starting from exploration, collection, preservation and evaluation of the germ-plasm is required. Accordingly, a bamboo improvement programme consisting of the following is in progress at various research Institutes in India:

1. Selection of bamboo plus clumps
2. Collection and conservation of plus clumps in germ-plasm bank
3. Standardization of mass multiplication techniques of improved propagules
4. Standardization of silvicultural and plantation management practices
5. Multi-location trial of the selected germ-plasm

Selection of Bamboo Plus Clumps

The bamboo productivity can be enhanced manifolds by selection of superior clumps and multiplying them for use in plantations. Lot of variability exists in bamboos in phenotypic characters which can be exploited using suitable methods of quantitative genetics for improving the productivity of bamboos in the country. For the selection of bamboo plus clumps, the point grading method/selection index method (Banik 1995; Singh 2008) is to be followed, in which different points have been awarded to different traits as per the weightage in end uses e.g. more weightage should be given to internode length, being an important trait in consideration for long as well as short internode bamboo. Singh (2008) has drawn scientific guidelines for selecting plus clumps of bamboos which include survey of potential areas, selection criteria, number awarded for different traits e.g.

internode length, height, girth, straightness, number of culms/clump and disease resistance of the culms. The maximum and minimum scores of these characters are decided on the basis of the phenotypic average value of base population of the species. The total score while evaluating the candidate plus clump is fixed to 100. The candidate clump, if attains the pre decided score and more would be declared as plus clump. After that, the rhizomes/culms will be taken from the selected plus clumps for establishment of germ-plasm bank and further multiplication using various proliferation techniques for supplying improved planting stock in plantation activities. Selection of high yielding clones coupled with suitable agro techniques for raising bamboo plantation can improve bamboo productivity substantially.

Keeping such rational approach in view and using selection index method (Banik 1995) as discussed above, the superior genotypes of the priority bamboo species in Northeast India were selected and conserved in bambusetum at Rain Forest Research Institute (RFRI), Jorhat, Assam (Table 2). These plus clumps are under genetic testing in multi-location trials at different places for further recommendations and deployment in the country.

Table 2. Superior Genotypes of Bamboo at Bambusetum - RFRI

S.N.	Species	No. of Plus Clumps
1.	*Bambusa tulda*	50
2.	*B. bambos*	50
3.	*Dendrocalamus hamiltonii*	50
4.	*Bambusa balcooa*	49
5.	*B. nutans*	25
6.	*B. pallida*	25

Collection and Conservation of Plus Plumps in Germ-plasm banks

Both i*n-situ* and *ex-situ* conservation measures are being adopted to preserve the genetic resources of bamboos in India. *In-situ* conservation measures include establishment of preservation plots in every state, where the biodiversity is being periodically monitored. In addition, there are 10 biosphere reserves (Maikhuri et al. 1998), 85 national parks and 450 wildlife sanctuaries (Anon 1997), which include the natural habitat of bamboo also. The bamboos are also protected by the local people in sacred groves. The major limitations of *in-situ* conservation are that natural stands of bamboo are scattered in pockets over large areas making it difficult to declare several bamboo reserves.

Ex-situ conservation activities for preservation of important genetic resources of bamboo need more emphasis. So far these activities are limited to establishment of bambusetum and germ-plasm banks. Clumps with higher scores (as discussed in Selection of Bamboo Plus Clumps) designated as plus clumps are used for germ-plasm conservation. Germ-plasm of selected clumps in the form of off-sets/rhizomes from 1-2 years old clumps should be collected in replicates and planted in the germ-plasm banks/bambusetums. Rhizomes are dug out from the soil preferably during February to May each year. Special care must be taken during collection so that the buds

of the rhizome should not be damaged. The culms of the offsets are cut without any split in internodes above 2 nodes especially in case of *Bambusa nutans, B. pallida, B. tulda* and *Dendrocalamus hamiltonii* and above 3-4 nodes in case of *Bambusa balcooa* and *B. bambos*. To avoid desiccation, the extracted rhizomes should be covered with wet gunny bags and transported to the germ-plasm bank/bambusetum without any delay. The time between collection and plantation should be as short as possible to avoid the withering of the collected offsets and thereby to reduce mortality rate. The live collections of bamboos are now available in bambusetums at various places in India (Table 3).

Table. 3. Bambusetums in India

S.N.	Place	State	Species/Live Collections
1.	Forest Research Institute, Dehra Dun	Uttarakhand	63
2.	Rain Forest Research Institute, Jorhat	Assam	34
3.	Institute of Forest Genetics and Tree Breeding, Coimbatore	Tamilnadu	26
4.	Van Vigyan Kendra, Chessa	Arunachal Pradesh	35
5.	Arunachal Pradesh Centre Bamborium, Bashar, Siang district	Arunachal Pradesh	31
6.	Kerala Forest Research Institute, Peech, (Sub-centre at Nilambur)	Kerala	21
7.	Kerala Forest Research Institute, Peechi, (Sub-centre at Palappilly)	Kerala	51
8.	Kerala Forest Research Institute Campus, Peechi	Kerala	13
9.	Tropical Botanical Garden and Research Institute, Palode	Kerala	32
10.	State Forest Department, Begur, Wynaad Division	Kerala	12
11.	Botanical Garden, Punjab University, Chandigarh	Chandigarh	20

Recently, some more bambusetums including three by National Bamboo Mission (Anon 2008) each at Guwahati (Assam), Hyderabad (Andhra Pradesh) and Pantnagar (Uttarakhand) are planned to be set up with superior clumps and provenances of various bamboo species.

Standardization of Mass multiplication Techniques of Improved propagules

Bamboo can be propagated by conventional (seeds/rhizome/off-set planting) and non-conventional (culm/branch cuttings and macro-proliferation techniques) methods.

Seeds

Availability of seed is limited to certain specific periods only as bamboos flower only once in life time. Most of the bamboo flower in long cycles ranging from 10 years to over 60 years depending upon the species. Usually the cyclic flowering is gregarious and after flowering, the entire flowered bamboo population dies. The huge quantity of seed produced are either washed out in hill slopes during rains, or eaten by rodents (rats). The remaining seeds fallen in ideal conditions germinate to seedlings for regeneration.

Rhizome Planting

This is the most common propagation method of bamboo. The bulky rhizomes of bamboos are dug out in the rainy season and planted in the field. The use of rhizomes for propagating bamboo has been limited to non-clump forming species. However, following are some limitations of rhizome planting:

- Not easy to transport
- Meagre development of roots
- Decay of rhizomes and
- Slowness of rhizomes buds to break dormancy.

Off-set Planting

The term off-set is described for bamboo propagules each composed of the lower part of a single culm with the rhizome axis basal to it. The age of off-set should not be more than 2 years at the time of planting for better results. Propagation of bamboos by off-set planting is very common method in villages of Assam. Both age of the off-sets and their collection time have significant effect on their survival and growth after field plantation (Banik 1991). More success is obtained when off-sets are collected and planted in the month of April before rainy season. Two nodes of the culm with rhizome are sufficient for better survival of the off-sets in field. These should be planted immediately after the excavation from mother clump and should be kept in moist gunny bags during transport.

Culm or Stem Cutting

Propagation of bamboo through culm or stem segments is known as culm cutting or stem cutting technique. Generally culm segment of bamboos of 1 or 2-3 nodes bearing healthy buds or branches used for propagation. Culm cutting should be taken from 1.5-2 years old healthy mother culms during February- April. The thin walled top one third portions of the segments should be discarded for better results. Rest of the culm is used to make either single nodded or two-noded cuttings depending on species (two- nodded in *Bambusa tulda, B. nutans,, Dendrocalamus hamiltonii* and one nodded in *Bambusa balcooa*). The clums are cut in such a way that about 5 cm culm length is retained on either side of the node/nodes. The leafy branch lets are trimmed to about five cm length. Cuttings with dried and damaged buds must be discarded. After 200 ppm IBA treatment, cuttings will be planted in raised beds under partial shade (Pathak et al. 2008).

Branch cutting

In thick walled bamboo species having prominent primary branches, branch cutting is the ideal planting material. The small size of cutting and extraction of more cuttings without damaging the mother clump, make this method more advantageous. Branch age should be 0.5-1year for better results. The planting practice is the same as for culm cuttings as discussed above.

Macro-proliferation (Seedling Multiplication)

The multiplication of bamboo seedlings to smaller size planting material is known as macro-proliferation. A bamboo propagule must possess a well established root system, rhizome and shoots for successful establishment. In order to increase planting stock before transfer to the field, macro-proliferation is practiced. A bamboo seedling, at the age of 30-40 days, produces new culms and start developing rhizome. In a period of four to five months, these plantlets develop five to six culms (tillers). These tillers may be separated into as many units with a small piece of rhizome and roots. The separated seedlings should be kept in shade and watered regularly for better results. These propagules attain the field planting height within four months, or they can be further multiplied through macro-proliferation. Banik (1985) reported that five to nine months old seedlings of *B. tulda* can be multiplied 3-5 times in number through this technique. The survival rate of these multiplied seedlings is well within 90 to 100%. A large number of identified planting stocks could be produced and continued for a number of years through this method, however, the seedling multiplication in this way should not be continued for a very long time.

Micro-propagation (In-vitro propagation)

In-vitro methods offer an attractive alternative method of mass propagation of bamboos. So far, tissue culture protocols have been developed for important species required for plantation in different parts of the country by different agencies. Micro-propagation techniques passed through four stages, viz. collection and sterilization of explants, culture establishment, shoot multiplication and root initiation and finally hardening & acclimatization before field planting preferably in rainy season. The protocols of the following species have been developed using explants from nodal segments and somatic embryogenesis as well (Anon 2008):

- *Bambusa balcooa*
- *B. nutans*
- *B. tulda*
- *B. vulgaris*
- *B. polymorpha*
- *B. nana*
- *B. pallida*
- *Dendrocalamus stictus*
- *D. hamiltonii*
- *D. membraneous*
- *D. asper*
- *D. giganteus*
- *Guadua angustifolia*

- *Oxytenanthera stocksii*
- *Pleoblastus variegata*
- *P. green*
- *Pseudosasa japonica*
- *Drepanostachyum falcatum*

The bamboo planting stock is now being produced through tissue culture on a large scale in various parts of the country. The planting material has been tested in multi-locational trials. A national certification system is in place and it is imperative that any large-scale plantation of bamboo should necessarily source its material from superior genotypes identified and to the extent possible only certified tissue culture raised material should be used for obtaining best performance in field.

Standardization of Silvicultural and Plantation Management practices

Raising of Plantations

Bamboo plantations should be raised with intensive management and planed planting schemes like cultivation of any other cash crops to enhance the yield per annum to a predetermined level. Usually bamboo prefers well-drained soils of sandy loams to loamy clay type, however, individual species have well defined habitats. Maintenance activities should be concentrated on protecting the young plants from competition for the first two years after that clump management operations are required. The bamboo plantation achieves its optimum productive stage generally by 4 -7 year as in case of sympodial bamboo and continued till the stand attains an age of around 20-25 years. After that the uprooting of entire plantation is suggested in phased manner for raising new plantations.

Management Practices

Management of bamboo stands is relatively simple and closely related to the striking generic and cultural features. In general, the mature culms are cut and regeneration obtained from new culms produced annually from underground rhizomes, and this practice followed everywhere regardless of the species and type of forest. However, some more points are as:

Soil working around the Clumps: New rhizomes of bamboo emerge at an upwardly inclined angle from the base of clump. During the period of emergence and growth any exposure to sunlight stops the rhizome development. Hence, it is advisable to raise the soil (make mounds) around the clumps every year before the new culms emergence. Such soil working also increases the number of new culms emergence.

Pruning: This is practiced only in those species which produce thorny branches like *Bambusa bamboos*. This should be started in the third year after planting. Pruning prevents congestion and helps in keeping the clump in working condition. All the branches up to 1.5 m height should be pruned leaving one node on the branch stalk.

Thinning/ Improvement cutting: This practice should be started in the second year after planting and continued every year before the onset of rains. All malformed and damaged culms should be removed. Culms causing

congestion should be cut to make the remaining culms equally spaced. Thinning operations during establishment period ensures that the clumps reach their productive age without any congestion. This practice also provides space for new culms to grow vigorously.

Harvesting and Harvesting Schedule: Once the clumps are established and reach productive stage, proper harvesting technique and schedule should be followed to ensure sustained production over long time. Usually the culm selection system is followed in harvesting bamboo culms. This system involves:

- 3 years old or above culms should be removed as they have no role in the new culm emergence. Only one and two year old culms give rise to new shoots.
- The cut should be given above the first prominent node (about 15 cm from the ground level) with a sharp instrument.
- Felling of bamboo should be avoided from October to December as during this period the young shoots are in growing process. The new shoots become mature enough to resist any damage by March – May, so felling operations should be completed between May-October each year.

Method of working large clumps: If the clumps are not thinned from the very beginning, they become congested at the time of productive age. There are special techniques of opening such congested clumps in plantations as well as in natural forests (Pathak et al. 2008), which are as:

1. Perpendicular Tunnel method
2. Horse Shoe method.

In the first method two tunnels are made right angles to each other so that the clump is divided into four quadrants. In the second method the clump is converted into a horseshoe shape by thinning the inner culms.

Multi-location Trials of the Selected Germ-plasm

To analyze the genetic worth of plus clumps/superior genotypes of bamboo, multi-location trils are needed to evaluate the stability performance of various quantitative and qualitative traits for:

1. Intensity of inheritance expression
2. Stability of the characters in different environmental conditions
3. Prioritization of the plus clumps for different end users
4. Geographical deployment of suitable plus clumps

Such type of multi-location trials are in progress at various research institutes in India under all India coordinated projects funded by Department of Biotechnology (DBT) and National Bamboo Mission (NBM). The results of these multi-location trials – being long-term experiments are still awaited. These trials will definitely come out with some productive clones of bamboo for further deployment in specific agro-climatic zones of the country, thereby, to meet the ever increasing demand of bamboo raw material.

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Challenges on Climbing Bamboo Utilization and R&D Directions[1/]

R. A. Navitidad

Abstract

In general bamboo can be classified into erect or climbing type based on the growth habit of their culms. A climbing bamboo has crooked or zigzag culm 1-5 cm in diameter with branches at the nodal portions. The main culm and branches grow to a considerable length with almost the same diameter forming a ramified crown structure which cannot stand upwards. Thus, they climb nearby trees for mechanical support above the ground or scramble over sloping ground or up rocky slopes and along creek embankments in the forests.

Climbing bamboos in the Philippines grow gregariously whenever found from low altitudes up to 800m asl. Recent botanical studies reported 16 species of climbing bamboos in the Philippines belonging to three genera: *Dinochloa* (8 spp.); *Cyrtochloa* (7 spp); and *Cephalostachyum* (1 sp.).

The DENR forest inventory in 1988 estimated the standing stock of climbing bamboos at 8.32 B lineal meters. This is greater than the combined standing stocks during that year for erect bamboos (2.44 B lineal meters) and rattan (4.57 B lineal meters).

Presently only a few climbing bamboos species have been commercially utilized i.e. puser (*Cyrtochloa fenexii*) for folding chairs and tables, woven plates, trays and hats; and bagtok (*Cephalostachyum mindorense*) for basketry.

Completed and on-going R & D projects at FPRDI indicate the huge potential of climbing bamboos as an alternative resource for furniture and handicrafts. Some *Dinochloa spp.* have solid culms. These resemble the diameter sizes and bending quality of rattan and can be used for steam-bent articles. The strips or thin splits from culm internodes are pliable with high folding endurance for weaving purposes. Preliminary data also revealed favorable results of preservative treatment, drying, bleaching and dyeing.

With the bright prospects for the utilization of climbing bamboos for furniture and handicrafts, R&D on proper processing, product design and development should be given priority. Studies geared towards resource conservation to ensure sustainable raw material supply are also imperative. These include updating on the

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inventory of harvestable volume and distribution of standing stock, appropriate harvesting methods, and on propagation as well as development and management of plantations.

Introduction

Bamboo is one of the most versatile and economically important forest products. It contributes to the subsistence needs of over a billion people in rural communities throughout the world. Among its traditional uses include fuel, wood, medicine, shelter, agricultural tools, and containers, hunting and fishing gear and other items for household purposes. Its processing and utilization for industrial products also play a vital role in livelihood and economic development in rural and urban areas. These include production of pulp and paper, housing and building construction materials as well as furniture and handicrafts. However, such products are processed mainly from erect-type bamboos. Scanty information is available on the domestic or industrial utilization of climbing bamboos.

This paper presents a perspective on the existing status of the resource as well as R&D breakthroughs and needed directions to enhance the utilization of climbing bamboos in the country.

Description Status of the Resource

Based on rhizome structure bamboo is classified as sympodial and monopodial (Rojo et al 2000). The former has several culms per clump while the latter is single-stemmed. Morever, the growth habit of the culms can be classified into erect and climbing type.

A climbing type can be easily distinguished from an erect bamboo by having crooked or zigzag culms with relatively small diameter (1-5 cm) which grow to considerable height and bear many branches at the nodal portion. The dominant branch may grow to the same diameter as the main culm forming ramified crown structures that cannot stand upward (Escobin et al 2005). Thus, they climb nearby trees for mechanical support above the ground or scramble over sloping ground or up rocky slopes and creek embankments in the forests.

Number of species and distribution

Rojo (1996) listed only 14 climbing bamboo species in the Philippines based on available literature. Recent botanizing activities by Escobin et al (as cited) reported the existence of 16 species under three genera: *Dinochloa* (8 spp.); *Cyrtochloa* (7 spp); and *Cephalostachyum* (1 sp).

The *Dinochloa* species are the “true” climbers while *Cyrtochloa* and *Cephalostachyum* species have scrambling, trailing or clambering culms. Two of the 16 identified species are commonly found in the Philippines and Borneo. The rest are endemic or found only in the country (Table 1). They grow gregariously whenever found from low altitude to 800 m above sea level. Most species have restricted distribution or are found only in a particular locality/province. However, *D. luconiae* and *D. acutiflora* occur throughout the Philippines.

Table 1. List of Philippine climbing bamboos: distribution and conservation status

Scientific name	Common Name	Origin and Distribution	Conservation Status
Cyrtochloa toppingii	Bukawe, Topping bikal	Endemic to the Philippines, Rizal	known
C. fenexii	Puser, paua	Endemic, Luzon (Abra, Ilocos)	known
C. luzonica	Luzon bikal	Endemic, Luzon (Zambales)	known
C. puser	Puser	Endemic, Luzon (Abra)	known
C. hirsuta	Baitu	Endemic, Luzon (Bataan)	unknown
C. mindoroensis	Mindoro bikal	Endemic, Mindoro	known
C. major	Bikal baboy	Endemic, Luzon (Bataan)	known
Dinochloa palawanensis	Balikaw, Palawan bikal	Endemic, (Palawan)	known
D. acutiflora	Bikal-baboy, balikau	Endemic, Luzon (Laguna, Tayabas)	known
D. luconiae	Osiu, bikal	Native to Philippines and Borneo	known
D. robusta	Balikaw, Palawan bikal	Endemic, (Palawan)	known
D. oblonga	Palawan bukawe, bikal	Endemic, (Palawan)	known
D. elmeri	Elmer bikal	Endemic	unknown
D. pubiramea	Bukau	Borneo, Philippines	unknown
D. dielsiana	Tagisi	Endemic	unknown
Cephalostachyum mindorense	Bagtok, Mindoro bikal	Endemic (Mindoro and Camarines)	known

Source: Escobin et al 2005.

Volume of standing stock

There is a huge volume of climbing bamboo poles in the Philippines based on the results of the RP-German Forest Resource Inventory Project (1988). The volume of standing stock was estimated at 8.32 B linear meters. This is greater than the combined standing stocks during that year for rattans and erect bamboos with 4.57 B and 2.44 lineal meters, respectively. It is presumed that volume of growing stock have increased in the last 16 years due to limited utilization but reduction of volume is also possible due to forest denudation in some areas of the country or conversion into “kaingin” or agricultural lands, human settlement and other land uses.

Existing and prospective utilization

The huge quantity of hitherto, untapped climbing bamboo poles, pose a big challenge to forest product researchers and the forest-based industries to unravel their appropriate commercial utilization.

Some climbing bamboos are presently utilized in limited quantities in the rural areas for fuel, fencing, trellis, skewer, "kaing"-making and woven novelty items. Other species have no known uses (Table 2). This may be due to lack of information on their technical (strength, durability, working characteristics) and commercial properties (availability and reliability of raw material supply).

Table 2. Uses of Philippine climbing bamboos

Scientific name	Uses
Cyrtochloa toppingii	General purpose
C. fenexii	General purpose, fences
C. luzonica	Trellis of crops, fences
C. puser	Fences
C. hirsuta	Barbicue sticks
C. mindoroensis	Fence, general purpose
C. major	Fence, general purpose
Dinochloa palawanensis	No known uses
D. acutiflora	General purpose
D. luconiae	Fences, basketry
D. robusta	No known uses
D. oblonga	No known uses
D. elmeri	No known uses
D. pubiramea	General purpose
D. dielsiana	General purpose
Cephalostachyum mindorense	Containers, handicrafts, novelty items

Source: Escobin et al 2005.

Bagtok (*Cephalostachyum mindorense*) was reported as a preferred raw material by indigenous tribes in Mindoro and Bukidnon for woven handicrafts such as hats, mats and baskets (PDI 1996). In Santa, Ilocos Sur the author had discovered 4 years ago that Puser (*Cyrtochloa puser*) is used for making woven plates and trimming (rim) of broad baskets (bilao). The same species was observed for the commercial production of handicrafts (woven plates, trays and hats) and furniture (folding tables and chairs) in Bangued, Abra. The manufacturer has been selling the products in other provinces, Metro Manila and to the USA (Balbin 2006).

Considering the above utilization of climbing bamboos they have bright potential as an alternative raw materials for the furniture and handicrafts industries.

R & D Status and Directions

Completed and on-going projects

To date, FPRDI has conducted 9 R &D projects related to climbing bamboos: 5 projects under the Manila Science Program and 4 under the Furniture and Handicrafts Program (Table 3). These cover basic (anatomy, natural durability, physical and mechanical properties, proximate chemical composition, identification of species) and applied R&D (drying, protection and preservation, bleaching and dyeing. steam-bending and development of novelty products.

Table 3. FPRDI on-going and completed R & D projects on climbing bamboos

PROJECTS / SPECIES	MATERIAL SCIENCE PROGRAM					FURNITURE & HANDICRAFTS PROGRAM			
	Natural Durability	Anatomy	Physical-Mechanical	Chemical	Identifi-cation Manual	Utilization for novelty products	Bleaching and Dyeing	Drying characteristics	Dev. of Bent F/H compo-nents
Cyrtochloa toppingii	XX	XX	XX	XX	XX				
Cyrtochloa fenexii	XX	XX	XX	XX	XX				
Cyrtochloa luzonica	XX	XX	XX	XX	XX				
Cyrtochloa puser	XX	XX	XX	XX	XX	XX	XX	XX	
Cyrtochloa hirsuta	XX	XX	XX	XX	XX				
Cyrtochloa major	XX	XX	XX	XX	XX		XX		
Cyrtochloa mindoroensis					XX				
Dinochloa sp. 1(Zambales)	XX	XX	XX	XX			XX		XX
Dinochloa palawanensis					XX				
Dinochloa acutiflora	XX	XX	XX	XX	XX		XX		
Dinochloa luzoniae					XX				
Dinochloa robusta					XX				
Dinochloa oblonga					XX				
Cephalostachyum mindorense	XX	XX	XX	XX	XX	XX	XX	XX	
STATUS	On-going	On-going	On-going	On-going	Comp-leted	On-going	On-going	On-going	Comp-leted

Research breakthroughs

The pioneer R & D project conducted at FPRDI dealt with steam-bending quality evaluation of climbing bamboo for making curved furniture and handicraft components. Results indicate the suitability of tagisi (*Dinochloa* dielsiana), with 1-2 cm diameter and solid culm, for making steam-bent articles (Natividad 2000). It can be bent to a radii ranging from 4 to 8 cm in green condition (MC > 40%) depending on the diameter class (Fig. 1).

Results of completed projects at FPRDI show that climbing bamboos have almost the same density, durability and anatomical properties (fiber diameter and length) as the erect bamboos. These are easy to dry by air or kiln drying with negligible defects; easy to treat with chemical preservative against fungi and insects; amenable to bleaching and dyeing; and have high folding endurance in strip form for weaving purposes (FPRDI 2005). Fig. 2 shows some of the fabricated prototype woven products.

During the 2006 National Trade fair at SM megamall some prototype products from puser (*C. puser*) and baguisan (*D. pubiramea*) were dislayed. These were fabricated at FPRDI in collaboration with CITC, BDT and PDDCP. These include artificial flowers from diagonally cut culms (Fig. 3).

R & D Directions

R & D gaps on the physico-mechanical, chemical, and processing properties of climbing bamboos should be pursued to establish baseline information and technologies for the development of new products i.e. furniture, handicrafts, home and fashion accessories, composite panels for housing and building construction and other purposes.

To sustain raw material supply it is also imperative to formulate policies for their conservation and R & D should be focused on propagation, plantation development and harvesting techniques for preferred species. An updated inventory of the standing stock is likewise needed together with a map on their geographical distribution to facilitate the collection/sourcing of raw materials.

Summary and Conclusion

Climbing bamboos are not as popularly used for household or industrial purposes as the erect ones but they are promising alternative raw materials for furniture, handicrafts and other related products for the local and export markets. Initial results of R& D projects on their processing and utilization indicate their suitability for woven products and steam-bent articles. However, there are still many R & D gaps which need to be addressed. These include generation of appropriate technologies on product development and management of the resource to ensure sustainable supply of raw materials for specific end-uses.

Generated technologies should be promoted and transferred for the development of community-based enterprises in areas where climbing bamboos are relatively abundant.

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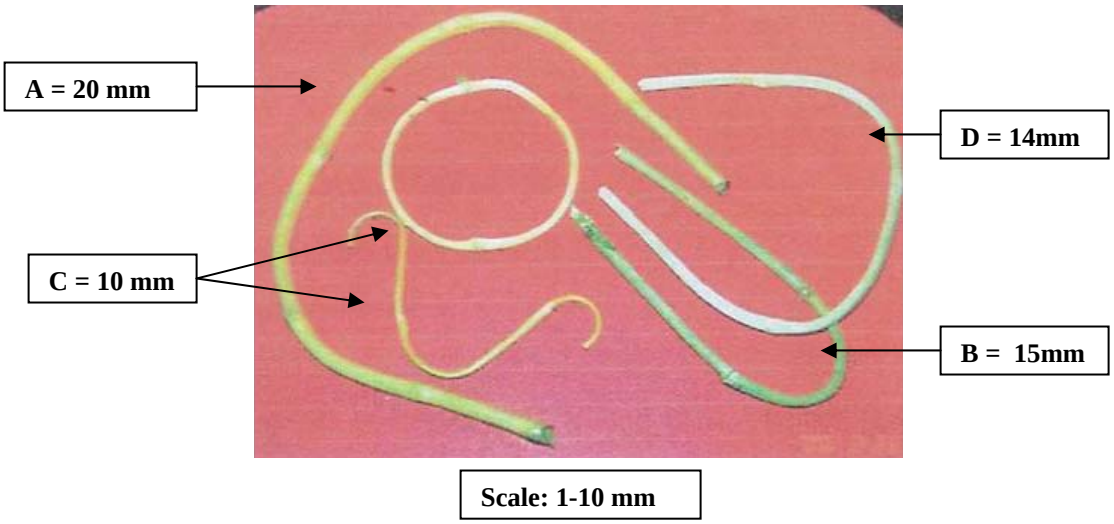

Fig. 1. Samples of Bentworks from tagisi: a) seat frame; b) basket handle; c) ladies bag handles; and d) hair-pin type bent for embellishment of chair back rest.

Fig. 2 Prototype products from Bagtok and Puser

Fig. 3. Artificial flowers from baguisan (left) and puser (right) culms.

Integrated Management of Bamboo Resources in the Colombia Coffee Region

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Abstract

The silvicultural management and planning of guadua bamboo forests as well as their capability of providing environmental services are analysed in this work. In these sense, the bases for inventory and mensuration are defined as the best way of procuring adequate information. Because of differences on growth and management, silviculture is separately discussed for natural stands and plantations. In addition, an approach to define the effect of site conditions on guadua productivity and quality is proposed. Furthermore, benefits of guadua forest referred to carbon sequestration and soils restoration are remarked. Finally, information was integrated to define the capability of land for guadua production and units of forest management (UFM), which are an instrument that government institutions use for forest planning. Silvicultural practices on natural stands are specially focused to harvesting, thus the possibilities of an adequate management depend on a proper definition of harvest intensity and harvest frequency. For guadua plantations, results on dynamics reveal the significant consequence of fertilisation and weed control, specifically on growth and mortality of culms. As a contribution to elucidate the worth of guadua forest providing environmental services in the coffee region of Colombia, carbon sequestration and soil protection was assessed and quantified. Values up to 900 Tn ha^{-1} of total carbon stock were evidence for guadua stands. Comparisons of soils properties among different land covers evidenced better conditions in soils under guadua stands even under those located on marginal areas. By using geographic information systems and software for modelling productivity of guadua stands, information was integrated and UFM defined. Besides guadua plantations were successfully used in processes of soil restoration, reducing significantly soil erosion. Silvicultural practices, forest planning and the quantification of environmental services, give the bases for an integrated management of this bamboo forest in the coffee region of Colombia.

Introduction

In the Colombian coffee region the woody bamboo species guadua (*Guadua angustifolia* Kunth) represents an important natural resource traditionally used by farmers for many purposes such as construction, furniture and handicrafts (Londoño 1998). Due to the variety of uses the commercial value of guadua culms has recently increased (Held 2005). Therefore, this resource has potential productive and protective functions essential for the sustainable development of this important region of Colombia (Camargo 2006).The species guadua has its natural habitat in Colombia, Ecuador, and Venezuela, but it has also been introduced to other countries in Central and South America, Europe and Asia. Its culms are an ideal construction material with a high percentage

of fibres and excellent structural properties such as high resistance to weight-ratio, high capacity to absorb energy and excellent flexibility. As a result, houses made of Guadua are very resistant to earthquakes (Londoño et al. 2002; Gutierrez 2000).

Currently, guadua is the more harvested species to obtain wood for different applications in the coffee region of Colombia. Some reports show that between 2000 and 2004 roughly 2,420,000 culms of guadua was logged from 2,557 ha (Moreno 2006). However, it represents that 91 % of guadua stands were not harvested in this period of time. During a recent inventory study an estimated area of 28,000 ha covered by guadua has been identified in the coffee region alone (Kleinn and Morales 2006).Natural Guadua stands are relatively small and have irregular shape. Most of them have areas smaller than 5 ha and form a highly fragmented pattern and are mainly located along valleys near to rivers (Camargo and Cardona 2005). Even though guadua is adapted to different site conditions, there are special environment which favour its growth and optimal development (Castaño and Moreno 2004). Guadua grows best between 900 and 1600 m above see level, at temperatures between 20 and 26ºC, precipitation between 1500 mm and 2500 mm per year, and in slightly acidic soils (Cruz 1994; Giraldo and Sabogal 1999).

The growth patterns of the Guadua and trees are completely different; therefore bamboo inventory and mensuration should be conducted by using different criterions (Camargo 2006).For reaching an adequate management of this resource basic information on the dendrometric attributes of culms, on stand variables as well as on stand management options is quite relevant. Also aspects such as stand productivity, performance in different environments and interactions between stand management and environmental factors such as site should be considered (Camargo 2006, García 2004; Hincapie & Penagos 1994).

Different response variables have been used to describe the effect of environmental factors. García (2004) i.e., grouped response variables into those that represent growth, such as diameter, height or culm length and those that represent quality (i.e. physical and mechanical properties) such as basic density and strength resistance. Agudelo and Toro (1994) found that the major influence on quality variables lies in the physical properties of the soil as well as in the topography of the site. Culms growing in fine textured soils on steep sites have been shown to possess improved physical and mechanical properties. Also, Londoño and Prieto (1983) observed that the combination of high solar brightness, high precipitation and location of stands on hills produces a positive influence on the growth and development of culms.

In Colombia management of guadua.stands is applied especially to natural stands. A number of studies have pointed out important changes in population dynamics when the stands are under different harvesting schemes in terms of intensity and frequency (Camargo 2006, Morales 2004). Regarding to guadua plantations, studies on growth and population dynamics have given basic information for silvicultural options. As a complement of silvicultural management, planning of guadua bamboo forest is also noteworthy. Forest planning is a priority for government institutions responsible of giving principles for forest management. In this sense, the definition of land capability for guadua plantations and the qualification of guadua stands in terms of productivity as well as to consolidate units of forest management can significantly contribute to the sustainable development and management of guadua in the coffee region of Colombia.

In the other hand, guadua bamboo forests also accomplish important functions contributing to the mitigation of climate change, soil protection and water regulation. Because of population dynamics and biomass of guadua, these forests have a high worth as carbon sink (Riaño et al. 2002). Moreover, the guadua has been often used by government institutions for reforestation programs and important changes can be observed concerning to improvement of soils conditions under reforested areas. For theses reasons, the enhancements of environmental services or ecosystems functions have been attributed to this bamboo species (Cruz 1994, Giraldo and Sabogal 1999).

In order to promote the proper utilisation and management of guadua and the productivity options available to farmers in the Colombian coffee region, information on growth and productivity as well as the bases of silvicultural management are analised in this work . In addition an application of a simple model to integrate spatial information and attributes of land and guadua stands is applied as strategy for planning of guadua forest. Also to elucidate the true meaning of environmental services and ecosystems functions offered by guadua bamboo forest, quantitative information on variables associated to environmental services and ecosystems functions as carbon sequestration and soil protection provided by guadua bamboo forest is presented here.

Silvicultural management

In Colombia and specifically in the coffee region, most of the silvicultural practices have been developed and applied to natural guadua stands. This statement has its main justification because there is considerably more area under natural guadua stands than guadua plantations. According to the most recent guadua inventory in the coffee region there is an estimates of 28,000 ha (Morales and Kleinn 2006). In contrast, have been registered no more than 4000 ha of guadua plantations (CARDER 2000) of which there are not yet official registers of harvests. In addition, practices related to establishing and the dynamics of clumps during the first stage of development are only focused when guadua plantations area managemed. In order to describe silvicultural practices applied to guadua in Colombia, natural guadua stands and guadua plantations should be separately analysed.

Bases of silvicultural management are supported on information on growth, productivity and quality. Consequently, before to describe silvicultural practices and their effect, it would be essential to emphasised on guadua inventory and mensuration.

Guadua inventory and mensuration

Growth pattern of tree and bamboos are wholly different. Hence, bamboo growth and productivity should be measured taking into consideration the best manner to obtain consistent information on dendrometric and stand variables. As in other bamboos, guadua culms are curved in the upper section. It means that the measured height does not correlate with culm growth. For trees, height and length are usually almost identical. In contrast, for this bamboo species culm length and culm height are considerably different. Therefore, the variable of interest is obviously culm length because it is directly related to the commercial product (Figure 1).

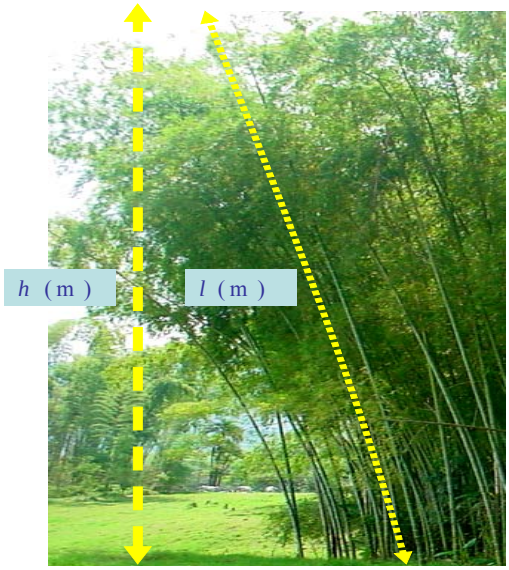


Figure 1. Differences between culm height (h) and culm length (l). Source: Camargo 2006

For trees, diameter is usually measured at breast height, which is fixed at 1.3 m in most countries. This concept is not appropriate for bamboos because diameter varies with the proximity to the nodes. Therefore, it is more appropriate to measure the reference diameter in the middle of the internode (i.e. between the nodes) where conventional breast height (1.3 m) would be. This means that the diameter is actually measured at slightly different heights (Figure 2)

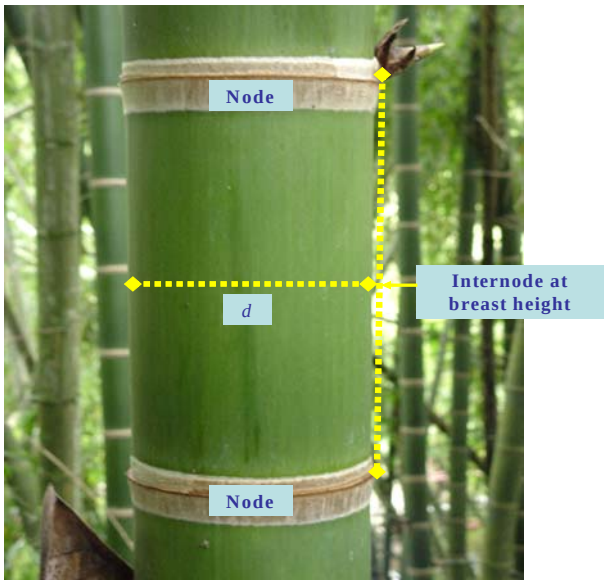


Figure 2. Culm diameter (d) variation between internodes. Source: Camargo 2006

For bamboo species, models for predicting culm height from diameter are not often used (Fu 2001; Watanabe and Oohata 1980). For guadua, a simple model has been used to predict culm length (*L*) from the perimeter at breast height (*C*), including a constant (*K*), which has been determined empirically (Arbelaez 1996, Cruz 1994). For volume, some studies have related it with biomass estimation (Reid et al. 2004) or with physical and mechanical properties of culms (Jamaludin et al. 2000)

Camargo (2006) estimated the relationship between culm diameter, culm length and culm volume by using linear and non-linear regressions. These models were used in regression analyses of culm length, apparent and net culm volumes being the dependent variables. The equations developed for tree mensuration are useful for predicting total culm length and culm volume using a number of independent variables. These models can be used with an adequate precision for estimating both variables. For estimating culm length the modified model of Cox, which includes the stand variable square mean diameter was the best. (R^2_{adj}=0.49, RMSE=2.5). For apparent culm volume the allometric model was the best among the models tested (R^2_{adj}=0.89, RMSE=0.005). A linear regression model was also fitted to estimate net culm volume from apparent culm volume (R^2_{adj} = 0.94, *RMSE* = 0.001).

With reference to stand variables, Camargo (2006) and Morales (2004) have defined that the most representative stand variable for gathering in guadua inventories is the total number of culms per hectare. This variable defines the potential productivity of the guadua stands and also is the base to determine harvest. Other variables as basal area and total volume moreover could provide important information on guadua stands. However harvest plans, traditionally have been defined with regard to number of culms to be harvested (Camargo et al. 2008; Camargo 2006).

Studies on plot design conducted within guadua stands permit to conclude that circular plots provide the highest precision in inventories (Rijal 2006). However, plots with this shape are highly demand of sample effort and cost of inventory could increase. In this sense, rectangular and square plots can be more easily established. Among both plots, the rectangular have showed the lowest standard error and consequently the highest precision. However, plots should be arranged with the longer side against the slope. In relation to plot size, Rijal (2006) suggest that plots between 50 m^2 y 200 m^2 have the best precision. These results are also consistent with Camargo (2006) and Schumacher (2006) who tested the precision of different plot sizes within natural guadua stands.

Silviculture of natural guadua stands

Traditionally within natural guadua stands most of the practices are associated to the harvest. These practices are focused in improving the access to stand and include pruning (elimination of lateral branches which are usually thorny) and removal of those culms which have reached the last stage of maturity and during the inventories are found dry, broken or dead. These culms are removed especially within stands with high culms density (over 6000 culms per ha). Only in few cases fertilisation is done. It is due to fact that there is scarce information on benefits of this practice and because of productivity of stands even without fertilisation is adequate, in terms of the amount of culms demanded in the market.

Guadua stands can improve their productivity through silvicultural practices. These practices also may contribute for reaching a sustainable yield. For this reason, it is required to consider different aspects which contribute to an adequate silvicultural management such as the effect of site quality and an adequate definition of harvest regimen.

Site quality

Due to the large number of variables that may influence growth and quality of guadua culms, multivariate seen to be the most appropriate technique to reduce the dimensionality of data (García 2004; Agudelo and Toro 1994; Hincapie and Penagos 1994). Some studies have been useful to identify trends on the variability of growth and quality in relation to site conditions and groups of variables linked to environmental factors which could represent growth or quality have identified (Camargo 2006; García 2004;:Hincapie and Penagos 1994).

To evaluate the effect of environmental factors on growth and productivity the study sites were located in the Colombian coffee region which has a total area of 1,029,524 ha and elevations between 900 and 2000 m.a.s.l. The mean annual temperature is between 20°C and 27°C and precipitation between 950 and 2500 mm per year with a bimodal distribution (García 2004). Soils are principally Andisols, slightly acidic and with good physical properties (Camargo et al. 2001).

Sampling design for data collection was based on a guadua bamboo inventory (Kleinn and Morales 2006) and specific information on site factors and stands characteristics is founded on a research conducted by Camargo (2006). Accordingly data were derivate from a total number of 101 field plots measuring 10 m x 10 m located completely within guadua stands. Response variables were classified into growth, stand and quality variables. Growth variables were the diameter at the internode at breast height, culm length, and wall thickness. Stand variables were basal area, quadratic mean diameter, percentage of shoots, percentage of young culms and total number of culms per hectare. Quality variables were compression strength, shear strength, basic density, curvature, and culm hardness. Independent variables were also recorded from the 101 temporary field plots and used for analyses. Previously, these variables were classified into topographic (i.e. elevation, slope), climatic (i.e. precipitation, temperature), stand (i.e. harvest intensity, distance to edge) and soil (physical and chemical properties).

An analysis of principal components provided information for the identification of key variables responsible for most of the variability between sites. The final set of environmental variables selected for the construction of predictive models was defined considering the high loadings of variables in the principal components and their higher correlation with the respective response variable. These variables were used in multiple regression models.

For fitting multiple regression models the stepwise procedure was performed. The degree of collinearity was evaluated for each model with the variance inflation factor (VIF) and the condition index. Predictors with values of VIF higher than 10, were discarded from the models due to collinearity problems. Within the regression analyses, for components with a high condition index (>30) the corresponding row was examined to see which variables had high values. A condition index of 30 to 100 indicates moderate to strong collinearity. The models selected after the stepwise procedure and the collinearity test, were also assessed by residual analysis. Those that

showed higher coefficient of determination (R^2), low root mean square error (RMSE) and low bias were considered to be preferred. Analyses were performed using the PROC REG procedure of the SAS/STAT® statistical programme (SAS INSTITUTE 1999).

Models for predicting culm length, basal area and culm hardness, showed the better performance. However, the variability in the productivity and quality of guadua could not be entirely described by the variables measured and a significant proportion of the variability remains unexplained. The best for growth variables was for culm length which includes 11 variables and explains 54% of total variation ($R^2 = 0.54$, RMSE = 2.3). Most of the variables contained in the model were related to soil properties (especially physical soil properties), however the temperature was the most important independent variable. Residuals analyses did not show any special trend and for all of the classes and the residual variation must be interpreted as random (Figure 3).

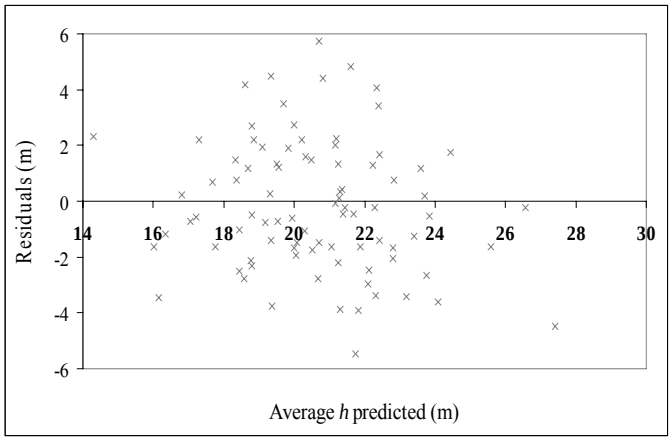


Figure 3. Plot of residuals versus predicted values of average culm length (*h*).

For stand variables the regression model for basal area gave the more reasonable goodness of fit ($R^2 = 0.51$, RMSE = 20.3). It means that 51% of total variation was explicated by the model. Five of the eight variables included in the model are soil properties and the most relevant was apparent density. The residuals analysis did not show any systematic bias when plotted against predicted values (Figure 4).

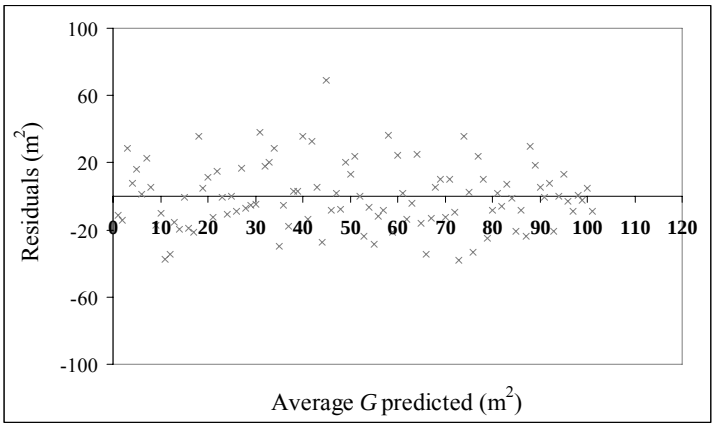


Figure 4. Plot of residuals versus predicted values of basal area (*G*).

The most sensitive quality variable was culm hardness that is explained in 51% by the model (R^2= 0.51, RMSE = 2.7). Being it the mechanical property that best represented the effect of the measured environmental variables on the quality of stands. Residuals analyses for this model did not show any abnormal trends (Figure 5).

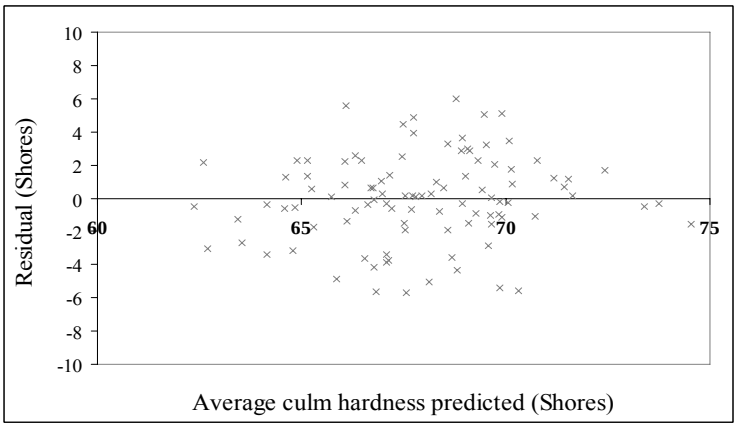


Figure 5. Plot of residuals versus predicted values of average culm hardness.

Effect of silvicultural management

Within Guadua stands individual competition for site factors occurs when the number of culms increases. Consequently, when culms are harvested, vital space is also regulated (Camargo 2006). Hence guadua stands should be harvested at a specific frequency and at an optimal intensity (Castaño 2001). It is suggested that harvesting be carried out during the dry season when the production of shoots and water content of culms are lower. Thus the risk of diseases and pest infestation after harvesting are reduced. The cut should be done 15 to

30 cm above ground level and closely above the node to avoid accumulation of water in the internodes and possible damage by decaying of the rhizome (Judziewicz et al. 1999).

Culms are considered commercial when they are mature, over-mature or dry. Therefore, harvesting should be planned based on the supply of commercial culms (Camargo 2004). Studies on silvicultural management have shown that after a harvest intensity levels between 12 and 50% together with frequencies between 6 and 24 months, stand dynamics and productivity increases (Morales 2004; Castaño 2001). However, when a high level of harvest intensity (50% on commercial culms) is applied continuously, the total number of culms in the stand could be reduced to half and consequently the sustainability of this resource could be endangered (Morales 2004). Different levels of harvest intensity, harvest frequency and fertilisation have been tested to evaluate changes in productivity of guadua stands. The response variable for these trials has been the production of new shoots which is for this study so called productivity.

When the effect of factors (intensity and frequency) is evaluated separately, it is not possible to reveal a tendency in productivity and there are not differences statistically significant. However, according to Morales (2004), when shoot production is simulated considering the combined effect of factors, two important changes can be observed on the dynamics of shoots. First, under any level of harvest intensity the total density of the stand abruptly decreases, especially during the first and second episode of harvest. This decrease on total density of culms, is obviously higher when increase the level of harvest intensity. Second, the total density of the stand tends to be stable only after seven years. In Figure 6, is showed the effect of three levels of harvest intensity with a frequency of six months. Changes in total number of culms per ha are simulated for a period of ten years by using the software SILVCAMARK 1.1 (Morales 2005). The areas enclosed in blue ovals show the two moments above mentioned, the abrupt decrease of total number of culms per ha and their tendency to the stability after seven years.

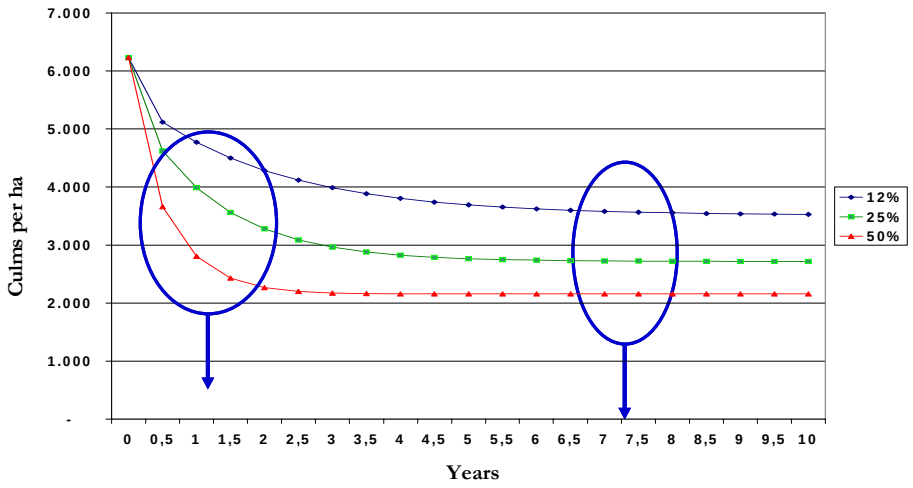


Figure 6. Effect of harvest intensity on the total number of culms per ha. Harvest was done every 6 months with intensities of 12%, 25% and 50% of commercial culms. Source: Morales 2004

Respect to the effect of fertilisation, this factor has been especially important reducing the level of shoot mortality and also increasing productivity. In this case, about 950 shoots per ha emerge every year with fertilisation while without fertilisation just 750. Regarding to mortality, it is of 12% with fertilisation and of 20 % without fertilisation (Morales 2004).

Silviculture of guadua plantations

In Colombia there are few guadua plantations and information on growth, population dynamics and silviculture is still quite general and recommendations are focused in how improve clump conditions and growth space during the phase of establishment (Camargo 2006). Requirements of weed control to improve the availability of light to guadua culms, as well as the possibility of intercropping by considering spacing and maintenance have been mentioned by Judziewicz et al. (1999), but have not been studied in detail. Riaño et al. (2002) have gathered data about growth and culm productivity in guadua plantations for up to six years. In their study, the authors also proposed models to describe clump growth and population dynamics.

Camargo (2006) shows results on the effect of fertilisation and weed control on growth. In this case, growth is expressed as the number of culms per clump, the estimated number of dead culms per clump, culm length and culm diameter at the lowest internode (basal diameter). Measurements of these variables were made on the three central clumps located in the effective area of each plot. Analysis of variance was used to determine differences between treatments and the Tukey test for comparison of the main effects of treatments.

The highest average values for the response variables were observed under chemical fertilisation and weed control done with herbicide. For the number of culms per clump the highest average was of 38 in the first 24 months which is equivalent to 23,750 culms per ha (Figure 7). The maximum number of dead culms per clump for the same period of time was 19 culms, which corresponds to 11,875 culms per ha and a monthly increment rate of 0.8 culms per clump or 500 culms per ha (Figure 8).

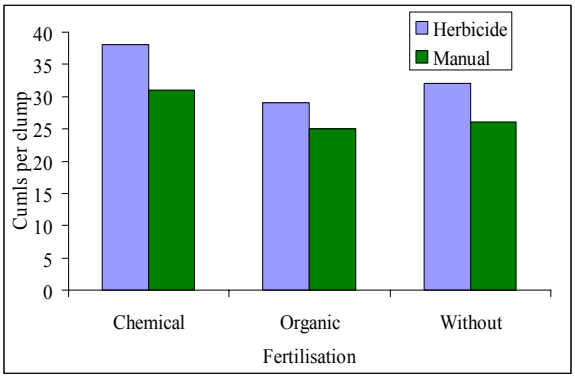


Figure 7. Effect of weed control at different levels of fertilisation on the average total number of culms per clump; 24 months after establishment. Source: Camargo, 2006.

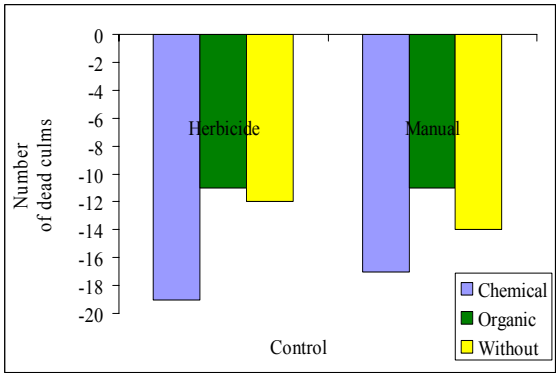


Figure 8. Effect of fertilisation at different levels of weed control on the total of estimated dead culms per clump; 24 months after establishment. Source: Camargo, 2006.

For treatments with chemical fertilisation and weed control with herbicide, the average culm diameter was of 3 cm and average culm length of 6 m, with increments for both variables being considerably higher than with other treatments (Figures 9 and 10).

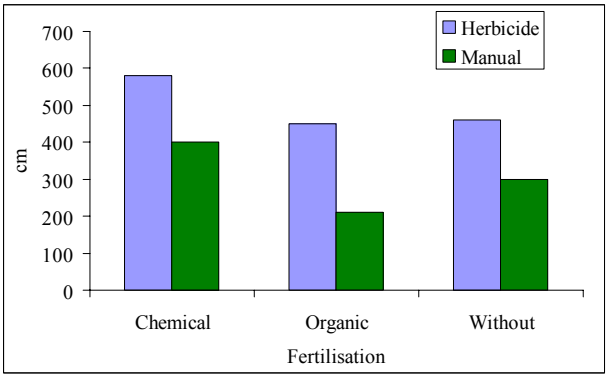


Figure 9. Effect of weed control at different levels of factor fertilisation on the average culm length; 24 months after establishment. Source: Camargo, 2006.

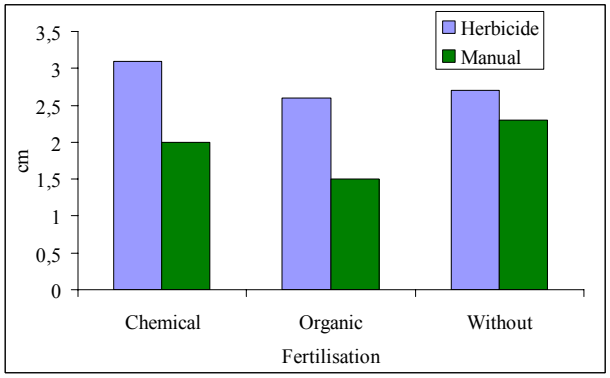


Figure 10. Effect of weed control at different levels of fertilisation on the average culm basal diameter; 24 months after establishment. Source: Camargo, 2006.

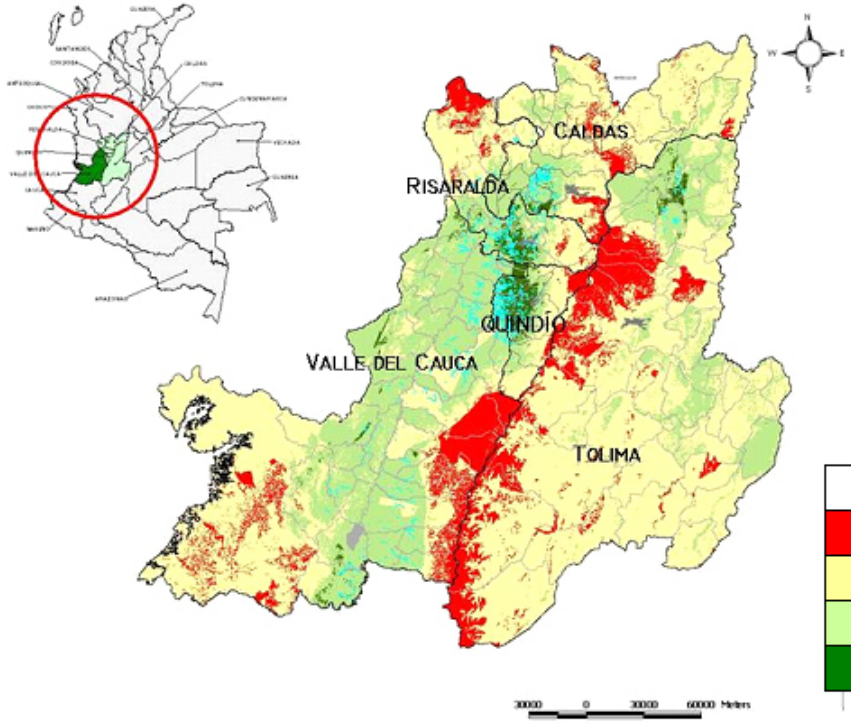
Thus it is observed that fertilisation and reduction of interspecific competition with herbicides are converted by this efficient plant into high biomass values in correspondence with high productivity expressed by increasing shoots production and culms growth.

Planning of guadua forest

The definition of land capability and potential areas for establishing guadua plantations in the coffee region of Colombia was carried out for five states in an approximate area of 5.766.397. A total of 24 variables were used in analyses to develop the model. These variables were included within five factors which represent site conditions: topography, climate, soils, landscape ecology and socioeconomics. By using a simple decision model based on the above mentioned five factors, it was feasible to define four classes of land capability: low, marginal, moderate and high.

In order to consolidate units of forest management (UFM) only 17 municipalities (470.328 ha) were incorporated in analyses. Additional information on volume of harvesting and characteristic of guadua stands related to site quality was included in the model. As a complement information on guadua forest inventories and baseline information on soils, climate conditions, geomorphology, environmental services and socioeconomic aspects, also was integrated. Thus, three classes of UFM were identified according of productivity level low, moderate and high. The software *Arc View 3.3* and its extensions *spatial analyst* and *3D analyst* were used. Also the extension *Model Builder* included within *spatial analyst 2.0* provided tools to develop the model.

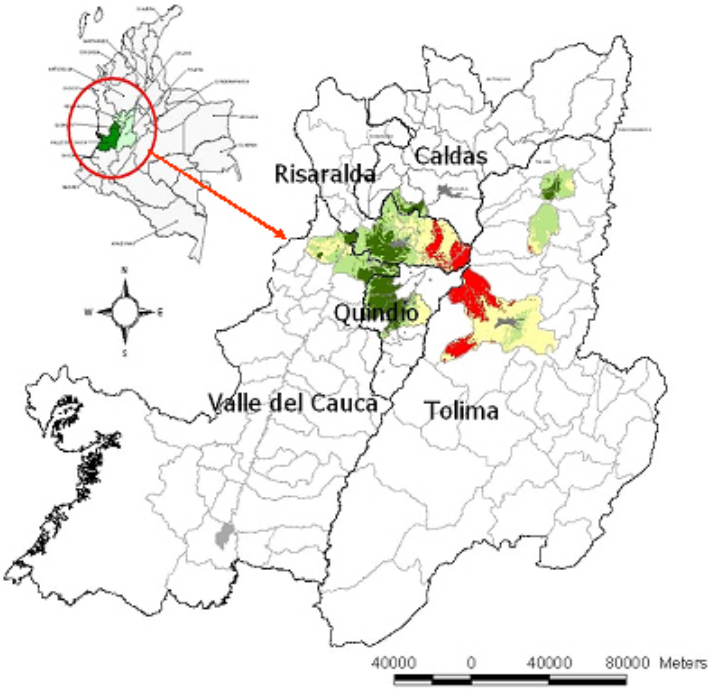
Only 2% of the evaluated total area resulted with high capability for guadua production. This area is located close to urban centers where are sited most of guadua stands (Figure 1). The main limitation for guadua production was the lack of roads (to access) and the absence of places for marketing. Also areas over 2000 m of elevation were immediately excluded, because of guadua does not grow well under these conditions.



Land Unit	Area (ha)	%
Low Capability	67281	12
Marginal Capability	3345448	58
Moderate Capability	1614691	28
High Capability	**124515**	**2**

Figure 11. Capability of land for guadua production. Coffee region of Colombia.

Regarding to UFM, those defined at the category of high productivity represent 19 % of the total area of municipalities analysed (Figure 11). Due to the characteristics of UFM in this category, it is feasible to develop intensive programs of forest management, since all aspects confirm a favorable level. Other UFM at the categories of moderate and marginal productivity could potentially become of high productivity. It is workable only if the volume of harvest increase and some conditions as access are improved (Figure 12).



Units of Forest Management	Area (ha)	%
Other	83529	16
Low productivity	162057	35
Moderate Productivity	137097	29
High Productivity	**87645**	**19**

Figure 12.Units of forest management for 17 municipalities in the coffee region of Colombia.

Guadua stands located within UFM were qualified in terms of productivity, quality and as potential protected areas. Consequently the conformation of UFM is significant as strategy to promote the management of small guadua stands. The fragmented pattern and small size of guadua stands could be a drawback. However, these forest areas included as a part of UFM can be an opportunity to integrate them to forest management and a reasonable strategy of forest planning. Moreover, management and market of guadua culms are incorporated within a UFM plan and not separately. Plans of management and strategies of marketing might now be done according to the specifics characteristics of UFM. The worth of the issues is because provided a tool for planning Guadua forest. Consequently, contribute to an adequate management of this natural resource in the Colombian coffee region and could be replied in tropical areas with fragmented forests.

Environmental services provided by guadua forest

Carbon sequestration within guadua stands

Aerial biomass was estimated with values of culm volume and wood density (Camargo 2006). Thereafter the carbon content was calculated by using a constant of 0.5 (Marquez 2000). Total amount of carbon dioxide in tons per ha was estimated from carbon content per culm and the average number of culms per ha. This information was associated to units of forest management (UFM) classified according to different levels of culm

productivity (Camargo et al. 2007).Information on altitude, slope and precipitation were employed in correlation analyses with carbon in soil under guadua stands.

A total of 812.2 Tn CO_2 ha^{-1} were estimated in average for guadua stands in the coffee region of Colombia. Aerial carbon was estimated in 251.3 Tn CO_2 ha^{-1} (31 %) for 6284 culms per ha, whereas 560.9 Tn CO_2 ha^{-1} (69 %) at 0.5 m of depth were calculated as stored in soils. Similar values have been registered for primary and secondary forests in Colombia with 99.2 Tn ha^{-1} and 93.6 Tn ha^{-1} respectively, at 30 cm of depth (Orrego and Del Valle 2001). The proportion of soil carbon regarded to biomass carbon, has been defined as higher for different authors. Lal et al. (1995) mentioned that carbon content in soils could be up to three times more than in living organisms. In the same way, within forest the soil carbon is 1.5 times more than in biomass (Brown 1997).

Correlation analysis showed positive and statistically significant relationships ($P<0.05$) among variables altitude, slope and precipitation with soil carbon stock. Regarding to altitude, it is important to highlight that, as altitude increases temperature decreases. Hence the percentage of organic matter accumulated in the soil tends to be higher, affecting carbon stock. In the other hand, precipitation eases the accumulation of soil organic matter. According to Fassbender (1986) precipitation influences the development of vegetation and therefore the production of organic matter in soils.

For the UFM with high productivity with an average of 5914 culms ha^{-1} the equivalence in CO_2 was of 868.7 Tn ha^{-1} (581.7 Tn CO_2 ha^{-1} in soil and 287 Tn CO_2 ha^{-1} in the aerial compartment). For the UFM with moderate productivity with 6313 culm ha^{-1} in average were estimated a total of 790.4 Tn CO_2 ha^{-1} (553.7 Tn in soils and 236.7 Tn in the aerial compartment). Finally, for the UFM with low productivity were estimated in average 7967 culms ha^{-1} which represent 234.7 Tn CO_2 ha^{-1} in the aerial compartment and 633.7 Tn CO_2 ha^{-1} in soils, for a total of 868.4 Tn CO_2 ha^{-1}).The distribution of carbon stocked was of 70% in soils and 30% in biomass (aerial compartment).

Guadua stands and soil protection

In the La Vieja watershed river (coffee region of Colombia) a total of forty sites were selected for soil assessment. Sampling was conducted in two stages. The first stage consisted to define on maps of land cover, transformed (mixed crops, crops, pastures and silvopastoral systems) and untransformed systems (guadua forest and forest[1]). In the second stage, a total of 40 sites were randomly located within transformed and untransformed covers for soil sampling. Finally, in each selected site three samples of soil were collected.

For each sample point were measured physical soil variables as soil stability, total porosity and texture. Soil stability (Average diameter of soil aggregates ADSA) was used as a reference variable to determine resistance to erosion or susceptibility to erosion. Whereas total porosity and texture, were employed to estimate the capability of soil for water storing (CWS), which is directly related to water regulation. Values for the variables evaluated

[1] This cover correspond to patches of forest where is not present the species *Guadua angustifolia*

were weighted at depth of 50 cm. Thereafter, the Kruskall Wallis test was performed for comparing the capability of soil for water storing and resistance to erosion among the different land uses and land covers

Comparisons of soils properties among different land use and cover evidenced values of CWS (water regulation) of 530 m^3 ha^{-1}. The higher value, although statistically not significant was for covers of forest with 572 m^3 ha^{-1}. Whereas the lower value was found under crops and pasture (Figure 13). The similar values of CWS obtained are explained because soils in the coffee region are highly homogeneous. Most of them are Andisols originated from volcanic ash; consequently have special physical properties as low bulk density and high effective depth (Malagon et al. 1995). While soil properties as those above mentioned do not change strongly, values of CWS will tend to be similar among covers. Previously, Sadeghian et al. (2001) found lower values of bulk density and soil compacting under guadua stands than those simplified land cover as crops and pastures. In this study it was evidenced that low values of bulk density and soil compaction contributed to a better balance between water and air within soils. It is important to remark that covers of forest and guadua forest are usually located in marginal areas where agriculture and cattle are not feasible. It means that natural soil conditions for these areas are limited by factors as slope and effective depth. Nevertheless, the value of CWS was higher under forest and similar to the other covers under guadua forest. It shows that even on limited soils, forest cover (guadua included) can maintain proper physical characteristics or improve them.

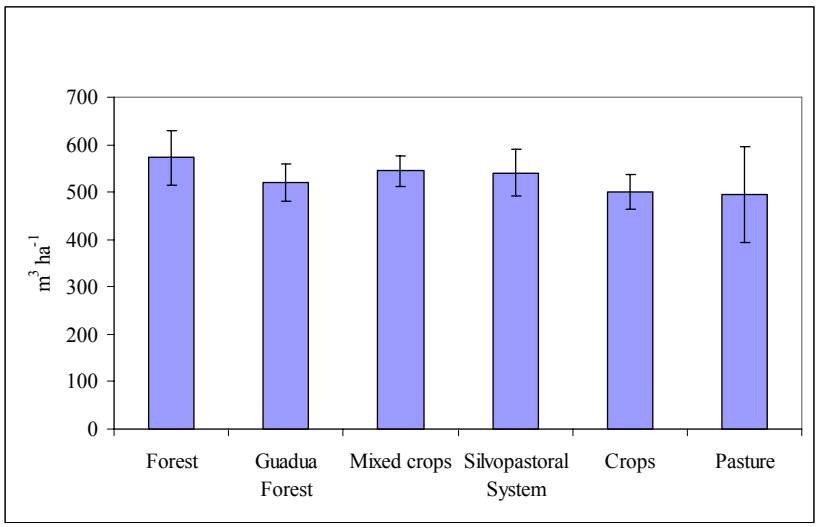


Figure 13. Capability of water storing in soils under different land use and land cover. La Vieja, watershed river. Vertical lines on the bars indicate the standard deviation.

The resistance to erosion showed significant ($P<0.05$) differences among the land use and land cover evaluated. Soils under guadua forest were significantly more resistant to erosion with a better structure represented by aggregates of 5.47 mm in average. Even though values under crops resulted very similar that those registered under guadua their variability was higher and the average was affected for extreme values, whereas mixed crops and pastures exhibited the lower values (Figure 14). Soil structure is related to different properties in soils. Changes on this variable are the result of land use practice and the type of material returned as organic matter in

residues (Deuchars et al. 1999). Soil structure is associated to vegetal residues (Douglas et al. 1986) and probably fallen leaves of guadua are contributing to improve it. With the results obtained it is not possible make general conclusions because there is a high natural variability associated to variables assessed. This variability can not be explained simply with the effect of covers, therefore is only feasible to elucidate trends. In this sense, to improve the basic information could be an interesting task for further research.

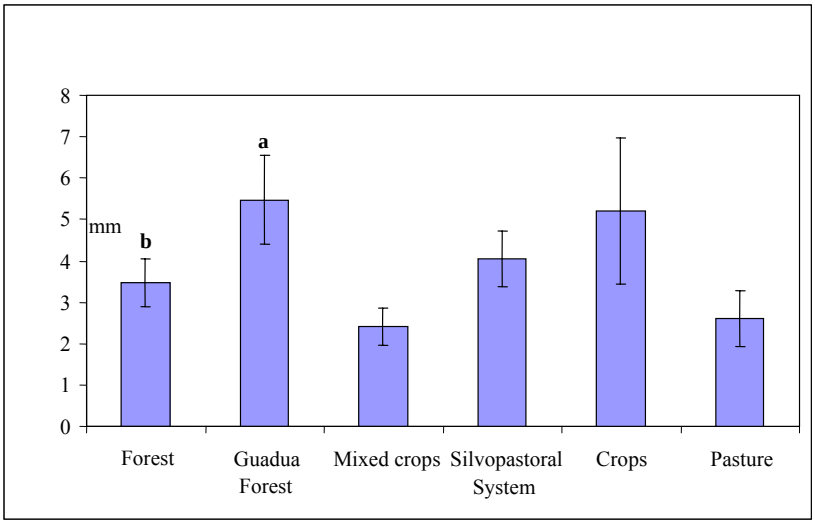


Figure 14. Resistance to erosion evaluated through average diameter of soil aggregates (ADSA). La Vieja, watershed river. Vertical lines on the bars indicate the standard deviation. Different letters indicate statistical significant differences (P<0.05).

The lowest values of ADSA could indicate a poor soil structure, however others factors different to currently cover could have a higher influence on soils properties. The history of land management (i.e. the preceding cover) can have a big influence on the present characteristics of soils. Deuchars et al. (1999) found that soil properties under pasture were negatively affected by cattle trampling even in areas where pastures were abandoned and regeneration forest was achieved, there problems in soil compaction and low porosity were evidenced after 15 years.

Guadua stands and soil restoration

An experiment were conducted to evaluate the short-term efficiency of guadua plantation for soil restoration and avoiding soil loss. Five treatments with three replications were randomly assigned within three blocks and in ffifteen plots of 9 x 12 m (108 m^2) which were adapted with lateral drains for conducting runoff and sediments toward a tank.The treatments evaluated were natural regeneration (T1), tree plantation (T2), guadua plantation (T3), temporary crops (beans) (T4) and pastures (T5). The experimental area was a hill with a slope of 36% in average that during three decades was covered by pastures. As a consequence the soils were eroded and compacted due to intensive livestock activities and especially by cattle tramping.

The soil loss was assessed during a period of seven months. The sediments collected in the tank have been dried and weighted daily to estimate soil loss (erosion) per each treatment. Precipitation has been also measured every day in a conventional rain-gauge. Variance analyses have been conducted to determine statistical differences in soil loss among the treatments evaluated. The post ANOVA test of Tukey was performed to determine differences among means.

Erosion was lower under treatment with guadua with 0.11 Tn ha^{-1} per seven months. Whereas soil loss in the treatments with crops was strikingly high with 0.26 Tn ha^{-1} per seven months. It is important to remark that the only treatment with significant ($P<0.05$) differences was temporary crops (Figure 15). Monthly evaluation of soil loss showed a high correspondence with values of precipitation. Being it an important evidence of the influence of this variable on soils loss. The results observed in this research are highly coincident with a research previously carried out with guadua by Rodríguez and Sepúlveda (2004) whom found low levels of soil loss under guadua stands when were compared with other land and use cover. Overall, erosion can be attributed to high rainfall erosivity and landform (slope). It increases as the level of cover decreased. In addition, on treatment T4 the soil is exposed to rainfall and readily transportable particles can augment the amount of sediments loss.

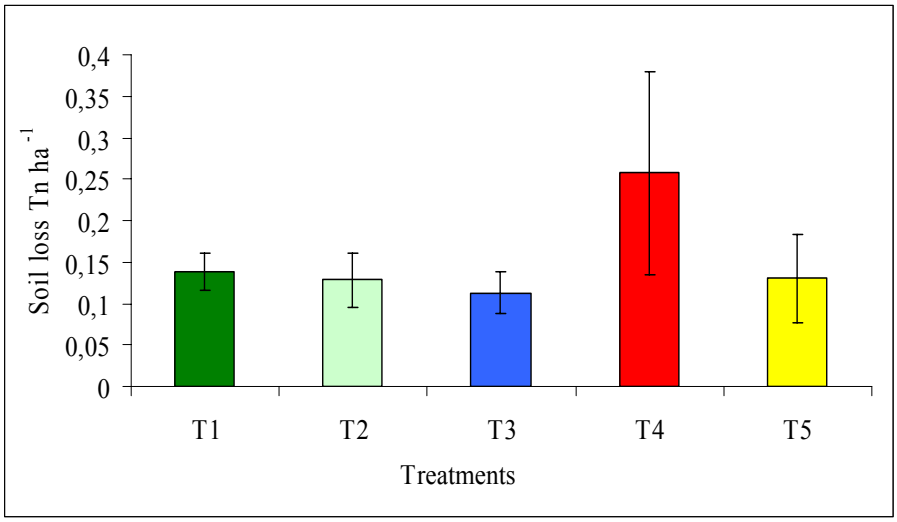


Figure 15. Soil loss (Tn ha^{-1} per seven months) under different treatments: natural regeneration (T1), tree plantation (T2), guadua plantation (T3), temporary crops (beans) (T4) and pastures (T5). Finca Nápoles, Montenegro, Quindío, Colombia. Vertical lines on the bars indicate the standard deviation. Different letters indicate statistical significant differences ($P<0.05$).

Conclusions and recommendations

Forest mensuration methods are adequate for determining the growth pattern and the explicit dendrometric and stand characteristics of guadua. Though these methods should be applied considering adjustments that depend on specific features of this bamboo resource. Thus information from inventories will be reliable and useful for making decisions.

For determining the effect of site conditions on guadua is necessary to define previously which variables could be used to evaluate the response to factors associated to site. In this sense predictive models for culm length, basal area and culm hardness show a reasonable goodness of fit and might be considered as response variables to determine the effect of environmental factors on guadua productivity and quality. Thus, average culm length and stand basal area can serve as indices of guadua stand productivity. Whereas average culm hardness is useful to determine culm quality within guadua stands. Although, the variability in productivity and quality of guadua could not be entirely described by the environmental set of independent variables measured, these results are a significant contribution to know on the potential use of this natural resource in the coffee region of Colombia.

Combining harvest intensity and frequency is possible for establishing the best level of silvicultural management, maintaining as a reference an adequate number culms per ha. For guadua plantation the fertilisation of Guadua and the reduction of interspecific competition with herbicides, represent high possibilities to increase the yield within guadua plantation. Nevertheless, now is required to study in detail this topic which has been barely studied for guadua.

The implemented model for forest planning was useful to define land capability and also units of forest management. Nowadays, government institutions can lead the planning of guadua stands based on this model. Besides, the units of forest management are an alternative against drawbacks relate to fragmented pattern of guadua stands.

Even though guadua bamboo forest in the coffee region of Colombia are highly fragmented, they fulfill important ecosystems functions and provide environmental services such carbon sequestration and soil protection that contribute to maintain the stability even within transformed areas (agroecosystems). Hence strategies for ecosystems conservation or an adequate management of these forests should be implemented, given that are almost the latter remnants of forest cover in this significant area of Colombia. Ecosystems functions and environmental services are provided by guadua bamboo forest even under harvesting. Thus some incomes and products are directly perceived by farmers and certainly, it could motive them to maintain areas under guadua forest within their farms. Thus it would be an strategy that could contribute to the sustainable development of rural areas upon the base of integrating production and conservation.

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Lei Bamboo (*Phyllostachys praecox*) Growth Degradation associated with Soil Properties using an Organic Material Mulching Technique

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Abstract

In the last 20 years, Lei bamboo (*Phyllostachys praecox*) has been extensively planted on former paddy soils for its high economic profit in Southeast China. However, Lei bamboo showed a significant degradation in growth after several years with an organic material mulching technique. Based on the inquiry of the farmers, we speculated that soil basic properties changed with the intensive management may be responsible for the bamboo degradation. Accordingly, an investigation of soil basic properties with the bamboo plantation was made in detail. A series of bamboo soils with various planting times was chosen to analyze the soil basic properties. Results showed that soil pH values decreased significantly from 5.71 to 3.85 with increasing planting time, while soil organic C, total N and P increased dramatically. At the same time, soil active Al which is toxic to plant growth increased dramatically from 3.85 to 197.6 mg kg^{-1} after 15 years of the bamboo plantation. High Al content was found in the degraded bamboo roots that verified the hypothesis that the intensive management made soil nutrients available imbalance and lowered the soil pH greatly that possibly resulted in the bamboo growth impairment. Therefore, the present practice of bamboo management had a great influence on soil quality that affected the bamboo sustainable production. A better or improved practice should be used in the future of the bamboo production.

Keywords: aluminum, bamboo, intensive management, soil properties

Introduction

Lei bamboo (*Phyllostachys praecox*) is a famous kind of bamboos for shoot food production in China. This bamboo has advantages in early shoot supply, long time of shoot production, high yield and delicious taste after tamed from the local nature species. Lei bamboo mainly distributes in the counties of De-qing, Yu-hang and Lin-an of Zhejiang Province, Southeast China. Since from 1990, the bamboo plantation has been obtained a great economic benefit using an organic material mulching technique to increase soil temperature and supply

shoot earlier in the winter. Hence, the cultivating area of Lei bamboo has been increasing greatly in the region. However, with the planting time increased, the bamboo stand degradation occurred and shoot yield decreased significantly. In the first year of organic material mulching, the yield of bamboo shoot can reach 35 ton per ha, but it drops to less than 10 ton per hm^2 when the stand degraded after 5 years. Thus, the sustainable bamboo production becomes a practical problem due to the bamboo growth obstacle. Presently, the area of Lei bamboo is about 27,000 hm^2 in Lin-an city, however, 1/4 of which is showing degradation with lower production. Some researchers considered that the main reason of the bamboo degradation was irrational bamboo stand management that resulted in a weak growth of bamboo and finally to the stand degradation (Jin et al. 1999; Yu et al. 2001). However, there was no sufficient evidence to elucidate the bamboo degradation with the intensive fertilization and the organic material mulching technique involved.

The organic material (rice straw and bran) mulching technique was developed by the local agricultural technician of Lin-an city (Jin et al. 1998). Using this technique, the bamboo shoot yield was improved greatly and the harvesting time was brought ahead that greatly increased the profit of the bamboo planting. Accordingly, this technique was extensively used in the region of Lei bamboo plantation and even to other neighboring provinces. According to our preliminary field investigation, the bamboo tended to degradation after 5 years using the mulching technique. However, judged from the bamboo growth, no evidence can support the explanation of bamboo degradation induced by irrational management practices (Yu et al. 2001) because the bamboos with or without the mulching technique showed no significant difference in growth in the field, indicating the farmers' management practices were not greatly different in the field using the technique or not, especially in the harvesting of bamboo shoot. Because of the large inputs of fertilizers and organic materials with high C/N ratio, soil acidification can be expected severe in the bamboo plantation soil.

The changes of soil properties with respect to the organic material mulching technique may be responsible for the bamboo withering. Therefore, the objectives of this study were to investigate the basic physiochemical properties of soils with bamboo plantation using the mulching technique to provide an evidence for a better bamboo management. At the same time, the information obtained from this study may be of benefit for us to understanding the influence of bamboo intensive plantation on soil properties.

Materials and Methods

Study Site Description

The study site is located at Lin-an city, Zhejiang Province of China. This region belongs to the sub-tropical monsoon zone. The landform here is hilly with elevation around 150 m. The annual mean temperature is 15.9 with a maximum of 41.3 and a minimum of -13.3 . The annual rainfall is 1550 mm with 236 free-frost days. In this region, the soil type belongs to ferrosols derived from red sandy rock-bed. Lei bamboo (*Phyllostachys praecox*) is a local species and was tamed to plant on the former rice field for high yield, so we selected the rice field plot as the control.

A technique of organic material mulching was developed and adopted in the Lei bamboo production. The mulching technique uses rice straw and bran, sometimes bamboo leaves as the mulching material. The bamboo

soil surface is usually started to mulching during the period from November or December to March of next year to increase soil temperature and keep soil moisture in the winter season. The data showed the ground temperature could raise 4-5 after mulched with organic materials (Fang et al. 1994). During the mulching process, rice straw was firstly mulched to a height of 10-15 cm from the surface and then rice bran was filled onto another height of 10-15 cm. The total rice straw and bran used in one time commonly reached 40 and 55 t hm^{-2}. In the next year, the undecomposed rice bran layer was removed in March or April while the rice straw almost decomposed or mixed into soils. In the next mulching time, the removed rice bran was mixed with new to be used. The fertilizer applications were used for three times, i.e. mid-May, mid-September and the time before the mulching, respectively. The fertilizer application rate was about 2.25 t hm^{-2} (N:P:K=16:16:16) and urea 1.125 t hm^{-2}, sometimes manures with equal nutrient used as well. The use of organic material mulching technique began from the 5th year after the bamboo transplanting.

Soil Sampling

During the bamboo plot selecting, similar soil position, landform, initial soil fertility and soil basic physiochemical properties before bamboo plantation were considered. The selected planting time was 1□5□10 and 15 years, respectively. After 10 years, the bamboo stand became to showing degradation in the field. The rice field was chosen as the control because the bamboo planted on soils shifted from the paddy soils. Each replicate of plot selecting was located at one farmer's field to keep the same original condition of soils from the influence of field management. The area of each selected bamboo plot is larger than 100 m^2. Due to the shallow root depth of Lei bamboo, the soil profile was separated into 5 layers as 0-5, 5-10, 10-15, 15-20 and 20-25 cm, respectively. Before the collection, litters and mulching materials on the soil surface were removed. We selected three sites for sampling and there replicates were done on the each bamboo plot and paddy plot. Fresh soil samples were air-dried and ground to pass through 2 mm sieve. In order to test the hypothesis of Al toxicity with low pH to Lei bamboo, roots of bamboo were also collected in each plot.

Soil Analysis

Soil basic physicochemical properties, including soil pH, organic matter, nitrogen, cation exchangeable capacity (CEC), were analyzed. Soil pH was determined by electrode method. Soil organic matter was measured with $K_2Cr_2O_7$ oxidation and $FeSO_4$ titration. CEC was extracted by 1 M NH_4Cl and K, Na, Ca and Mg were determined by the atom adsorption system (AAs). Because Al may be one factor influencing bamboo growth in red soil with low soil pH, various Al forms were also measured. These Al forms included exchangeable Al, dissociated Al, amorphous Al, organic bound Al and total Al. The exchangeable Al was extracted by 0.1M KCl (James et al. 1983), dissociated Al (Al_d, dithionate), amorphous Al (Al_o, oxalate) and organic bound Al (Al_p, pyrophosphate) were determined by the method proposed (Odes 1963; McMeague and Day 1966). Bamboo roots were digested with $HClO_4$+HF and Al content was measured by AAs.

Results and Discussion

Effects of Bamboo Plantation on Soil Properties

As shown in Table 1, soil pH value decreased with increasing planting time. After the bamboo planted 15 years soil pH dropped to 3.85 that was almost 2 units lower than that of the paddy soil. Such a result indicated that bamboo plantation accelerated the soil acidification when using this intensive management model. Soil acidification is a naturally occurring phenomenon and is usually the result of long-term additions of protons to the upper layers of the soil profile that effectively results in the displacement of exchangeable bases and their subsequent leaching. However, accelerated acidification of soils associated with export of alkali through product removal, or movement of cations associated with nitrate leaching, has brought into question the long-term sustainability of crop and forage production systems (Helyar 1976). In this study, the accelerated acidification in a short term exerted an important impact on bamboo sustainable production. When using the organic material mulching technique, bamboo soils simultaneously received nitrogen fertilizer with a rate of ca. 800 kg N hm^{-2} annually that accordingly made a direct impact on the soil acidification. Due to acid release in the decomposition, the mulched organic material also had an impact on soil acidification but no evidence was obtained up-to-now in the bamboo plantation.

Soil organic matter content increased greatly from 31.0 to 79.2 g kg^{-1} after 15 years (Table 1). Obviously, the increase of soil C and N (from 2.02 to 4.61 g kg^{-1}) was closely related to the input of fertilizer and organic matter. During the first 5 years, soil organic matter and nitrogen contents were slightly lower than those in the control of paddy soils. In the process of paddy field shifted to upland, easily decomposable organic matter decomposed rapidly due to a better oxidation condition. After the rice straw and bran mulching (from the 5th year), soil organic matter and nitrogen increased with increasing planting time. Usually in the intensive managed moso-bamboo, soil organic matter decreased gradually with planting time (Xu et al. 2003). Because there was no organic matter input to the moso-bamboo only chemical fertilizer applied, soil organic matter oxidized and decomposed rapidly without extra input.

Soil total phosphorus content increased significantly from 0.500 to 2.005 g kg^{-1} with increasing planting time. Since the source of P was derived from the fertilizer application and the movement of P in soils was difficulty especially under the acid soil because P can be bound closely with Fe and Al minerals. Meantime, the bamboo soils were shifted from paddy soils where nutrients are not easily leached through runoff due to a plat landform with ridges. The accumulation of P reached such a high level that may result in bamboo blooming earlier and bamboo degradation. We found some blooming bamboo culms in the field, but the number was few. However, compared with soil P, soil total potassium showed no difference in various blocks (Table 1). This indicated that applied K was balance to the bamboo growth if no significant K leached.

Soil available P and K increased greatly after the bamboo planted for 15 years. Especially, the available P increased from 7.14 mg kg^{-1} in the paddy soil to 475.6 mg kg^{-1} in the bamboo soil of 15 years. The overloaded soil P exerted a great risk to the surface water environment. Available K content increased but the total K content showed no increase even with high fertilizer input, indicating large K leached from the bamboo field.

Effects of Bamboo Plantation on Soil Al Forms

Aluminum in soil includes mineral and aqueous forms, where Al minerals are mainly primary and secondary minerals such as aluminosilicate and non-aluminosilicate Al. According to its bound form with minerals, soil mineral Al can be classified as exchangeable Al, hydroxide bound Al, organic complexed Al, hydroxide Al and non-crystalline aluminosilicate Al. Water soluble Al includes dissociated Al, mono-nuclear hydroxide Al, multi-nucleus hydroxide Al, Al-F, $Al_2(SO_4)_3$ and organic complexed Al. Soil Al chemical forms are comlicate in soils that depends on the environment, especially on soil pH value. When pH is less than 5, Al is mainly present in Al^{3+} form. When pH increases, $Al(OH)^{2+}$ and $Al(OH)_2^+$ occurs. When pH is equal to 7, Al will be present in $Al(OH)_3$ or gibbsite. Under the alkaline condition, $Al(OH)_4^-$ or aluminosilicate is present. Mono Al ion can be complexed with inorganic ligands, such as PO_4^{3-}, SO_4^{2-}, F^-, organic acid, protein or adipose. The toxicity of various Al forms on plant is different. Relatively, the toxicity of various Al forms show an order as: Al^{3+}> $Al(OH)^{2+}$> $Al(OH)_2^+$> F-Al >>organic complexed Al.

Because soil Al form is closely related to soil pH and organic matter, the change of pH and organic matter will result in a great change of soil Al form and distribution pattern. As shown in Table 2, the total soil Al content in the surface layer (0-25 cm) decreased in the bamboo plot significantly but the exchangeable Al content increased greatly from 3.85 mg kg^{-1} to 197.6 mg kg^{-1} compared with the paddy soil. The extracted amorphous Al, dissociation Al and organic bound Al also increased significantly in the bamboo plot. Soil Al dissociation degree (Al_d/Al_T) and activation degree (Al_o/Al_d) both increased as well. Accordingly, the bamboo plantation greatly increased the solubility and movement of Al that exert an extreme toxic risk on bamboo growth. Possibly, the improved soluble Al affected the bamboo shoot and resulted in a yield drop. Due to fixation with soil solid phase or phosphate, the concentration of Al in soil solution is generally very low that has little effect on plant growth. However, when soil pH is lower than 4.5, Al will release substantially from bound form to soluble form and be harmful to plant growth. As pointed out, plant root growth and development is the primary target of Al toxicity (Sivaguru and Horst 1999; Vebelen et al. 2006). When soil soluble Al concentration arranges 10 to 20 mg kg^{-1}, plant will appear obvious harmful diagnosis (Shen and Yan 2002). There is no evidence to indicate the tolerance extent of Lei bamboo. Factually, the bamboo shoot production decreased significantly and inferred that Al toxicity might mainly responsible for the yield decline.

The bamboo plantation greatly influenced soil Al distribution pattern in the profile (Fig. 2). In the paddy soil, soil total Al distributed evenly in the layer of 0-25 cm, while it increased with increasing soil depth in the bamboo soils (the 15th year). As indicated in Table 2, the total Al content is lower in the bamboo plot than that of paddy plot, suggesting the current bamboo plantation management also improved Al leached from the surface layer.

Soil Properties and Al Form Transformation

Soil Al forms are influenced greatly by the other soil basic properties. Al dissolved from the minerals to soluble phase is determined by the system pH. We can find out clearly that the content of exchangeable Al exponential decreased with increasing pH within the pH segment of 3 to 6 (Fig. 3). This result is well consistent to that explained by the physicochemical computation. From the Table 2, no linear relationship existed among the pH

and Al_d, Al_p, Al_o and Al_T. However, a good relationship was present between the pH and Al dissociation degree (Al_d/Al_T), indicating pH value also controls soil Al dissociation degree.

Theoretically, the content of organic matter could determine the ratio of organic bound Al (Al_p), but there was no good relationship present between the pH value and ratio of Al_p/Al_T. Possibly, the composition of organic matter was different among the various blocks and pH influenced the effect of organic matter on Al complexation. The combination effect of organic matter and pH on organic bound Al was obvious in the bamboo soils.

Organic Material Mulching Technique and its Implications

Soil acidification is a slower process in the natural environment. Using the rice straw and bran mulching technique, the bamboo soil acidification was accelerated. Namely, soil pH almost dropped 0.12-unit per year. The bamboo soil acidification might result from the fertilizer application, mulching material decomposition and bamboo root acidic secretion. However, we did not have enough evidences to distinguish the acidification contributions from these sources. One point could be confirmed that it was the mulching technique with high fertilizer application accelerated the soil acidification. Additionally, Al content in the bamboo root was measured and the results showed that it increased greatly in the degraded bamboo root (Fig. 4). In the first year after the bamboo transplanting, Al content in the root was about 2000 mg kg^{-1}, but increased dramatically to 8000 mg kg^{-1} after 10 years of bamboo planting. Of course, the accumulation of Al in the bamboo root was related to soil active Al (Fig. 5). Therefore, we inferred that the bamboo degradation with intensive management was mainly resulted from the soil acidification due to the high fertilizer application and mulching technique.

Certainly, the mulching technique was extensively accepted and brought profit for the bamboo farmers. However, the adverse effects of rice mulching on soil quality were not yet been studied in detail. The bamboo withering after 5 to 10 years after the mulching did not obtain enough notes from the soil view by the farmers. Moreover, the effects of mulching technique on the bamboo ecological environment merit further studies.

Conclusions

With the increasing bamboo planting time, the contents of soil organic matter and total nitrogen increased greatly. Total phosphorus accumulated obviously after 15 years of bamboo plantation. The contents of available phosphorus and potassium also increased greatly with the bamboo planting time. However, soil pH value lowered significantly on the contrary. Soil exchangeable, dissociated, organic bound and amorphous Al increased significantly with the bamboo planting time. Soil Al dissociation degree increased with the bamboo planting time as well. The accumulation of Al in the bamboo root was greatly in the degraded bamboo stand that was also closely related to the active Al in soil. It was soil acidification and accordingly high active Al that affected the bamboo shoot growth and finally resulted in the bamboo degradation. The current management of bamboo production should be improved to meet the sustainable Lei bamboo production.

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Table 1. Soil properties changed after Lei bamboo plantation with various planting years

Panting time	pH	OC ($g.kg^{-1}$)	TN ($g.kg^{-1}$)	TP ($g.kg^{-1}$)	TK ($g.kg^{-1}$)	AP ($mg.kg^{-1}$)	AK ($mg.kg^{-1}$)	CEC ($cmol.kg^{-1}$)
0	5.71 a	31.0 b	2.02 b	0.500 d	11.11 a	7.14 d	40.5c	13.4 c
1	5.37 a	25.5 c	1.86 b	0.735 c	11.50 a	38.3 cd	62.3 bc	15.7 c
5	4.76 b	25.0 c	1.71 b	0.741 c	12.41 a	54.1 c	75.9 abc	14.3 c
10	4.33 b	33.1 b	2.07 b	1.280 b	11.06 a	171.8 b	110.8 ab	19.2 b
15	3.85 c	79.2 a	4.61 a	2.005 a	11.03 a	457.6 a	131.9 a	32.5 a

*Different letters represent 5% significance with Duncan's test.

Table 2. Soil Al forms in surface layers of paddy and bamboo soils (mg kg^{-1})

Time yr	Al_{ex} *(mg kg^{-1})*	Al_d *(mg kg^{-1})*	Al_p *(mg kg^{-1})*	Al_o *(mg kg^{-1})*	Al_T *(g kg^{-1})*	*Dissociation degree* Al_d/Al_T*(%)*	*Activation degree* Al_o/Al_d*(%)*
0	*3.85 a*	*1404 a*	*344 b*	*2088 a*	*54.1 b*	*2.60*	*1.49*
1	*4.25 a*	*1583 ab*	*245 a*	*2073 a*	*54.0 b*	*2.93*	*1.31*
5	*86.6 b*	*1870 bc*	*545 c*	*2217 a*	*54.3 b*	*3.45*	*1.19*
10	*91.0 b*	*1860 c*	*612 d*	*2276 a*	*52.5 b*	*3.55*	*1.23*
15	*197.6 c*	*1800 c*	*653 e*	*2210 a*	*49.4 a*	*3.67*	*1.23*

*Different letters represent 5% significance with Duncan's test.

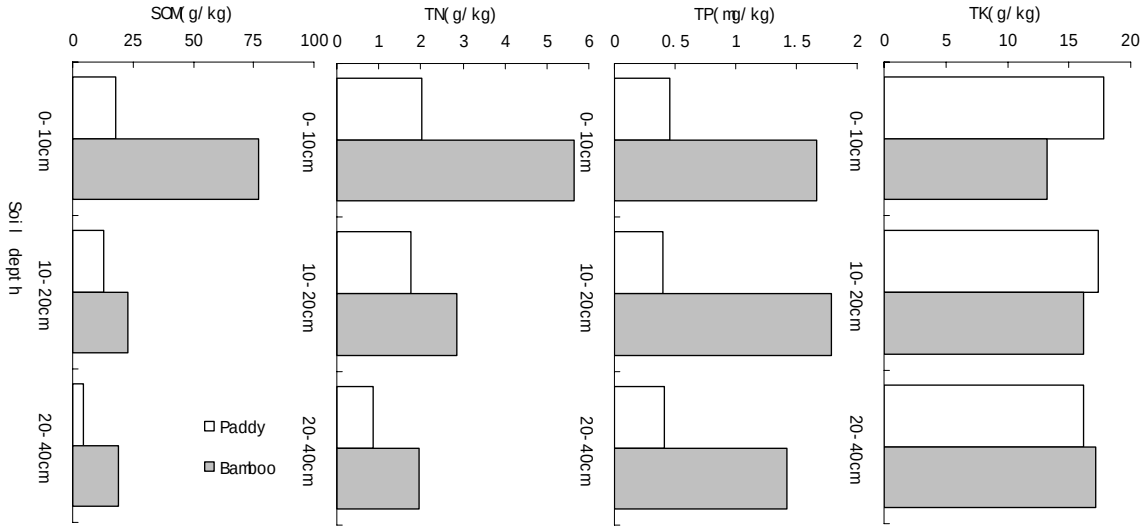

Fig. 1 Soil nutrients of C, N, P, K distribution in profiles of paddy and bamboo soils with 15 years

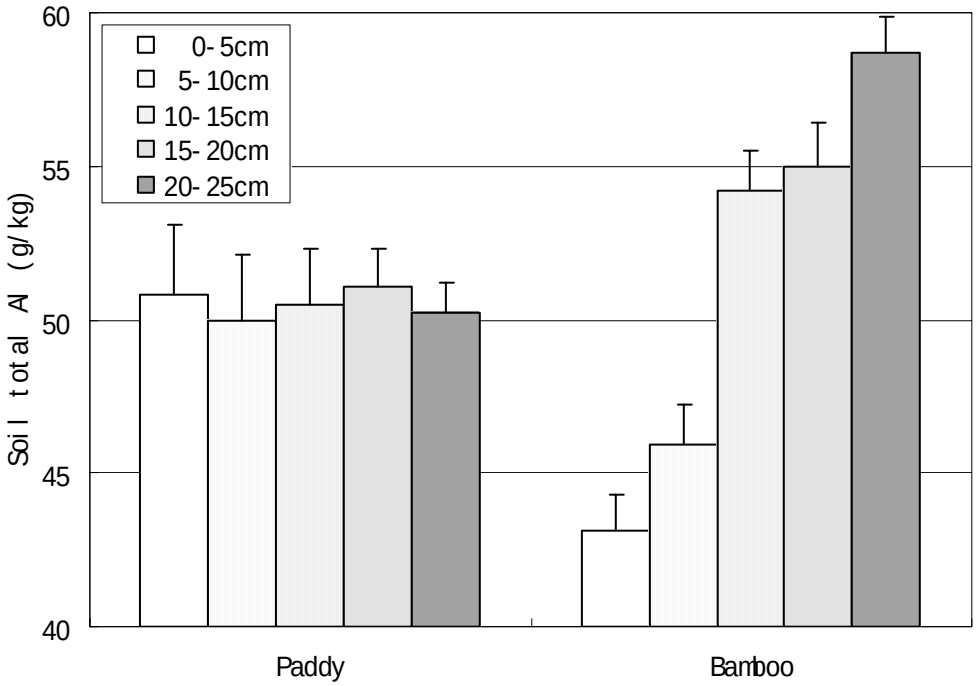

Fig. 2 Total Al content varied with depth in the paddy and bamboo soils with 15 years

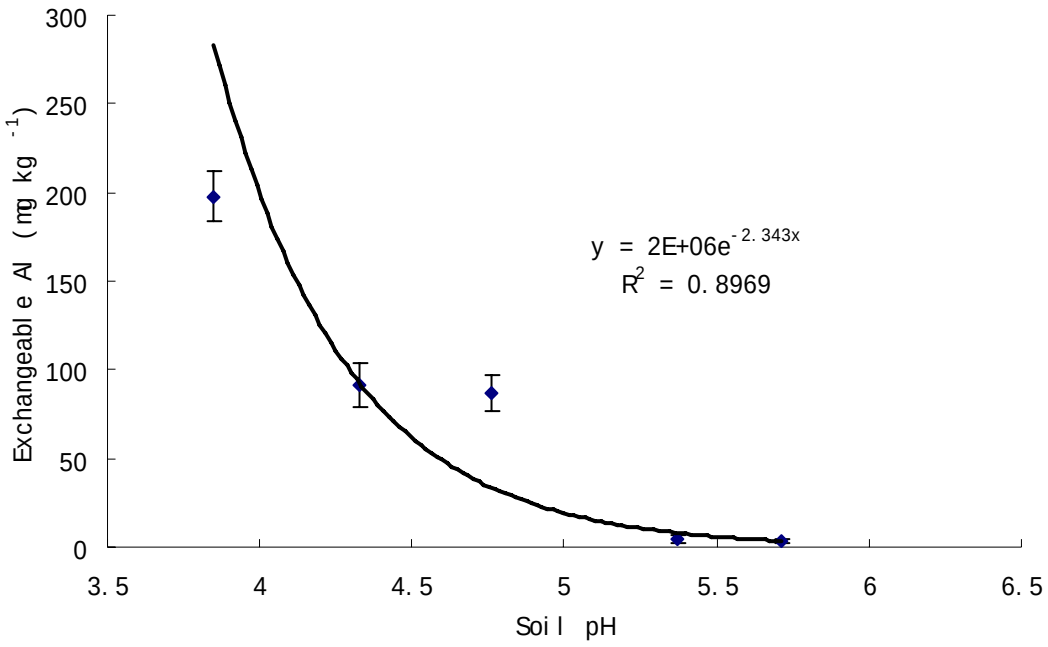

Fig. 3 Soil exchangeable Al content varied with soil pH value

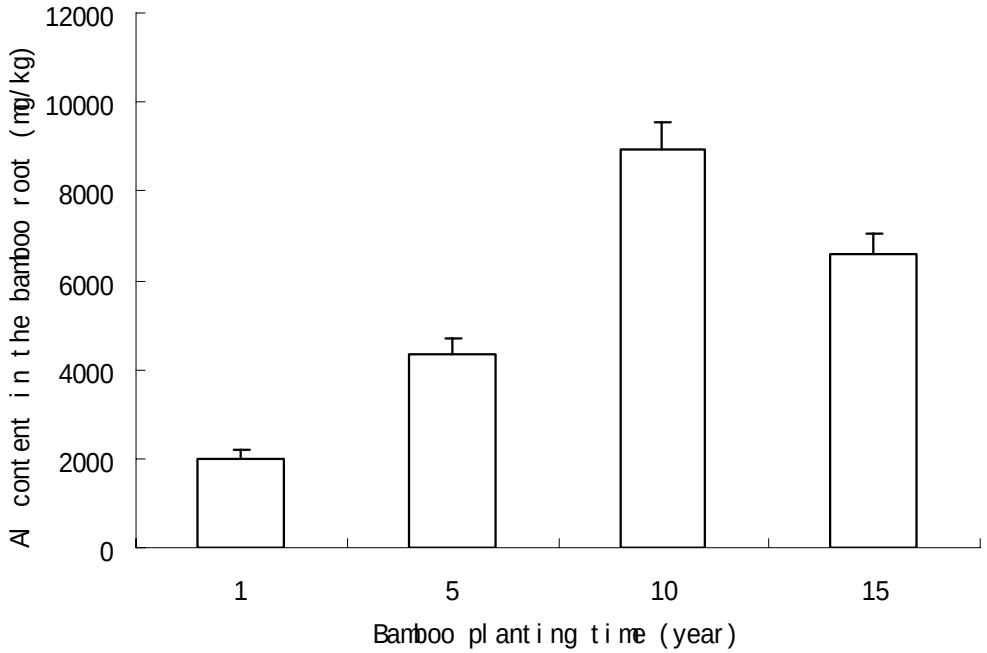

Fig. 4 Al content in the bamboo root varied with planting times

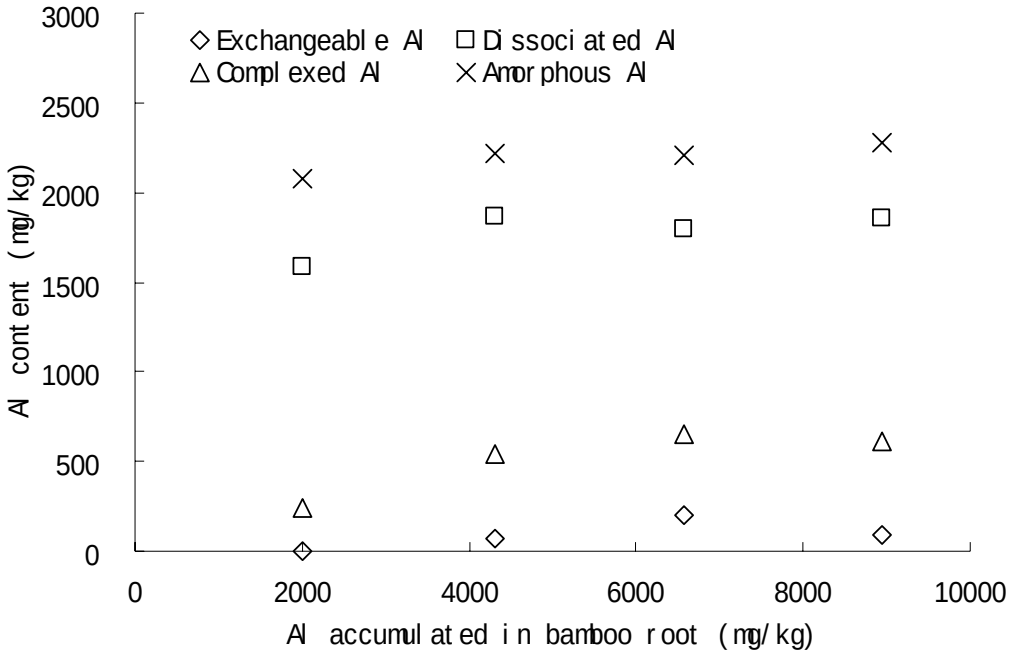

Fig 5. Relationships among the Al accumulation in bamboo root and various Al forms in soil

Optimising Inputs for Production of Bamboo Shoots and timber[2]

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Abstract

This paper discusses silvicultural management effects on yields of bamboo shoots as a vegetable and for biomass production by bamboo culms. Bamboo yields respond positively to silvicultural practices, both in terms of shoot number and yield and biomass production. Fine-tuning is necessary for optimal input:output relationships. However, data collected on the physical and mechanical properties of culms from different silvicultural practices are important from a practical perspective: managing clumps for sustainable shoot or timber productions does not appear to seriously interfere with the intended use of culms. However, differences between species and treatments that affect the ages of culms at harvest are important considerations when choosing bamboo production practices

Introduction

Bamboo in a natural and plantation context is commonly harvested for its shoots as a vegetable, and for culms (poles) as a wood substitute. Global trade to the extent of US$ 7 billion attests to this. As a non-timber forest product (indeed a misnomer, for it often replaces timber) bamboo does not figure in inventories of forest timber resources, but its sustainable management is equally as important as that of forests, whether it is harvested for shoots, for timber, or for both. Sustainable management should be an important goal for natural and plantation stands of bamboo, yet surprisingly little research has been directed towards defining appropriate guidelines to stakeholders in the bamboo industry, an industry that accesses c. 40 Mha, or 1% of global forest area (FAO 2005). The sustainable management of the bamboo resource is not only relevant to the tangible products of sustained shoot and culm harvests, but also for the sustained provision of important ecosystem services such as carbon sequestration, erosion containment, and local climate regulation (Zhou et al. 2005). Unregulated exploitation of stands is a major reason for degradation of bamboo resources worldwide. Harvesting of very young culms for fiber or timber has jeopardized bamboo growth since ancient times, e.g., in China, but more recently inappropriate harvest has lead to extremely low (when overexploited) and extremely high (when unmanaged) standing-culm densities. If bamboo stands are left undisturbed, biomass production increases until

[2] This draws upon publications by Midmore (2009a) and Kleinhenz and Midmore (2001)

aboveground and belowground competition results in decreasing annual rates of biomass gain. Control of standing-culm density is the most important measure to combat such a decline in productivity.

In order to be sustainable, outputs from production must be at least matched by inputs, and provision of those inputs must not jeopardise the sustainability of the resource pool from which the inputs are drawn.

Four major examples may be cited. Firstly, the pool of carbon dioxide which provides the chemical basis for much of biomass (on average c. 50% by dry weight of biomass is carbon – Scurlock et al. 2000) is to all intents and purposes limitless, and unlikely to diminish because of the photosynthetic demand by bamboo. Within the canopy on still days carbon dioxide may drop to a concentration that does limit photosynthesis, but that is another story. Secondly, the fresh water resource available to bamboo globally is sufficient to satisfy the demand by 40 Mha of bamboo, but locally this may not be so. Spatial heterogeneity in the distribution of water resources for bamboo, whether it simply be rainfall or captured and stored water resources, will influence the biomass production of bamboo, and the choice of plantation set-ups. Inordinate demand on stored water reserves to the detriment of that water use by other industries, especially if the total resources are depleted over time, cannot be considered as sustainable. Practices to increase the efficiency of producing shoots or culms per unit of water uptake and to optimise the use of the water resources should be implemented.

Thirdly, the spatial heterogeneity of mineral nutrients contained with the soil likewise strongly influences bamboo biomass production, and, if not replenished as they are removed in harvested shoots and culms, can limit the sustainability of bamboo stands. As a final example, the availability of labour or mechanical practices that satisfy the high demands for either by the bamboo crop will constrain the sustainability of bamboo production. Excessive costs for mechanical solutions to harvesting and processing of bamboo products, or competition with alternative livelihoods for the normally surplus labour pool, can limit the sustainability of bamboo production. These need to be considered when planning for expansion of the industry. On the positive side, establishment of new bamboo plantations and their intensive management open up new job opportunities and scope for economic growth, regionally and nationally.

In order to address the sustainability of bamboo production, from an input-output perspective, it is necessary firstly to consider potential yield and output data, and then to relate that to known resource availabilities and to resource use efficiency by bamboo stands in the face of varying input availabilities.

Expected bamboo yields

Bamboo is best known for its fast growth rate. It can produce harvestable culms within 4–7 years of planting, which subsequently can be harvested annually. For this reason, it is expected that in the future, the major demand for bamboo will be for timber substitution more than for edible shoots. Recognising this potential, in recent years, there has been increasing documentation of bamboo productivity (Isagi 1994; Isagi et al. 1997; Kleinhenz and Midmore 2001; Hunter and Wu 2002; Wang 2004; Castaneda-Mendoza et al. 2005; Midmore 2009a).

Focusing on the above-ground culm biomass, but excluding data for branches and leaves (and data that appear erroneous), the above-ground culm weight of the highest-yielding bamboo stands (c. 150 t/ha) is similar to that

of average forest tree stands (100–160 t/ha), but does not match that of the very high values attained by some tree stands (300–1,700 t/ha; Hunter and Wu 2002). In contrast to trees that can accumulate biomass over long periods through radial and vertical extension of stems (trunks), bamboo culms lay down most of their biomass within their first year of growth, largely from current assimilation but also from redistribution from older culms and rhizomes (Magel et al. 2006), and die off after a maximum of 8–10 years, resulting in a decline in biomass of individual culms over long periods. Isagi (1994) referred to this as the biomass accumulation ratio (biomass/net annual production) and showed it to be 4.66 for a stand of *Phyllostachys bambusoides* in Japan.

Culms on average comprise c. 75-83% of total aboveground biomass, branches *c*. 12-15% and leaves *c*. 5-7%. On an annual basis, above-ground culm growth rates (fresh weight) of 10–30 t/ha/year have been reported (summarised by Kleinhenz and Midmore 2001), which is in line with those of woody species (Hunter and Wu 2002). Although one report with *Bambusa bambos* mentions 47 t/ha/year, productivity of bamboo on an annual basis is generally no greater than that of woody species, and bamboo is no more efficient at sequestering carbon than are woody species. Below the ground, bamboo sequesters carbon in the form of rhizomes, and below-ground biomass is greater proportionately for monopodial (running) species at c. 43% of total biomass compared to c. 31% for sympodial (clumping) species (Kleinhenz and Midmore 2001). The rhizome therefore represents an important sink for sequestered carbon but, according to Hunter and Wu (2002), this sink is no larger than that of woody trees. One advantage of bamboo over trees is that culms can be harvested much sooner than trunks of woody species (Figure 1) and another is that they can be harvested on an annual basis without the environmental consequences of clear-fell. Given that culms can be harvested on an annual basis, inter-culm competition for light is lessened, and younger culms, those with greater photosynthetic efficiency, gain greater access to light, supporting therefore faster growth rates. This is evident in Zhu et al. (2009) who show the drop in light interception by the canopy when older culms are harvested and the capture of that light by younger culms soon thereafter. The effect on biomass is marked. For example, net annual biomass production of 9.3 t/ha per year in 12-15 year old Dendrocalamus asper was raised to 26.3 t/ha per year one year after culms >4 years of age were removed from the clumps (Kao and Chang, 1989).

Removal of all culms at harvest represents removal of c. 150 kg N, 30 kg P and 260 kg K per hectare, leaving between 25 to 70% of those amounts in the rhizomes (Kleinhenz and Midmore 2001). Exceptionally, higher values up to five times these have been reported. On an annual basis, with culm yields of on average 13 t/ha/yr c 36 kg N, 9 kg P and 63 kg K are removed per hectare, but with culm yields possibly four times these values much more would be removed.

Leaf litter annually provides between 13-22% of the total NPK in total biomass, when stands are 6 years or older, and some is taken up for incorporation into new leaves which are the major sinks for nutrients. The resorption efficiency is higher for K (c. 43%) less for P (37%) and least for N (19%) (Embaye et al. 2005). Internal recycling is important for bamboo to make efficient use of nutrients, as is the ability to take up nutrients from a decomposing litter mass (Das and Chaturvedi, 2006). Nevertheless, without nutrient inputs the soil nutrient resource declines, as illustrated by data of Wu et al. (2006) showing that total soil N decreased by 5.2% and available P by 15% following 3 years continuous cropping with *Phyllostachys iridescens*.

Shoot harvests represent a smaller nutrient sink than culm harvests. For example, nutrients removed in fresh shoots (on average 16 t/ha/year yield; 5-10% dry weight; 4.0, 0.6, and 4.0% N, P, and K) average at 49, 7, and 49 kg N, P, and K/ha/year. In stands managed for optimal shoot production a significant amount of biomass and nutrients are removed in shoot and culm harvests – about 85, 16, and 112 kg N, P and K/ha/year are removed when bamboo is grown for average shoot and timber yields Kleinhenz and Midmore 2001). Shoot yields reported to reach 40 t/ha per year (Pan 1986) would considerably increase the demand for nutrients.

A series of field experiments have been conducted in Australia and the Philippines (Midmore et al. 1998; Midmore and Kleinhenz 2000; Kleinhenz and Midmore 2001, 2002) and more recently (Midmore 2009a). In the latter, best practice was imposed as a 'control' treatment, and then in other treatments omitting one or other practice (for example, omit fertiliser and/or irrigation, omit the thinning regime) to study the impacts upon shoot and culm (pole) production. The following section draws heavily on the outcomes of the series of experiments conducted under project activities funded by the Australian Centre for International Agricultural Research, and published recently by Midmore (2009a).

Appropriate management practices for sustainable shoot production

Although a group of species with a long association with Asian cultures, bamboo in Australia was originally planted starting in the 1990s with a view to producing bamboo shoots to offset the importation of canned produce (Midmore 1998), and later to expand into rewarding export markets identified in Asia (Collins and Keiler 2005). In contrast, in the Philippines, bamboo is harvested mainly as a timber substitute, with only localised cultivation and use of shoots as a vegetable—indeed local ordinances often prohibit shoot harvests (Virtucio and Roxas 2003). In other Asian countries it is valued not only for timber, but also for fresh shoots especially in the hot summer monsoon season when other vegetable species are in short supply.

Management factors that influence shoot production (Kleinhenz and Midmore 2001 and many of the >200 cited references contained therein) fall mainly under irrigation, fertiliser, mulch and thinning regimes. Species has an overriding effect on shoot size, number and timing of production and some tentative conclusions are drawn from the experimental data published by Midmore (2009a).

Irrigation and rainfall

Supply of water to bamboo just before and during the shoot season has been recognised as an enhancing factor for the onset and continued production of shoots from running (monopodial, e.g. *Physostachys pubescens*) species of bamboo (Kleinhenz et al. 2003), and data from more recently reported experiments (Zhu et al. 2009; Malab et al. 2009) and others (e.g., Thanarak 1996) confirm this for clumping (sympodial) bamboo species.

For example, in the Philippines, at the two sites where irrigation was an experimental factor (Ilocos Norte and Capiz), irrigation increased the number of emerged shoots,; the effect was greatest if combined with fertiliser application (Malab et al. 2009; Marquez 2009). In an Australian site in Queensland (Zhu et al. 2009), a treatment of withholding irrigation was confounded by a complete absence of clump management and the combined effect of which was to significantly reduce the number and size of shoots that emerged. However, the

major irrigation factor under investigation was that of testing the need for irrigation during the dry winter season. In Queensland, the water-use efficiency of shoot production was raised by 28% by omitting irrigation during winter (Zhu et al. 2009), and in the Northern Territory (NT; – Traynor and Midmore 2009) year-round irrigation was also shown not to be important for shoot production, provided it was supplied just before the anticipated shoot season—a 'date' characteristic to each species for reasons which remains a mystery. At one of the sites in the NT, the number of shoots was even greater in the treatment without winter irrigation than in the treatment supplied with irrigation throughout the year.

If winter temperature is low, clumping bamboo will not respond to winter irrigation in terms of shoot production.

Fertiliser

As for many other agricultural and horticultural crops, nutrient application rates, ratios between nutrients, schedules of nutrient application, form of fertilizer, and nutrient placement are equally important considerations in bamboo production. Since bamboo is a perennial crop, however, nutrient management schemes that have been developed for annual crops may not apply to it. Moreover, bamboo is grown for several products, and it is understandable that optimal fertilization will vary with purpose of cultivation. Due to increasing scarcity of resources in the future, there is a need to match efficient fertilizer use to sustained productivity, and to sustain favourable soil conditions over the short and long term.

Based on earlier research (Kleinhenz and Midmore 2002) and the response curves of percentage leaf nitrogen (% leaf N) to N application rate, it has been proposed that fertiliser N be added to ensure that % leaf N is maintained at close to 3%.

Application of fertiliser at these and even higher rates invariably allowed clumps to achieve high shoot yields (Zhu et al. 2009), consistently hastening not only the onset of shoot production (Traynor and Midmore 2009) as already seen by others (e.g., Thanarak 1996; Li et al. 1998), but also the rate of emergence and number of shoots. Even organic fertiliser has shown a small, but consistently positive response.

In Queensland, withholding N fertiliser led to significantly lower % leaf N than in fertilised treatments, the latter receiving an average yet unsustainable 700 kg N/year (Zhu et al. 2009). Leaf N declined during the shoot season, perhaps due to a within-clump dilution effect with the rapid growth of new culms and leaves during that period. Withholding N fertiliser may also lead to smaller (and unmarketable) shoots or reduce shoot number and therefore yield, depending upon species and location. The magnitude of the depressive effect of withholding N fertiliser on shoot production, both number and size, varies between years, especially without irrigation (Decipulo et al. 2009). Mortality was significantly lower in low N treatments than in other treatments (Marquez 2009).

Extensive research looking at the rates of N required to maintain % leaf N at c. 3% show that they are often uneconomic for shoot production and that a lower leaf N concentration is called for, specific to species and grower expectation.

Culm thinning practice

The intensity with which culms are removed from clumps, and reciprocally the number remaining, and the choice of culms harvested, governs the age structure of culms within a clump. To maximise early capture of light energy, some recommend leaving all culms in a clump until 4 years after planting (e.g., for *D. asper* – Thanarak 1996). It has become clear that for high yields of shoots to be harvested as a vegetable a bamboo stand should contain a high number of young culms (ideally only 1 or 2 years of age at the time of the shoot season). Older culms do not support nearly as many shoots per culm as do young culms (Malab et al. 2009). Indeed, in a high rainfall site in the NT of Australia, shoots selected for culm production at the beginning of the shoot season themselves produced edible shoots near the end of the same shoot season (Traynor and Midmore 2009). In a drier environment of Queensland, shoot production was greater when all early shoots were removed for sale, leaving only late-season shoots for culm production—possibly minimising the effect of apical dominance that may inhibit later shoot emergence. Likewise in the Philippine treatments with more young culms raised the productivity index (the number of shoots produced per standing culm – Malab et al. 2009), and in a rainfed site of Bukidnon, the standing culm density (SCD) of 10-10 (ten 1-year-old and ten 2-year-old culms) gave more shoots than the 6-6 treatment (Decipulo et al. 2009).

To be sustainable, the number of culms left to support the next year's shoot harvest must match the number of culms to be harvested on an annual basis – the duration (or lifespan) of culms between shooting and their harvest will depend upon the optimal total number to achieve full canopy cover and capture of light energy. For example, if 15 culms per clump represent the optimal number for such light capture, a clump could equally contain 5 one year old culms, 5 two year old and 5 three year old culms (a total of 15 culms at the time of shoot harvest) or 3 one year old culms, 3 two year, 3 three year, 3 four year and 3 five year old culms (again a total of 15 culms). The former would be preferable for shoot production systems (more younger culms) and the latter for pole or culm production (older culms are preferable for most purposes). Of interest, weight per harvested shoot was not affected by thinning regime in the NT, or by the spatial arrangement of standing culms in Queensland (widely spaced versus narrow spacing within a clump – Midmore 2009a).

Leaving all shoots to grow into culms causes congestion in the clumps, and constrains production of shoots in later years. For this reason, some minimal annual thinning of culms or shoots is necessary if clumps are to continue to produce shoots (and culms) on a sustained basis.

Species

Bamboo species harvested for shoots number less than 50, but even this number represents a great diversity in terms of possible management practices specific to each species. Shoot number per unit area in bamboo with large culm diameters (e.g., *D. asper*) are considerably fewer than in smaller-shoot-producing species *Bambusa oldhamii*. With clumps close to 10 years of age, the latter produce on average over 20 shoots per clump in optimally managed treatments in Queensland (Zhu et al. 2009). In contrast, the mature *Dendrocalamus asper* (giant bamboo) of Bukidnon produces few shoots, on average c. 1 shoot per standing culm (Decipulo et al 2009), but they are large if harvested for consumption (reaching 4.5 kg). Age of the clump also affects shoot number. Young clumps for example of *D. latiflorus* in the NT of Australia, aged between 3.5 and 4 years

produced many shoots early on but fewer as the clumps aged (on average *c*. 40 shoots per clump in the first year of measurement, *c*. 30 in the second and *c*. 10 in the third year). However, the proportion of marketable shoots increased over time (Traynor and Midmore 2009).

Appropriate management practices for sustainable culm production

The same production inputs, water, nutrients and management of culm populations influence culm production and as for shoot production, species has an overriding influence on culm production, in terms of both numbers and size.

Irrigation

Withholding irrigation altogether (as compared to satisfying evapotranspiration demand) in an environment with barely 1500 mm of annual rainfall reduces biomass yield by 40% (Zhu et al. 2009), but that is confounded by also withholding fertiliser. The same effect was evident by withholding winter irrigation at another warmer site with similar rainfall – culm yield was reduced by 24% compared to full irrigation (Traynor and Midmore 2009). Irrigation throughout the year at only 50% of pan evaporation reduces culm yield by 15%, not as great as withholding all irrigation during the dry season. At another warmer site, on a lighter soil, the 50% irrigation treatment did not affect culm yield, although culm water use efficiency (WUE – based upon weight of culm per unit of irrigation) was double that of the 100% irrigation treatment (Traynor and Midmore 2009).

In similar trials in the Philippines, in one site in Capiz, neither lack of irrigation nor irrigation supplied only just before and during the shoot season reduced culm yield compared to the fully irrigated treatment (although both treatments had higher culm WUEs than the irrigated control – Marquez 2009). In another site with irrigation treatments, in Ilocos Norte, culms that experienced the reduced irrigation treatments were thinner in diameter and their biomass lower (Malab et al. 2009).

It has been suggested, based upon experimental data, that sympodial bamboos can dissipate up to 3300 mm/year rainfall equivalent (Kleinhenz and Midmore 2000), but c. 2000 mm/year offers the best returns in terms of water use efficiency, both for shoots (if concentrated just prior to and during the shoot season) and for culms.

Fertiliser

As mentioned earlier, nutrient application rates to ensure that leaf nitrogen remains at close to 3% are considered to be excessive, although bamboo has a great capacity to take up much available soil nitrogen – a luxury uptake (Kleinhenz and Midmore 2002). Much focus has been on N fertilizer (the most readily available nutrient, and with the lowest unit cost), but bamboo also responds to potassium, and the nutrient use efficiency if greater than that for nitrogen and phosphorous (Table 1).

In recent trials in the NT of Australia (Traynor and Midmore 2009), culm yield was unaffected by fertiliser application in the first year of measurement, and marginally enhanced in the second year – an indication that perhaps, even for a young plantation at full irrigation, clump water demand was not being met. In Queensland,

the withholding of fertiliser reduced culm yield in a mature plantation by 40%, but this was confounded by the concomitant absence of irrigation (Zhu et al. 2009).

Similarly in recent trials in a rainfed site of Bukidnon (Decipulo et al. 2009), withholding fertiliser reduced culm yield considerably. Under irrigated conditions in Capiz, withholding fertiliser reduced culm yields by c. 40%, the effect being greater with application of mulch (Marquez 2009). Lack of fertiliser was also responsible for reduced culm diameter under irrigated conditions at Ilocos Norte, as it was under conditions of no management (i.e. no irrigation, fertiliser, mulch or clump cleaning – Malab et al. 2009).

Timing, placement and form of fertilizer also play an important role in bamboo responses, and these are discussed in detail by Kleinhenz and Midmore (2001). Split applications increase nutrient use efficiency, although no particular timing for application appears to be superior.

Culm thinning and species

The effect of culm thinning treatment on culm biomass is closely related to the effect of species. In small-diameter species such as *B. oldhamii* (Zhu et al. 2009), thinning of culms to leave only a small number (five) from year to year constrains culm yield potential (to c. 24 t/ha/year for 12–16-year-old clumps) compared to leaving all shoots and thinning the resulting less-than-1-year-old culms at the time of harvesting the 2.5–2.8-year-old culms (c. 33 t/ha, with one year reaching 47 t/ha). However, across treatments where shoots are removed during the shoot season, there was only a weak negative relationship between the number of shoots removed and culm biomass production. With younger (3.5–7.0-year-old) clumps of *D. latiflorus* in the NT of Australia, thinning treatments did not affect individual weight of culms; most likely because complete canopy closure had not occurred (Traynor and Midmore 2009). Hence, culm yield was a reflection of the number of culms harvested. Culm yield ranged from 3.5–3.7 to 6.8 t/ha/year for the treatments with SCD of 4-2-2, 2-2-2 and 4-4-4, respectively.

The commonly grown *B. blumeana* in Ilocos Norte in the Philippines only responds to thinning regime in terms of culm diameter; the lowest within-clump population (3-3 SCD) had the highest diameter, but otherwise yields were related to the number of harvested culms. The average culm yields ranged from 7 t/ha/year to slightly more than 10 t/ha/year, and reflected a probable yield constraint due to lack of water (Malab et al. 2009). The same species grown in Capiz, but harvested after 4–8 years from planting had much lower culm biomass yields (averaging 1.8–5.6 t/ha/year over the ages of 6–8 years) and culm yield was depressed when culms were retained to be harvested at 4 years of age (Marquez 2009). Culm numbers harvested were low, and culms were quite thin. Yields were, however, still increasing over time, with yields for 8-year-old clumps ranging across treatments from 7 to 13 t/ha.

With average culm dry weight yields of c. 44 t/ha/year over 3 years, yield of *D. asper* in Bukidnon (Decipulo et al. 2009) was greatest in the treatment that retained the higher number of culms (80 t/ha/year, 10-10 SCD) and least in the treatment with least culms retained (22 t/ha/year, 3-3 SCD). This emphasises the close relationship between annual biomass production and number of culms removed per year. Quite clearly leaving many culms for timber production is at variance with harvesting many shoots as a vegetable. Species with smaller sized shoots are those that lend themselves best for the dual purpose of producing shoots and timber. Our data

(Midmore 2009b) suggest that larger culm diameter species are better suited to timber production only, but such a conclusion maybe confounded with site effects. Definitive large scale experiments maintained for a number of decades are still needed to confirm or otherwise these conclusions.

Sustainable management practices for optimal culm quality

From an economic perspective, in traditional forestry, short rotations are preferred over longer rotations, as are silvicultural practices that favour fast growth, but these may be offset by reductions in physical and mechanical properties of timber and lumber grade recovery. Across two species studied in the Philippines, *D. asper* and *B. blumeana* (Alipon et al. 2009), physical and mechanical properties, such as relative density and moisture content, were not generally significantly affected by the imposition of silvicultural treatments. However, inherent differences between species were marked. Strength properties were still improving in culms older than 3 or 4 years in *B. blumeana*, but in *D. asper* those of 1-2-year-old culms were equivalent to those of 2-3-year-old culms. *D. asper*, if it were to be used for construction purposes, could be harvested at close to 2 years of age, whereas culms of *B. blumeana* should be at least 3 years old and ideally older (Alipon et al. 2009).

For *B. blumeana*, the treatment that led to the oldest culms at harvest (4–5 years of age) overall resulted in the most suitable culms for construction or housing purposes (but that treatment had inferior shoot production compared to the well-managed control treatment with harvest of culms at a younger age).

For *D. asper*, the treatment that gave highest biomass (10-10 SCD) had comparable strength to the untreated clumps but pulping characteristics were inferior.

Conclusions

Bamboo yields respond to silvicultural practices, both in terms of shoot number and yield and biomass production, and fine-tuning is necessary for optimal input:output relationships. However, data collected on the physical and mechanical properties of culms from different silvicultural practices are important from a practical perspective: managing clumps for sustainable shoot or timber productions does not appear to seriously interfere with the intended use of culms. However, differences between species and treatments that affect the ages of culms at harvest are important considerations when choosing bamboo production practices.

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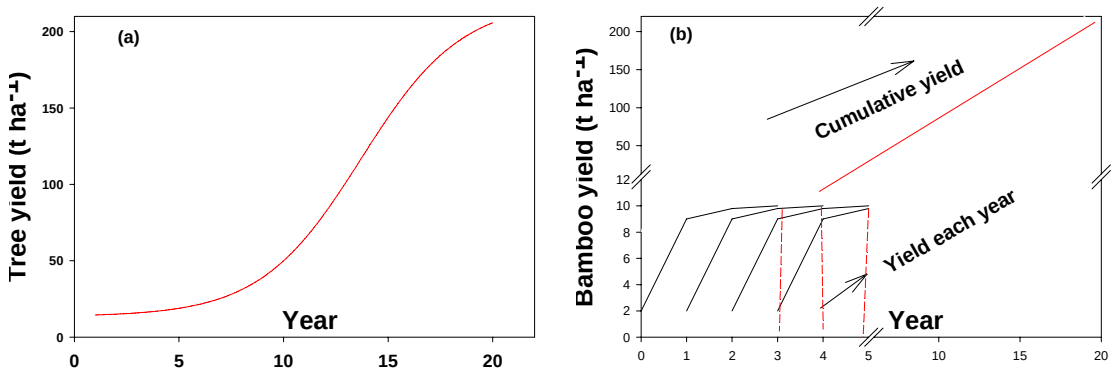

Figure 1. Comparative analysis of (a) one-off harvest of one tree trunk at 20 years and (b) annual harvests of culms from bamboo. From Midmore 2009a [with Permission]

Table 1 Average fertilizer-use efficiency of N, P and K in bamboo production for shoots and timber

	Fertiliser-use efficiency (t yield / kg nutrient)		
	Bamboo product		
Nutrient	Shoots	Timber	Average
N	0.03	0.17	0.13
P	0.04	0.02	0.02
K	0.08	0.54	0.45

Data from Kleinhenz and Midmore (2001)

Bamboo Resource and Policy in Mizoram, India

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Abstract

Bamboo resource is typical renewable and important material for local dwelling people. India is rich in its resource and Mizoram is specific state for growing stock and usage. In this study, the operational system of bamboo policies and administrative organization is examined to use the resources fluently in case bamboo flowering would occur. According to the statistical information, Mizoram was remarkably large amount resources per capita in India. There was so much bamboo area in north east divisions out of state. Two processing plants already established in Mizoram but full operation was the future subject in 2009. Bamboo policies already came into force and invested a large amount of fund as Centrally Sponsored Scheme. It is pointed out that three problems to resolve are left for providing the benefit from bamboo in the near future. Collect and use of statistical information, collaborate with departments of State Government in terms of bamboo use, and incorporate with the results of research activity on governmental policy operation.

Keywords: India, Mizoram, bamboo policy, operation, system

Introduction

The population has integrated to urban area, whereas rural area decreased in population all over the world. It is true the urban area concentrated the materialistic wealth for living people who immigrated from rural area. Various materials brought us convenient life while the wealth supported by large amount of exhausted resources that wouldn't last so long. But though some of local resources used for productive activities and daily life continuously by many local dwellers, they can't be exhausted under considering the carrying capacity. Especially, cyclic resources are important for sustainable development and society that is a key factor of future generation. This concept required the precondition of using renewable resource such as vegetable matter.

Bamboo belongs to the *Gramineae* family and has about 90 genera with over 1,200 species, and is naturally distributed in the tropical and subtropical belt between approximately 46° north and 47° south latitude, commonly found in Africa, Asia and Central and South America (Lobovikov, et al., 2007). India, China and Myanmar have 19.8 million hectares of bamboo reserves which is nearly 80% of the world's bamboo forests; of this India's share's is 45% (Nath, et al., 2008). It was pointed that India was the second richest country in bamboo genetic resources after China (Behari, 2006). However, According to the latest statistics, the major bamboo producing countries are India, followed by China, Indonesia and the Lao People's Democratic Republic (Lobovikov, et al., 2007).

Bamboo has called the poorperson's gift to mankind and the quality and availability both caused and effects in the larger socio-cultural and economic dimensions of a community (Behari, 2006). It has been estimated that the combined value of international and commercial consumption of bamboo is to the tune of US $ 10 billion in the world (Borah, et al., 2008). Such a large number of economic impact on results in important resources for local dwelling people who are easy to approach and use. The over-exploitation of timber also focused research on bamboo production, cultivation and utilization in recent years (Rao, et al., 2008). Therefore, bamboo is worth for thinking the way of usage as a large amount of renewable local resources.

Research purpose and method

Bamboo is used in domestic needs for house construction, fuel, fodder, food, tools, religious ceremony, and previous study already analyze the resource, physical characteristics, utility, market values and propagation success in Manipur, India (Singh, et al., 2003). It is extremely versatile, strong, renewable and environment friendly plant species (Nath, et al., 2008). In order to use this useful resource, it would be needed the financial support of administrative sector and its operation of local people, because the government has the power to tax the primary products or subsidize a process (Chundamannil, 1990), and it is critical problem for local area to accept the related policies. In India, the National Bamboo Mission (NBM) provides for resource creation right from nursery state to high-end value additions and marketing of bamboo products (Gupta, 2008). Mizoram state also established original bamboo policy in 2002 under the rich in bamboo forest (Bamboo Development Cell, 2004). Moreover, as it is predicted before, the gregarious bamboo flowering occurred and has economic impact on the people of this state (Lalnunmawia, et al., 2005). Especially, the people who depend on the bamboo resources will have faced serious problem.

In this paper, the bamboo resource of Mizoram was identified in India through analyzing of bamboo policies and contents of them. The operational system of policies and administrative organization is also examined to use the resources fluently even if bamboo flowering would occur.

Bamboo Resources

The grand total of bamboo area was estimated 96,071km^2 and the percentage share of it was 14.2% compared with forest area (Table 1). As shown in this table, Mizoram was 49.3% relatively larger bamboo area than other states. These states amounted to 84.5% of bamboo area in India and 4 North East states contain this list. It was indicated that bamboo resources were unevenly distributed.

Table 1. Forest and bamboo area in India

States	Bamboo Area (Sq. km)	Forest Area (Sq. km)	Percentage Share (%)	Per Capita (person/hectare)
Maharashtra	14,428	47,476	30.4	0.01
Chhattisgarh	11,521	55,863	20.6	0.05
Madhya Pradesh	9,508	76,013	12.5	0.02
Mizoram	9,210	18,684	49.3	1.04
Assam	8,214	27,645	29.7	0.03
Andohra Pradesh	6,598	44,372	14.9	0.01
Orissa	6,353	48,374	13.1	0.02
Karnataka	5,976	35,251	17.0	0.01
Arunachal Pradesh	5,714	67,777	8.4	0.52
Manipur	3,692	17,086	21.6	0.17
Sub Total	81,214	438,541	18.5	0.02
Grand Total	96,071	677,088	14.2	0.01

Note: The list arranges top ten state of bamboo area.

Source: Rai, et al.(1998), Forest Survey of India (2005)

Table 2 Distribution of bamboo area by Forest Division

Name of Forest Division	Geographical Area (Sq. km)	Bamboo Area (Sq. km)	Bamboo Area as % of Geographical Area
Aizawl	1,635	790	48.3
Champhai	3,496	461	13.2
Darlawn	1,538	871	56.6
Kawrthah	790	515	65.2
Kolasib	1,559	973	62.4
Mamit	1,504	894	59.4
N. Vanlaiphai	1,009	495	49.0
Thenzawl	2,335	1,415	60.6
Northern	13,866	6,413	46.2
Chhimtuipui	3,459	629	18.2
Lunglei	1,623	451	27.8
Tibung	1,139	330	29.0
Southern	6,221	1,409	22.7
Total	20,087	7,822	38.9

Source: Department of Environment & Forests (2002, 2003)

Bamboo area per capita also was shown following table and Mizoram was remarkably large amount that doubled by Arunachal Pradesh of North East.

The inventory work has been taken up for rapid assessment of bamboo resources of Mizoram in 2000 (Department of Environment & Forests, 2002). A joint project has conducted by Environment & Forest

Department and Forest Survey of India in order to collect the resource data. According to the division wise distribution, bamboo area was larger northern part than southern part (Table 2). There was so much bamboo area in north east divisions The data of bamboo area in Mizoram was differed from both tables, because of the difference of indicator and criteria on land use.

Bamboo Use

Bamboo is used for construction materials, charcoal and vinegar, handicraft, paper pulp, and so on. According to the survey in Karnataka, 49% of bamboo is used for making agricultural implements whereas the remaining 51% is used for other purposes (Rao, et al., 2008). There is no statistical data or reliable information of bamboo use in Mirzoram, and the following products of bamboo are amenable to industrial development (Bamboo Development Cell, 2004).

1) Bamboo laminated boards and flooring

2) Bamboo ply board (strip board and mat board and applications)

3) Reconstituted bamboo wood

4) Bamboo charcoal, and vinegar

5) Bamboo shoot

Actually, there are two processing plants established in Sairang and Lengpui. Bamboo flooring board industry in Sairang was jointly developed by Bamboo Development Agency, Venus Bamboo Products Ltd.in West Bengal, and Boarke Machine Company in Taiwan (Department of Industries, 2009). Department of Industry invested the financial support to development of bamboo-based Industries. Though a lot of administrative expenditure had already been expensed, the plant hadn't operated yet hearing from a staff of government in February 2009.

Bamboo processing plant needed some resources for operating. The bamboo stock has been delineated on map with the help of natural and artificial features (Department of Environment & Forests, 2002). Unfortunately, though there is no information of usage, bamboo resources and annual yield was shown the following table 3. The growing stock ranged 800 to 4,000 thousand tons and average amount of each division were relatively larger southern part than northern part. Distribution of culms and annual yield are also large in southern division statistically. However, the yield was calculated by fixed percentage, and there is little reliability for the information.

Table 3. Division-wise bamboo resources and annual yield

Name of Forest Division	Growing Stock (1,000 tons)	Distribution of Culms (Millions)	Annual Yield (1,000 tons)	Annual Yield by Bamboo area (tons/hectare)
Aizawl	1,515	375	333	4.2
Champhai	805	199	177	3.8
Darlawn	2,063	516	454	5.2
Kawrthah	1,262	316	278	5.4
Kolasib	2,826	706	622	6.4
Mamit	2,711	678	597	6.7
N. Vanlaiphai	1,266	316	279	5.6
Thenzawl	3,821	955	841	5.9
Northern	16,269	4,061	3,580	5.6
Chhimtuipui	3,639	774	910	14.5
Lunglei	3,034	644	759	16.8
Tibung	2,318	438	579	17.6
Southern	8,991	1,856	2,248	15.9
Total	25,260	5,917	5,828	7.5

Source: Department of Environment & Forests (2002, 2003)

Bamboo Policy

In India, recently the potential of bamboo for developing it as one of the sunrise industries resulted in launching of bamboo development program by the Prime Minister in 1999 with a view to focus on the development of bamboo sector (Kerala Bamboo Mission, 2009). National Mission on Bamboo Application (NMBA) under Technology, Information, Forecasting and Assessment Council (TIFAC), Department of Science and Technology was established in 2002 to focus on the commercialization of value added applications in the bamboo sector. The National Bamboo Mission (NBM) is fully centrally Sponsored Scheme under the Department of Agriculture & Cooperation, Ministry of Agriculture, Government of India (National Bamboo Mission, 2009).

Based on the activities to be carried out under the provisions of the NBM and depending on the continuance of the NBM beyond the X Plan period, after the detailed peer review to be carried out towards the end of 2007, the following targets are sought to be achieved. India has adopted plan economy since the independent and settled the five year's finance of governmental sector. Total plantation area in two Plan periods amounts only 3% of bamboo area in India (Table 4). But this scheme will try to prepare for the opportunity from creation of resource, processing, and purchase of production. Though Xth Plan already finished in the fiscal year 2007, there is no information about the results of this scheme yet on website (National Bamboo Mission, 2009).

Table 4. Total target under NBM in whole India

Area Expansion	Xth Plan	XIth Plan	Total
Forest Area	16,000ha	72,000ha	88,000ha
Non-Forest Area	16,000ha	72,000ha	88,000ha
Nurseries - Centralized	160	185	345
Kisan	50	30	80
Mahila	50	30	80
Improvement of existing stock	7,500ha	28,500ha	36,000ha
Tissue Culture Units	1	2	3
Bamboo Bazaars	71	124	195
Retail Outlets (Show-Rooms) in 10 Metropolitan cities	3	7	10

Source: National Bamboo Mission (2009)

As described before, Mizoram has plenty of bamboo resources and gregarious flowering of bamboo (*Melocanna baccifera*) predicted that next cycle would occur in 2007 (Lalnumawia, 2005). Former Chief Minister Zoramthanga named "bamboo Minister" tried to build a new prosperity for Mizoram out of bamboo. Bamboo Policy of Mizoram 2002, which has been formulated the ecological and economic potentials of the bamboo resources. The aim of this policy was to use them as an industrial raw material for ensuring the sustainable development of local people. Specific policy in Forests Department is as follows (Department of Environment & Forests, 2006);

1) Bamboo Flowering and Famine Combat Scheme (BAFFACOS) with fund provision from the Planning Commission and Twelfth Finance Commission Award.

2) Management of gregarious flowering of bamboo in the Northeast which is Centrally Sponsored Scheme from the Ministry of Environment & Forests, Government of India.

3) The National Bamboo Mission which is a Centrally Sponsored Scheme from the Ministry of Agriculture, Government of India.

Two policies were established on the occasion of bamboo flowering and funded by federal government. The system of these schemes was similar to Joint Forest Management (JFM) implemented from the year 1990 (Masuda, et al., 2005). The subsidy of JFM granted directly to Forest Development Agency (FDA) at local area. Bamboo Development Agency also received the grant and the member at district level in Aizawl is shown the following figure 1. Each member has the chance to see the meeting each other irregularly and usually exchange the official document.

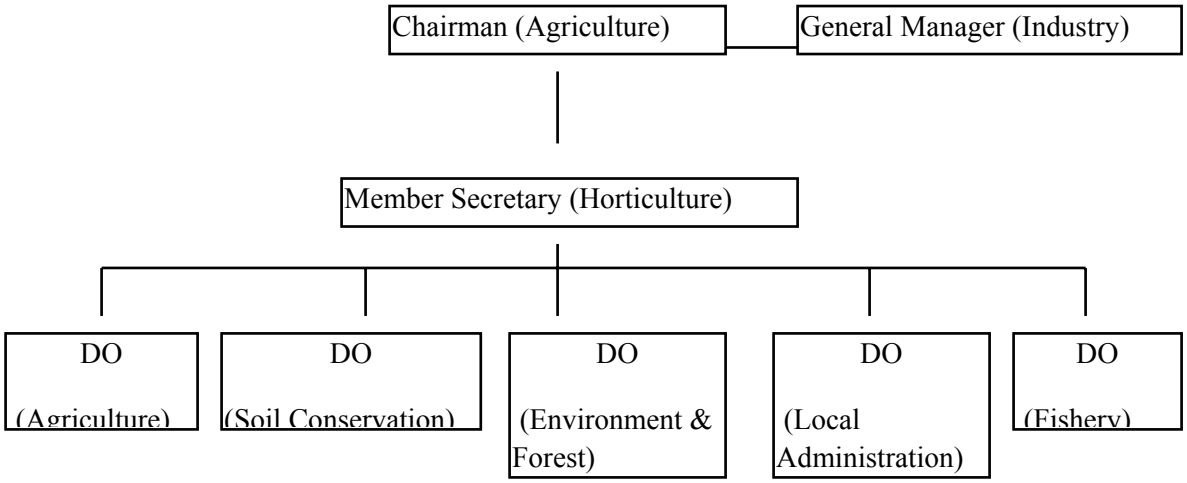

Figure 1. Bamboo Development Agency at Aizawl District

Source: Hearing Survey

Notes: "Do" is the abbreviation of District Officer.

There is no intention to change the bamboo species on NBM. However, introduction of improved varieties of bamboos from outside will be given more importance due to the short term economic benefit. But many bamboo area has been allotted for practice of shifting cultivation (Jhumming) every year. Allocation of land for "Jhumming" is mainly done by village council which is directly controlled by Local Administration Department. Moreover, bamboo flowering is the good opportunity for changing the bamboo species. In fact, part of bamboo area converted to agricultural land by local farmers and the recover of bamboo depends on the timing of farming according to the ecological research. At the same time, the new Government of Mizoram is trying to change the present practice of "Jhumming" by adopting "New Land Use Policy" by providing alternative occupations for cultivators (Das, 2004). The operation of district level NBM should be attracted more considerable attention for economic development.

Conclusions and future problems

This paper reviewed the bamboo resource, use, and policy in India and Mizoram. It was estimated that the bamboo resource was rich in Mizoram and used the growing stocks for some products. Bamboo policies already implemented and invested a large amount of fund from Central Government. But there are three problems to resolve in the near future for providing the benefit from bamboo.

1) Statistical information

Fundamental information is important for governmental staff to operate the policy. It is true that bamboo resources and uses are available, but district wise data calculated by fixed percentage not to reflect the actual situation. A lot of staff related with bamboo policies from state to district level. In fact, according to the hearing survey, each staff usually has collected quantitative information watching the charge of their area.

2) Collaboration of departments

As shown in figure 1, Bamboo Development Agency consists of several departments in Mizoram. From a viewpoint of actual material flow, resource management, processing, and consumption was controlled by each department. Besides, bamboo forest overlapped agricultural and forest area, the former is charged of Agriculture and Horticulture Department, the latter is charged of Environment & Forests Department. However, except for official meeting, it isn't clear that departments collaborate the aim of bamboo use and economic development respectively. The inspection of policy is also needed to check the results of policy because several people estimated the failure of bamboo plantation in 2001-2003. Effective system of bamboo policies is needed to use the resources successfully.

3) Results of study

Some researchers of Mizoram University and Japanese laboratories have conducted the study activities on the occasion of bamboo flowering. The results of these studies already published and reported the fragmentary information of ecological aspect of the phenomenon. Unfortunately, these efforts don't have to connect the actual operation of bamboo policy. Now is the time to provide the useful information of bamboo for researchers as the social responsibility of academic body.

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Evaluation of Above Ground Biomass produced by *Dendrocalamus asper* in North Western Himalayan Region of India

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Abstract

Bamboos, ubiquitous in there distribution and having high productivity can be the ideal species to establish carbon sinks. Regression model was developed to predict the above ground biomass produced by *Dendrocalamus asper* in the mid hills of North Western Himalayan region of India. Biomass produced by *D. asper* was evaluated on fresh & dry weight basis at two aspects in two year old plantation. Micropropagated plants were used for the plantation. Biomass produced after the plantation was 17% higher at the hill top as compared to river bank on the fresh weight basis and 19.8 per cent higher on dry weight basis. Soil carbon status was also evaluated before and after the plantation. Per cent soil carbon also varied at the hill top and near the river bank. However, increase in soil carbon was noted at both the aspects two years after the plantation.

Introduction

Bamboo, due to its biological characteristic and growth habits, is not only an ideal economic investment but also has enormous potential for alleviating many environmental problems facing the world today. Bamboo, being the fastest growing plant removes more carbon from the atmosphere in any given period. Bamboo accumulates biomass quickly and offers the opportunity to maintain and increase carbon stocks through carbon sequestration. India has an estimated 8.96 million ha of bamboo forests with an annual production of only 4.5 million tones (Rawat & Pal 2004). Though, biomass production and carbon storage estimation has been done in various species of bamboo in India as well as in the world but biomass accumulation varies with environmental, anthropogenic and topographical factors from species to species. In India many studies on biomass production in bamboo have been conducted, in Madhya Pradesh on *Dendrocalamus strictus* (Singh & Singh 1999), Tamilnadu on *Bambusa bambos* (Shanmughavel & Francis 2001), in a dry deciduous forest of Uttar Pradesh on *D. strictus* (Singh et al. 2004) and in the central Himalayan Region on *Thamnocalamus spathiflorus* (Saxena et al. 2001). Himalayas are extremely rich in biodiversity and 'sustaining the Himalayan Ecosystem' is one of the missions under the National Action Plan on Climate Change. In Uttarakhand state of India, very large portion of the area is mountain region and there is a great pressure on the forests in the rural areas for timber and fodder because of which all around the villages there are lots of degraded lands. Bamboo plantations lauded for their ability to

sequester carbon, can be an effective, cheaper, and income generating option to face the challenge of climate change and to fulfill the demand of livelihood for the forest dependent people. Out of few big bamboo species, which are able to grow at lower temperature, *Dendrocalamus asper* is one of the economically viable and socially useful species for cultivation in the mid hills of Himalayan region. No reports on biomass produced by *D. asper* are available from the mid hill region of India. The Present study was conducted to estimate the above ground biomass produced in *D. asper* plantation at two aspects (hill slope and river side) in the mid hills of Uttarakhand state of India.

Materials and Methods

The study was conducted during 2006-2008 at Agriculture Research Station, Majhera and Jarmila, Garampani, Nainital, Uttarakhand, India. Altitude, latitude and longitude of the study site are 1000 m (a.s.l.), 29º30.137', 79º28.784', respectively with two aspects i.e. top of hill and side of river bank. Maximum temperature, minimum temperature and maximum relative humidity were recorded 32.1ºC in the month of June, 4.83ºC in the month of January and 97.67 per cent in the month of August, respectively on the basis of mean of three years data. Annual rainfall of this site was 554.30 mm (Fig 1).

Methods as given here pertain to data collection procedure and analysis for biomass using acceptable linear equations for the encountered species in this study. Plants of *D. asper* were produced through micropropagation (Agarwal et al. 2008) and planted at ARS, Majhera at the top of the hill and at Jarmila by the side of the river bank of Kosi (spacing 5m) in the year 2006 (Fig 2). Sampling was done during December 2008 by selecting five plants from each site. Five poles of various diameter and height from each plant were harvested. Fresh weight of each pole with branch & leaves was taken and dry weight was recorded by drying at 70ºC for 72 hrs in an oven after harvesting. On the basis of fresh & dry weight linear regression equation was developed (Singh et al. 2009) to estimate the above ground biomass of *D. asper*. For the estimation of soil carbon, sampling was done according to Jackson (1973) at 0.5m and 1.0 m radial distance from the centre of the plant. Soil sampling for control was done before the bamboo plantation. Estimation of organic carbon was done by Soil testing laboratory (Uttarakhand Tea Development Board), Bhowali, Nainital (UK) India.

Results & Discussion

Model for the prediction of above ground biomass in *D. asper* was developed. With the help of this model, estimation of above ground biomass produced by *D. asper* at two aspects in the mid Himalayan region was done. The results indicated change in the biomass on the basis of fresh and dry weight. For fresh weight, height of the pole, girth to height at 1.0 m and 1.5 m affected the biomass by 99.8 per cent whereas in dry weight it was 97.6 per cent (Table 1).

Table 1: Linear relationship between above ground biomass of bamboo plant components (y Kg pole^{-1}) and height (x_1, m), girth to height at 1m (x_2, m) & girth to height at 1.5m (x_3, m).

S.N.	Biomass (Kg plant^{-1})	Intercept (a)	Slope (b_1)	Slope (b_2)	Slope (b_3)	R^2
1	Fresh weight	-1.30	0.463	-3.74	30.2	0.998
2	Dry Weight	-0.809	0.393	-6.68	18.43	0.976

Above ground biomass produced by *D. asper* at two aspects varied. Biomass produced in two years after the plantation was 17 per cent higher at the hill top as compared to river bank on the fresh weight basis. Average biomass produced was 542.24 kg ha^{-1} and 450.06 kg ha^{-1} at ARS Majhera and Jarmila, respectively. Dry weight was recorded approximately 63 per cent less than the fresh weight (Table 2). Average biomass on the basis of dry weight was 208.43 kg ha^{-1} at ARS Majhera which was 19.8 per cent higher than Jarmila (166.99 kg ha^{-1}).

Table 2: Above ground biomass produced by *D. asper* at two aspects

S.N.	Treatments	Average Biomass (Kg ha^{-1})* ARS, Majhera (Hill Top)	Jarmila (River bank)
1	Fresh weight	542.24	450.06
2	Dry weight	208.43	166.99

* On the basis of one pole/plant

Soil carbon concentration in both the aspects was estimated up to 20 cm depth. Soil carbon of the hill top was found higher than the soil carbon of river bank. Negative correlation was found between the per cent soil carbon and radial distance from the centre of the plant (Table 3). Per cent soil carbon increased by 64-70 at ARS Majhera and 32-60 at Jarmila due to litter deposition (leaf fall) as compared to control.

Table 3: Soil carbon due to plantation of *D. asper*

S.N.	Radial distance from centre of plant	Per cent Organic carbon ARS, Majhera (Hill Top)	Jarmila (River bank)
1	0.5 m	2.57	0.97
2	1.0 m	2.15	0.58
3	Control	0.78	0.39

There are few studies on biomass production by *D. asper*. Mathematical regression models are commonly practiced in determining the biomass of forest all over the world because it does not damage the growth of the

measured forest (Lu Yong 1996). Similar model was developed through this study to estimate the above ground biomass production of *D. asper.* Kao & Chang (1989) have reported growth and biomass production in a *D. asper* plantation after establishing a 0.1ha plantation (spacing 5X5 m) for 16 yr in Taiwan in 1972. Maximum net annual production (estimated at 41.4 t/ha) was recorded during the 8th yr after planting. In the present study biomass produced by *D. asper* ranged from 0.17-0.21 t ha^{-1} in the two years of growth period. At the river bank, biomass produced was less as compared to hill top, probably, due to flood, quality of soil and less sunshine hours on per day basis.

Biomass production in the subsequent years would be directly correlated to the existing quantity of biomass in the previous year. Therefore, annual biomass production would increase substantially as the plant grows further. Increase in per cent soil carbon at both the sites, two years after the plantation indicated positive effect of plantation on soil health. More concentration of carbon at 0.5 m radial distance than 1.0 m shows that variation is caused by the smaller size of the canopy. Per cent carbon in the top layer of soil (0-10 cm) reported by Singh et al (2009) in a *Shorea robusta* forest of Central Himalaya varied from 1.79-2.03. Due to *D. asper* plantation per cent increase in carbon as compared to control at ARS Majhera is quite comparable with *Shorea robusta* forest.

Biomass prediction in the subsequent years of growth shall be helpful to measure the rate of carbon sequestration in a *D. asper* stand in the Himalayan region. However, multilocational studies shall be required to confirm the results of the present study.

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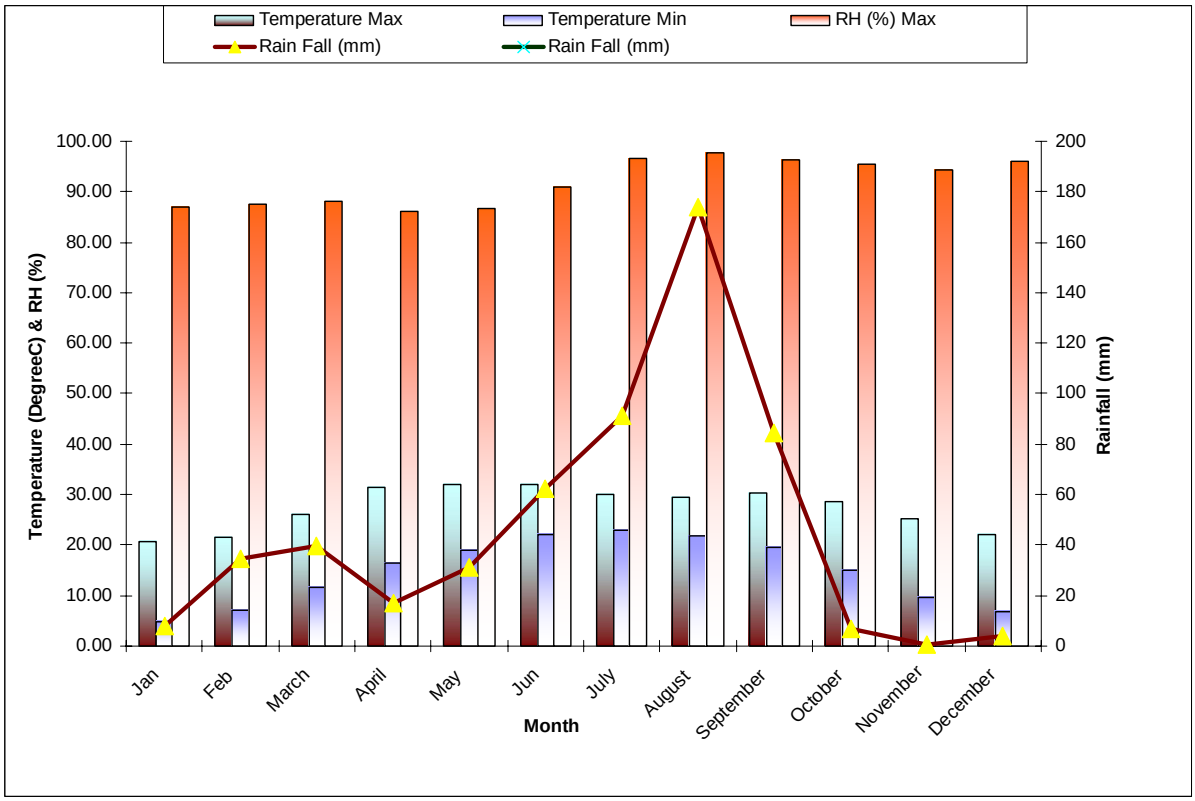

Fig 1. Mean weather parameters for the study site

Fig 2. Bamboo Plantation at hill top (a-b), at river bank (c-d)

Distribution and Assessment of Bamboo in South Kordofan State, Sudan

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Abstract

An inventory and assessment of bamboo was carried out in eight different sites in South Kordofan State of the Sudan. The common bamboo species growing in the area is *Oxytenanthera abyssinica*. However, Findings of the present study revealed the occurrence of a second bamboo species in some forest sites inventoried viz. *Sinarundinaria alpina.* It has not been commonly known before to be indigenous to South Kordofan. Results obtained indicate significant differences between the forest sites in stocking and other growth characteristics. In this connection, stocking ranged from 305 to 1100 clumps/ha. These differences may be attributed to over exploitation as related to proximity or remoteness from populated areas. The study emphasized the importance of further research work and development of the country's bamboo resource at large and particularly South Kordofan, the Blue Nile and South Darfur States where bamboos are naturally growing.

Introduction

Sudan is one of the largest African countries. It covers approximately 2.5 million km^2. It is located between latitude 4 - 22^0 N and Longitude 22 - 36^0 E. (Fig 1). The forest resources endowment of the country is highly diverse ranging from mere desert scrub at the northern frontiers to very rich savannah and pockets of tropical rain forest in the southern parts of the country. Even though Sudan is not rich in its forest resources but the fact remains that it is one of the African countries having potentialities of diversified forest products. Bamboo is one of several forest resources of the country that has received only very meager attention. Only very little and fragmented efforts were made to assess the bamboo resources of the country. The problem of proper management and maintenance of the remaining bamboo forest resource has been strongly emphasized in conjunction with the present day deterioration of the natural forests of the country as a result of over exploitation and desertification (Elhouri *et al*. 2001). Vast areas of natural forests of South Kordofan include bamboo as an integral part of them. Consequently, information is needed on the bamboo resource as a prerequisite for proper planning, sustainable management, maintenance and protection. Andrews (1950) and Khan (1966) have reported that *Oxytenathera abyssinica* is the only bamboo species that grows in the Sudan as indigenous species. This has been further supported by Kigomgo (1988), Elamin (1990) and Hashim (1997). However they reported that another bamboo species viz. *Sinarundinaria alpina* which was formerly known as (*Arundinaria alpina*) is naturally growing in the upper reaches of the Imatong mountains in Sothern Sudan. Phytogegraphically, bamboo

in northern Sudan stretches from east to west covering vast areas of the Blue Nile, South Kordofan (Nuba Mountains) and parts of Sothern Dar fur. However its actual extent of distribution has not been documented as no substantial inventory of bamboo resources has been carried out.

The present work is the first attempt ever to assess the bamboo resource of this area using a planned inventory. Southern Kordofan state is considered one of the main production areas of bamboo in the Sudan and is reputed for its sizable production of bamboo according to official forest royalty records of the Forests National Corporation FNC, 2008).

Therefore the main objective of the present work was to assess the status of bamboo and define its geographical distribution within Southern Kordofan state.

The specific objectives were:

1. To undertake an inventory of the bamboo and delineate its occurrences in Southern Kordofan state in the Sudan.

2. To quantify the bamboo resource stocking and variations in eight different sites in Southern Kordofan state.

3. To identify the associated forest tree species within the bamboo occurrences.

Materials and Methods

Southern Kordofan State lies between latitude 9° 13'- 12° 38' N and longitude. 27° 05' - 32° E. (Fig.2.) Total land area amounts for about 13200 Km^2.

Eight sites were selected based on representation of the various parts of the state and according the past records, results of a pilot survey which was conducted before the actual inventory and primary data collected from the FNC and other sources.

The bamboo inventory was carried out in all the eight different forest sites within South Kordofan State using a random sampling procedure. Two base lines perpendicular to the contour were maintained in each inventoried site. Sample plots of 20 x100 m were laid down along each line at 50 m distance. Sample plots were replicated three times. Within each sample plot measurements were recoded for the number of clumps, clump circumference, culm height, culm diameter, and number of culms in the clump. In addition a count and listing of all forest tree species associated with bamboo in the sample plots were carried out.

Data collected were subjected to analysis of variance (ANOVA) using Statistical Analysis Systems (SAS) Version 6.12 SAS (1996). Duncan New Multiple Range Test procedure was used to separate means (Duncan 1951; 1955).

Results

Analysis of variance showed significant differences ($p > 0.05$) between the sites for all measured variables. Table (1) depicts the differences between the eight studied sites in Southern Kordofan with respect to number of clumps, culm height, culm diameter, clump circumference and number of culms.

Table (1): Variation in number of clumps, culm height, culm diameter, clump circumference and number of culms at the different studied sites (per sample plot) in Southern Kordofan State, Sudan.

Forest Site	Number of Clumps	Culm height (m)	Culm diameter (cm)	Clump circumference (m)	Number of culms
Bonjae	97^{cd}	4.34^{cd}	1.93^{b}	3.891^{ab}	92^{a}
Omjamena	22^{e}	6.501^{a}	2.50^{a}	4.29^{ab}	81^{ab}
Caw	84^{d}	4.43^{cd}	1.17^{de}	4.27^{ab}	60^{bc}
Abu faida	161^{b}	4.75^{c}	1.31^{de}	4.29^{ab}	55^{c}
Amsharmot	134^{bc}	4.90^{bc}	1.47^{cd}	5.06^{a}	50^{c}
Eltogola	61^{d}	5.48^{b}	1.71^{bc}	4.45^{ab}	41^{c}
Alfras	123^{c}	3.16^{e}	1.22^{de}	3.08^{b}	37^{c}
Kokaya	220^{a}	4.03^{d}	1.06^{e}	3.60^{ab}	35^{c}

Means with the same letter in a column are not significantly different at $p > 0.05$ using Duncan New Multiple Range Test.

Number of Clumps

The eight forest sites in Southern Kordofan showed significant variability between them in the number of clumps per unit area. However, the number of clumps ranged from 22 to 220. The biggest number of clumps was recorded by Kokaya forest site (220) and the least number was recorded by Omjamaena forest site (22). Abufaida forest site ranked second with (161) but it is significantly smaller than Kokaya forest site which showed no significant differences with Amsharmot forest site (123). Further more, Caw forest site (84) and Eltogola forest site that recorded (61) showed no significant difference between them. In addition Bonjae forest site (97) and caw forest site (84) together with Eltogola forest site showed no significant differences between them.

Clump circumference

This characteristic showed the least variation between the studied sites. Amsharmot forest site recoded a significantly bigger circumference (5.06) m than only Alfras forest site (3.08) m but not the rest of the sites (Table 1.).

Culm Height

Omjamena forest site recorded significantly taller culms (6.50) m compared to the other sites and was followed by Eltogola forest site which recorded a significantly taller culms (5.48) m than the rest of the sites. However, Bonjae and Caw forest sites showed no significant difference between them recoding (4.34) and (4.43) m respectively. Generally, Alfaras forest site produced significantly shorter culms (3.16) m compared to the rest of the studied sites.

Culm diameter

The biggest culm diameter (2.5) cm was recorded in Omjamena forest site while the smallest culm diameter was produced by the Kokaya forest site (1.06) cm with significant differences between them. Bonjae forest site ranked second to omjamena forest site and it recorded (1.97) cm which was significantly different from the remainder of sites with the exception of Eltogola forest site (1.71) cm. However, the rest of the sites showed no significant differences between them in culm diameter.

Number of Culms

Bonjae and omjamena forest sites produced significantly bigger number of culms (92) and (81) respectively and were not significantly different from each other. These were followed by Caw forest site (60) with no significant difference with Omjamena but significantly different compared to Bonjae. The remainder of the sites did not show significant differences between them in the number of culms including Caw forest site as shown in Table (1)

Table (2). Approximate stocking of bamboo in the selected forest sites of South Kordofan, Sudan.

Forest Name	Approximate area/ha	Mean number of clumps/ 0.2 ha	Number of clumps/ha
Bonjae	607	97	485
Eltogola	485	22	305
Abu faida	10117	84	805
Amsharmot	8000	161	500
Caw	12000	134	420
Alfras	3600	61	615
Omjamena	4500	123	110
Kokaya	2800	220	1100
Total /average	42109	88	543

Table (2) shows the approximate areas of the forests sites where the bamboos inventory was conducted. The total area of the eight forest sites amounts approximately 42109 ha. The density of bamboo clumps ranged from

305 clumps /ha at Eltogola forest site to 1100 clumps /ha at Kokaya forest site. However, the average number of clumps for all studied sites of South Kordofan was estimated at around 543 clumps /ha.

Discussion

The present work showed that bamboo is naturally distributed in a disjuncted manner in South Kordofan State. The inventory covered eight forest sites but only two of them were reserved forests. The management plans of these forests excluded bamboo despite its clear importance as a commonly used market item. Variations between the eight sites in stocking may be attributed to proximity of some of the studied sites to highly populated areas which exerted heavy pressure and over exploitation of bamboo resource. This was shown clearly by the fact that the remotely located forest sites like Kokaya (1100), Abu Faida (850) and Alfaras (615) were better stocked compared to the sites located near towns and highly populated villages like Omjamena and Eltogola forest sites with (110) and (310) clumps/ha respectively. The prominent bamboo species in the areas is *Oxytenanthera abyssinica* according to Andrews (1950), but however, the present work have identified a new bamboo species growing naturally in some forest sites viz. *Sinarundinaria alpina.* Bamboo in some sites form almost pure stands, but generally found mixed with different forest tree associates. The most frequent associates of bamboo in all its ocurrencies in these sites are *Combretum* species and *Diospyrus messpiliformis*.

Tree species like *Anogeissus leiocarpus, Commiphora abyssinica Sclerocarya birrea* and *Dichrostachys cinerea* were found growing with bamboos in some of the inventoried sites but not as frequent as the combretum and diospyrus species mentioned above. These results are in agreement with the reports outlined by Mooney (1963), Williamson (1974), Jiping (1987) and Diab (2002) on tree species associated with bamboo in some tropical areas of Africa.

Results of this works indicate that the average stocking of the bamboo is 543 clumps/ha. This stocking seems to be quite reasonable compared to other naturally growing bamboo stands else where (297-325) clumps/ha. If these forest sites were carefully managed and protected for sustainable culm production they will certainly contribute to the welfare of rural people as an income generating activity and employment. In addition, research and development is timely needed to quantify and assess the bamboo resource, develop silvicultural and appropriate harvesting techniques and marketing opportunities. This work is recommended to be replicated at the national level especially at the Blue Nile and South Dar fur states where bamboos grow naturally at different sites but were not inventoried yet.

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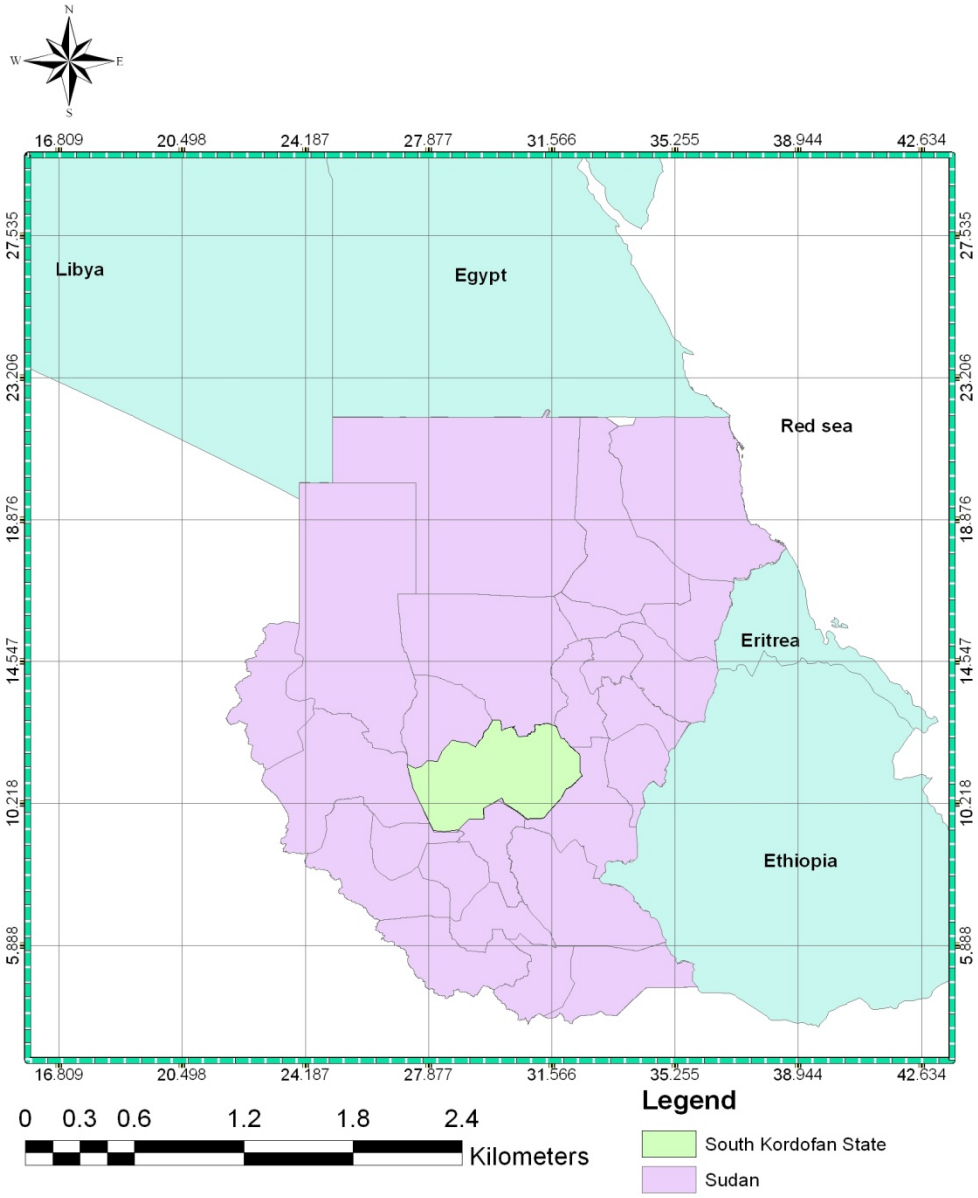

Figure 1. Map of the Sudan

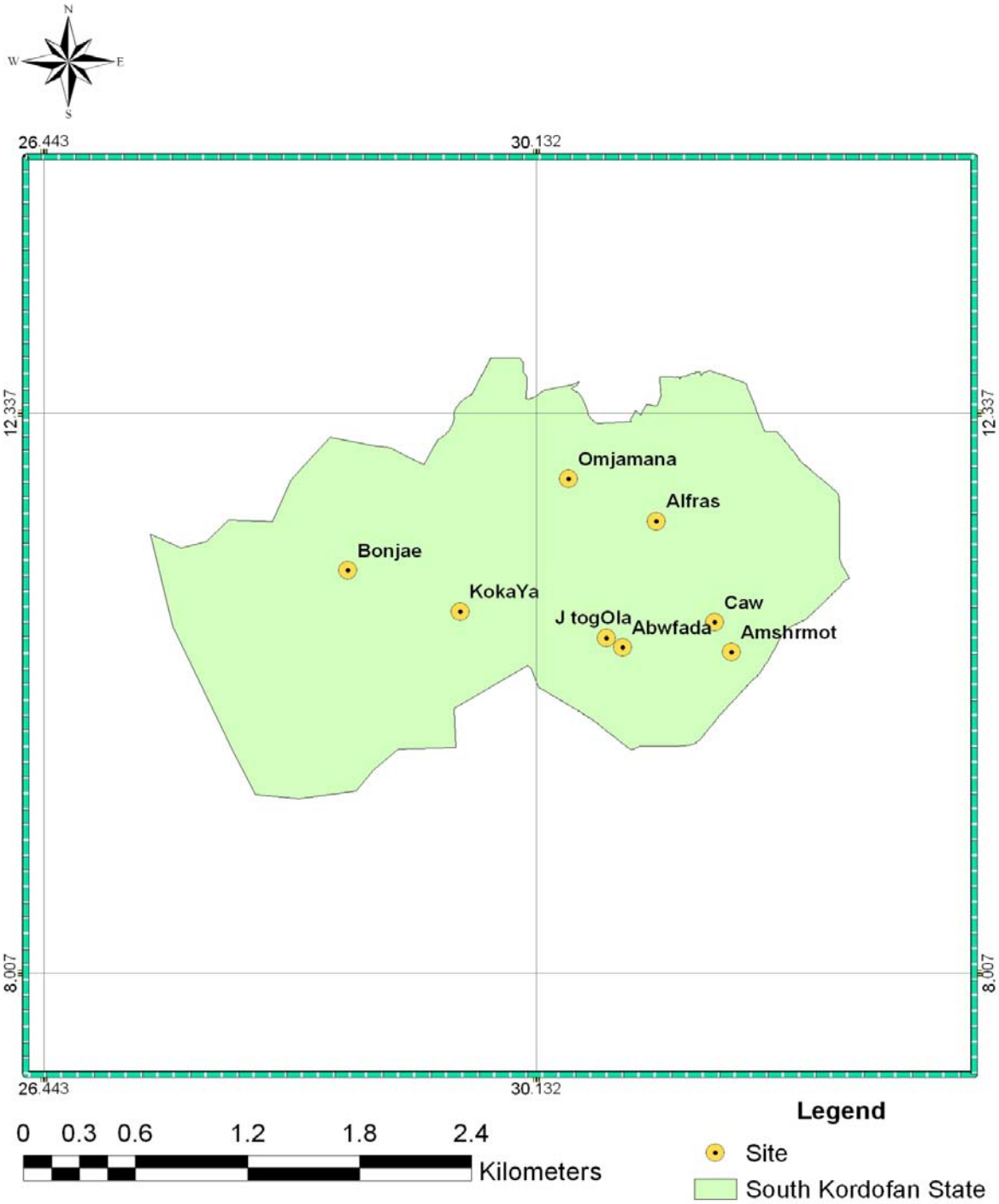

Figure 2. The Studied Bamboo Forest Sites in South Kordofan Sudan

The Preservation of Bamboo Forests undertaken by NPO Kitakyushu Biotope Network Group in Kitakyushu, Japan

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Abstract

In Japan, nearly all the bamboo forests are not maintained any longer, and because bamboos are very fast growing, this result in a rapid expanding spread of large bamboo forests. There are now devastating problems occurring for the bamboo forests, which are invading the adjacent forests and surrounding areas. Bamboo forest thinning had always been the solution to prevent damage of such spread of bamboo forests to other tree varieties and the surrounding fields. Especially since there is no longer a large demand for bamboo material, as well as the high loan costs in Japan, bamboo forest thinning is quite difficult to undertake. In Kitakyushu (Japan), the NPO Kitakyushu Biotope Network Group undertakes thinning of bamboo forests through participation of citizens, company employees, all of them are volunteers. Since November 2001, several environmental preservation activities were organized with the goal of preserving the bamboo forests in danger. Some of the main purposes of these activities were to make the citizens and the local government aware of the aggravating and severe problems and try to find also ways for the use of bamboo material. Already more than 2000 citizens have participated in these activities, and several hectares of bamboo forest are being maintained. Most of the bamboo material was chipped and the chipped bamboo material had been used for making of soil products.

Introduction - Problems which are facing the bamboo forests

In former times, bamboo has played a crucial role in the daily life of many Japanese people. Bamboo was used as building material, in fishery and agriculture, and as a basic material for making daily life tools and utensils. Moreover, bamboo sprouts were and still are a much loved food in Japan. Most probably, bamboo charcoal was used as energy resource as well. The change from an agricultural society into an industrial society, which means changes in life style, resulted in the fact that there was less need for bamboo material. Above that, the very high loan costs in Japan are another main reason for the import of cheaper bamboo sprouts and with bamboo prefabricated building material and other tools, mainly from China and other Asian countries, resulting in less demand for local bamboo. Since there is no longer any market for the local bamboo material, the bamboo forests cannot be maintained any longer (figure 1 and figure 2).

Figure 1: A not maintained bamboo forest

Figure 2: A maintained bamboo forest

Situation of the Bamboo Forests in Kitakyushu

The city of Kitakyushu is located in the western part of Japan on the island of Kyushu. Kitakyushu has one of the largest bamboo forest areas in Japan (city area: about 480 km^2); the total bamboo forest area is not exactly known but is estimated to cover about 1500 ha. In the south of Kitakyushu is located a place which is called Ouma, an area well-known in Japan for its bamboo sprouts. The Ouma bamboo sprouts are distributed all over Japan. Because there is still a large demand for the Ouma bamboo sprouts, the bamboo forest in this area are rather well maintained compared to bamboo forests in other parts of Kitakyushu which are not maintained at all.

Another part of the city, located in the northwest of Kitakyushu is the Wakamatsu ward. The Wakamatsu ward is a very rural not densely inhabited area, and an area with large bamboo forests. In Wakamatsu, most of the

bamboo forests are not maintained. In former times, the Wakamatsu ward was an island. Still these days Wakamatsu ward is surrounded by water; in the north by the Hibiki Nada Sea, in the south and east by the Dokai bay, in the west by the Onga River, and in the southwest by the Egawa River. The Wakamatsu ward can be divided into 5 zones, as is shown on the map (figure 3).

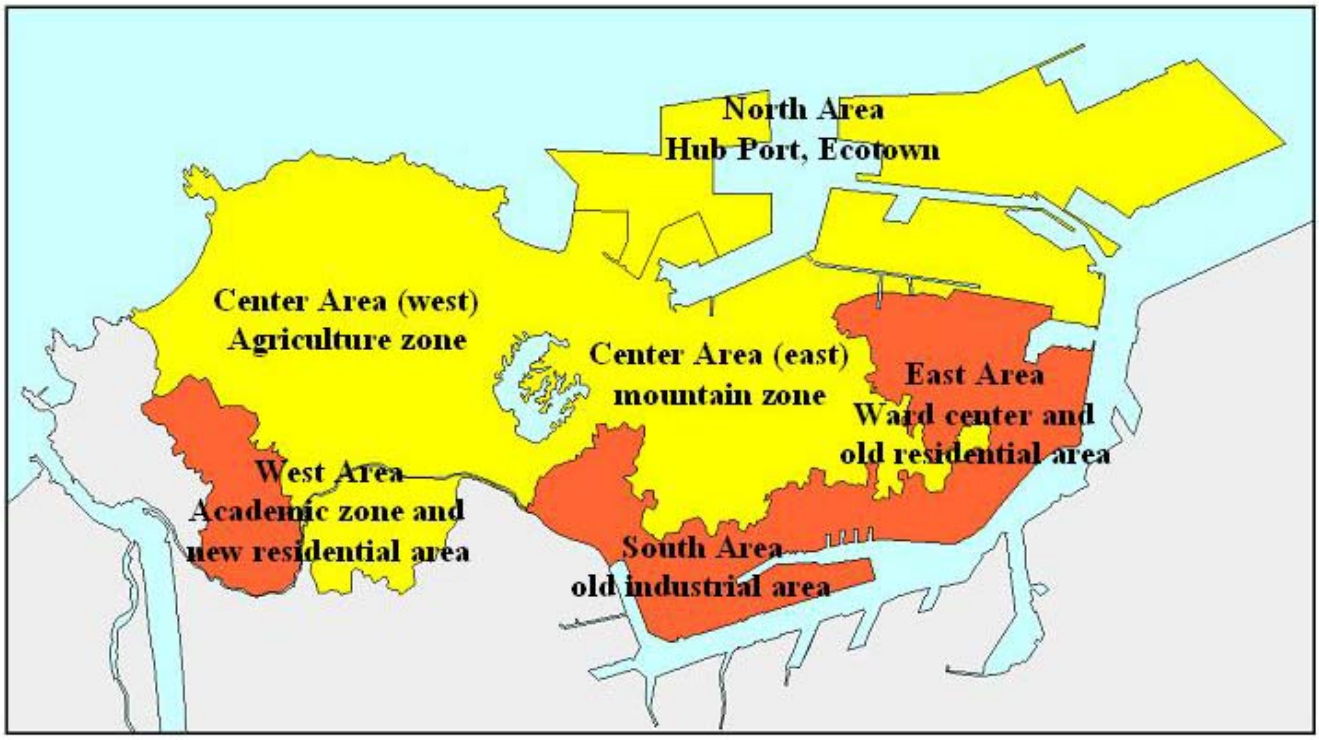

Figure . Map of the Wakamatsu Ward

The 5 zones are;

Zone 1: The old ward center, which is located in the eastern part of Wakamatsu. In this part of the ward are left many old buildings, some of them do have a high historical value.

Zone 2: In the south, an old industrial area along the northern shore of the Dokai bay.

Zone 3: In the west, a new residential area and academic zone, within the center of it the Kitakyushu Science and Research Park.

Zone 4: In the north, the Wakamatsu seashore area, with a new hub port and the so-called Ecotown, an industrial area where industries related to recycle techniques are located.

Zone 5: The most central part of the Wakamatsu ward has a rich abundant nature. This area can be split up in a western and eastern part. The western part is mainly occupied by agricultural land. The eastern part has plenty of beautiful mountains with the Ishimine Mountain and Takato Mountain as the one with the highest peaks. The bamboo forests are mainly situated in the zones 3 and 5 (figure 4).

Figure 4: the Ishimine Mountain and Takato Mountain

Bamboo Preservation through participation of local citizens in Kitakyushu

In recent years, the role and participation of local citizens in sustainable community planning has become more and more important because the improvement of our environment cannot any longer be realized only on a scientific level, but through participation of local government, local industries, research institutes and local grassroots organizations. Also the problem of thinning out and maintaining the bamboo forests must be undertaken through a good collaboration between bamboo forest owners, local government, local industry and the local citizens.

NPO Kitakyushu Biotope Network Group

The Kitakyushu Biotope Network Group has been created in July 2001. Members of the group consist of academics, company people, local government people, local citizens, students, etc. There are about 25 core members. Since June 2003, the Kitakyushu Biotope Network Group has become a Non Profit Organization (NPO). The main goal of the Kitakyushu Biotope Network Group is to work on issues of environmental protection, mainly dealing with preservation of nature in the urban and suburban area as well as dealing with topics of environmental education. The sustainable community planning activities undertaken by the NPO Kitakyushu Biotope Network Group can be divided into environmental preservation activities related to;

1) forest and bamboo forest preservation
2) river and seashore preservation
3) agriculture activities for children

Since 2001, the Kitakyushu Biotope Network Group has organized over 100 sustainable community planning activities. In this report only the activities related to bamboo forest preservations will be mentioned as is shown in table 1.

Table 1 List of bamboo related activities

Date	Name of the bamboo related event
10 Nov. 2001	2nd EPA: Bamboo Forest Preservation Project
29 April 2002	3rd EPA: Clean Up the Egawa River by use of a bamboo raft
19-22 Aug. 2002	5th EPA: First Bamboo Design Workshop
14 Sept. 2002	Junior Meister Course: Making of Bamboo Charcoal Part 1
12 Oct. 2002	Junior Meister Course: Making of Bamboo Charcoal Part 2
23 Nov. 2002	6th EPA: Bamboo Forest Preservation - International Collaboration
9 March 2003	9th EPA: Satoyama Preservation
29 Nov. 2003	Dream Cupid: Making of Bamboo Charcoal
12-14 Nov. 2004	17th EPA: Green Town Planning Workshop in the Kitakyushu Science and Research Park
20 Aug. 2005	Bamboo Craft Course for children
11 Sept. 2005	21st EPA: Fishing with bamboo pole in the Egawa river
3-6 Nov. 2005	23rd EPA: Second Bamboo Design Workshop [Shelter 3X3X3]
18 Feb. 2006	26th EPA: Egawa River and Dokai Bay Project Part 9: Water Purification of the Dokai Bay by using of bamboo
9 July 2006	28th EPA: 5 year Commemoration Project Part 1: Cooking Papa
17 July 2006	28th EPA: 5 year Commemoration Project Part 2: Cross the Dokai Bay with a bamboo raft
5, 6 Aug. 2006	28th EPA: 5 year Commemoration Project Part 3: Nagasaki Historical Road Bamboo Lantern Event
27 Aug. 2006	Bamboo Craft Course for children
14 Oct. 2006	Bamboo Craft Course for children
23 Nov. 2006	Bamboo Craft Course for children
10 Feb. 2007	31st EPA: Bamboo Preservation Event

2,3 June 2007	Bamboo Craft Course for children
18 Aug. 2007	Bamboo Craft Course for children
7,8 June 2008	Bamboo Craft Course for children
23 Aug. 2008	Bamboo Craft Course for children
29, 30 Nov. 2008	Bamboo Craft Course for foreign students

Note 1: EPA = Environmental Preservation Activities

Besides the environmental preservation activities (EPA) and other activities mentioned in table 1, bamboo forest maintenance activities are undertaken every second Saturday of each month. Since January 2004, except for the month of August, on every second Saturday of the month, a small group of citizens has started to preserve the bamboo forests in the area around the Kitakyushu Science and Research Park. The cut bamboos are chipped and these chips are used for soil making products, as well as for the making of bamboo charcoal. The cut bamboo material is also used in all the activities mentioned in table 1. A part of the bamboo material was also used for bamboo objects, small artistic objects made by the students of the University of Kitakyushu.

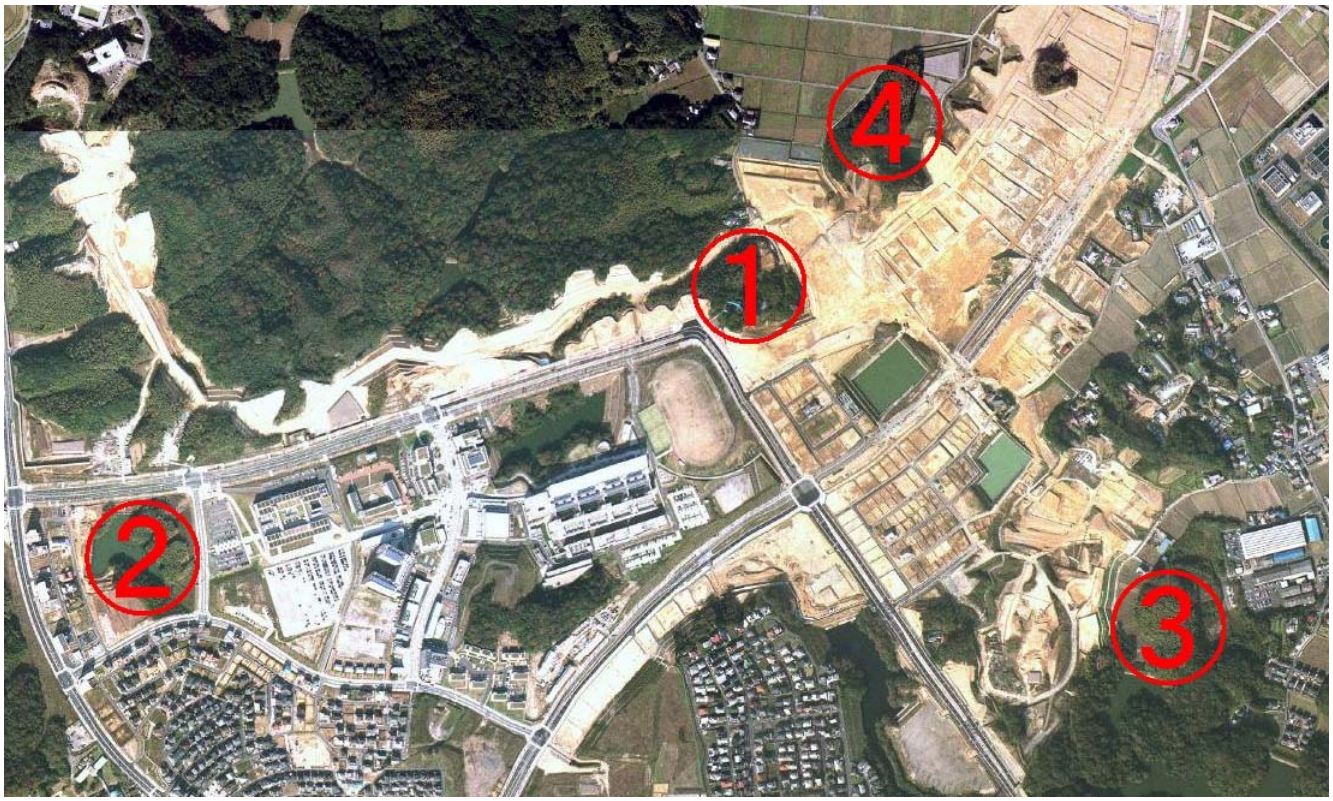

Figure 5: Area map of the Kitakyushu Science and Research Park

(Aerial photograph reference: Google Map)

In the area around the Kitakyushu Science and Research Park there are four forests which are maintained as is shown in table 2 and figure 5 and 6 (figure 5 and figure 6).

Forest 1; the Yatsurugi Shrine, a small shrine surrounded by a small forest, in this forest nearly all the bamboo has been cut away because in a shrine forest there was originally no bamboo.

Forest 2; the Hibikino South Park, a 4 ha large park, in the middle is a pond and around the pond is a forest and bamboo forests.

Forest 3; the Honji Conservation Area

Forest 4; the Hibikino North Park

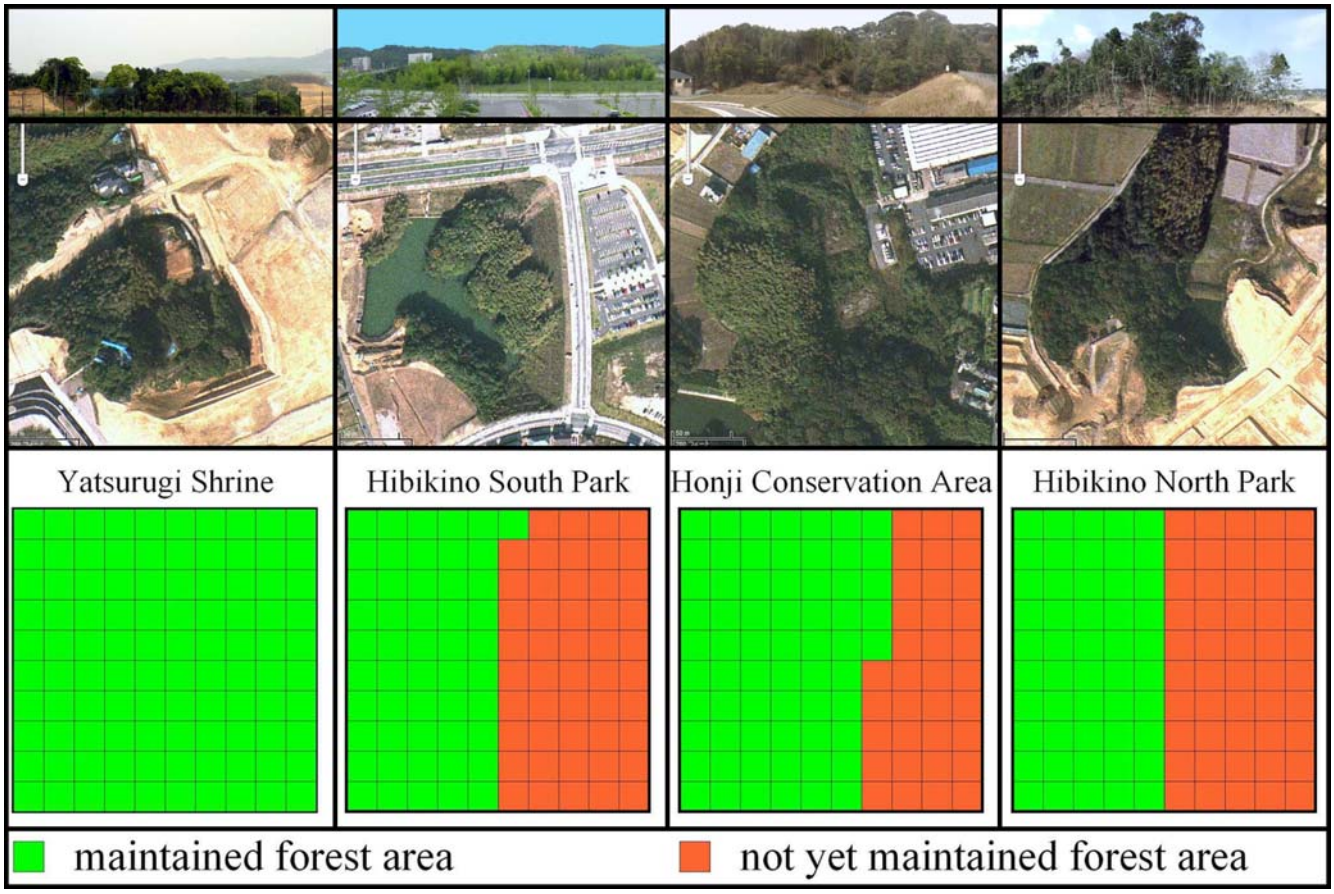

Figure 6: Yatsurugi Shrine, Hibikino South Park, Honji Conservation Area, Hibikino North Park

Table 2 Bamboo forest maintenance

	forest area (A)	bamboo forest area (B)	maintained area (C)	bamboo forest maintenance ratio (C/Bx100)
Yatsurugi Shrine	19,600 m^2	-	19,600m2	100%
Hibikino South Park	28,000 m^2	11,400m2	6,200 m2	54%
Honji Conservation Area	25,000 m^2	13,300m2	8,600 m2	65%
Hibikino North Park	21,000 m^2	7,800m2	3,900 m2	50%

There are three cases for the preservation of bamboo forests and adjacent forests;

Case 1: In case 1 the bamboos have invaded the adjacent forests. In that case all the bamboos are cut down. The main reason for that is because most of the trees died or nearly died because no sunlight infiltrates any longer the forest once bamboos have reached their full grown height.

Case 2: The zones with only bamboo are preserved the following way. First of all, the older bamboos are cut away. Afterwards thinning of the bamboo forest occurs, until a well balanced density has been reached. Depended on the place, 2 or 3, up to 10 and more bamboos are left on 3.3 m^2 (1 tsubo corresponds to 3.3 m^2, a Japanese area unit).

Case 3: The third way of preservation is keeping bamboos and normal trees together. The density of trees and bamboos vary from place to place. The infiltration of sunlight is one of the most important elements to decide the density of thinning the forest.

Due to the fact that all participants are non-professionals, these preservation and thinning methods cannot always be seen as the most appropriate ones (figure 7).

Figure 7: Cutting and carrying of the bamboos

Number of participants

The bamboo forest activities have started in 2001, and since January 2004, with a monthly average of about 37 people, 52 regularly organized maintenance activities were undertaken with a total of about 2000 participants as is shown in figure 8 (figure 8).

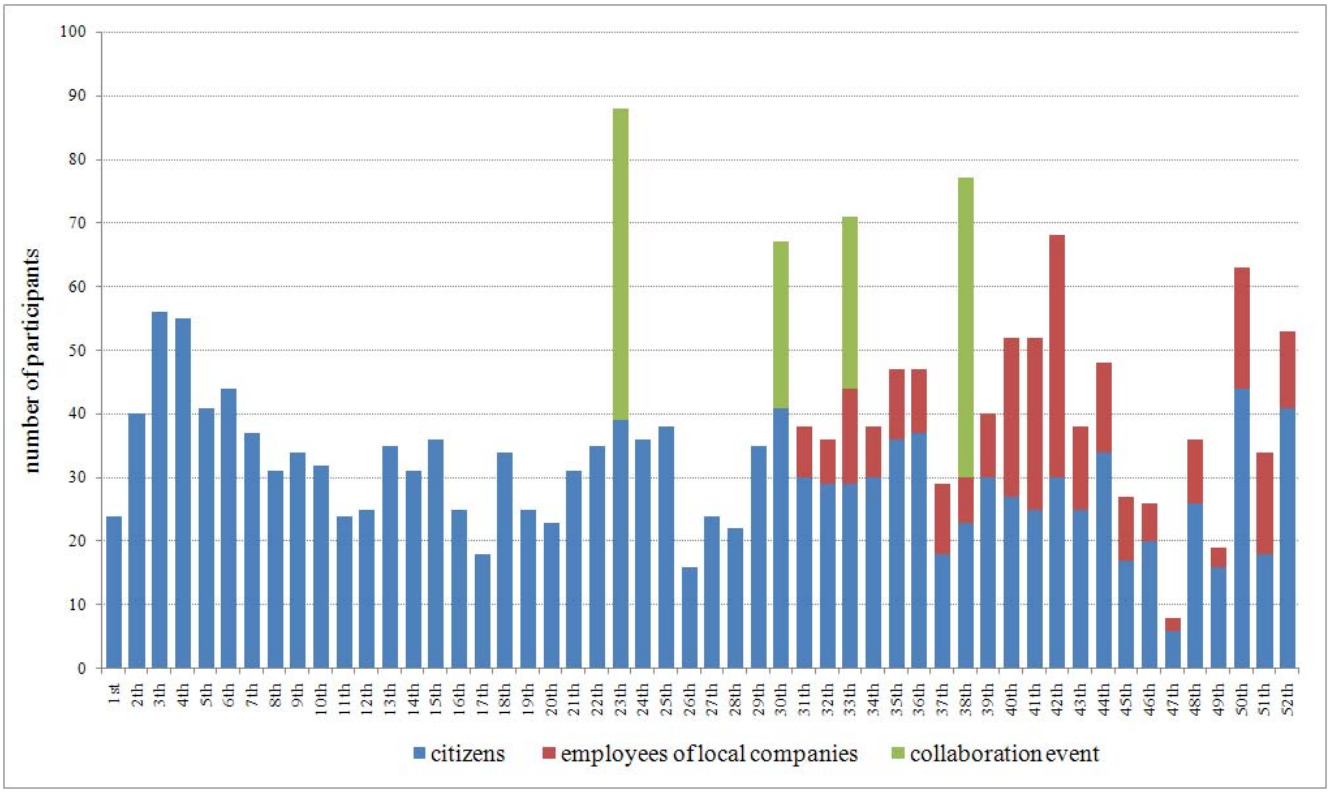

Figure 8: Number of participants

The first months of 2004, when the activities started, more than 50 participants attended the events, many people were interested but due to the hard labor work of cutting and carrying the bamboos, many participants attended only once or twice. The peak moments are events with more than 70 participants, events which are organized in collaboration with events organized by the city or by other organizations. Due to long lasting bad weather in 2006, the number of participants decreased. At the end of 2006, the employees of four local companies joined the group of volunteers. In Japan, Corporate Social Responsibility (CSR) has become very important and local companies are starting to join the bamboo forest preservation activities. Participating companies are; 1) Kowa Seiko Corporation, 2) Yaskawa Electric Corporation, 3) Duskin Corporation, 4) Hibikinada Development Corporation.

The age of the participants is not investigated, but we can see that there is a shift from mostly elderly participants in the beginning, to a more mixed age structure of participants. This can be explained by the fact that people working in the companies have joined. Moreover, nearly all participants were males, and since companies have joined the number of female participants has increased.

Conclusion

In this report the role of the NPO Kitakyushu Biotope Network Group in the preservation of bamboo forests has been explained. It can be said that the preservation of bamboo forest in Japan only can be solved through intense participation of local government, industries (companies CSR program), research institutes, local grassroots organizations, and NPO's etc. With over 100 activities, the NPO Kitakyushu Biotope Network Group has elaborated a lasting bamboo preservation project, these activities show a solution to let local citizens take part in solving bamboo forest problems. All activities attracted many participants, which mean that the citizens of Kitakyushu are concerned about the bamboo forests. In the future, it will be important to establish several bamboo preservation key areas, and make a network of these areas, so that the local citizens not only participate in one-day events but become members of these organized preservations projects and take more initiative in their own local area.

Performance of Exotic Bamboo Species in Kenya

Victor Brias

Abstract

During the period 7 August to 6 September 2006 the author analyzed the performance of trial plantations of exotic bamboo species that were established by the Kenya Forestry Research Institute (KEFRI) between 1988 to 1990. The objective of studying the KEFRI trial plantations was to analyze the trial plantations in various regions Kenya in order to provide up to date information on species to site matching, with specific focus on identifying suitable species for developing bamboo plantations in the Lake Region, Highlands and coastal regions of Kenya.

Observations and analyses of species performance and were made in 4 bamboo plantation trial plots located in Kakamega, Muguga, Gede and Jilore. Measurements and estimations of culm size, height, and clump density were made by selecting samples of various clumps of each species on each of the ‘ sites.

Since the climatic conditions of the trial sites differ significantly from the native habitat of the species, a strict methodology was needed for analyzing the data. A benchmarking system was used for gauging the relative performance of the species on the sites in relation to the known characteristics of the same species in their natural range in Asia. Since there was no record of culm weight of the various species planted, the author employed a mathematical method of calculation, which provides a rough estimation of the dry weight of culms.

The analytic results of the trial sites provides a rough assessment of the potential performance of the exotic bamboo species in selected areas of Kenya. Information on species to site matching was provided based on the observations and analyses.

Acknowledgements

The present study was originally conducted as part of the author’s assignment as a technical expert in bamboo plantations for the Eastern Africa Bamboo Project (EABP) funded by the Common Fund for Commodities (CFC), executed by the United Nations Industrial Development Organization (UNIDO), and supervised by the International Network for Bamboo and Rattan (INBAR). The author expresses his thanks to CFC, UNIDO, and INBAR for their permission to publish the study in this revised form.

The author also expresses his gratitude to Mr. Gordon Sigu of the Kenya Forestry Research Institute for his assistance in data collection and measurements on the field.

Background: KEFRI Trial Plantations

In 1988 the Kenya Forest Research Institute (KEFRI), through the initiative of Dr. Bernard Kigomo, started a bamboo research program that involved the establishment of trial plantations of exotic bamboo species in six locations within three regions of Kenya. The 6 trial plantations sites of KEFRI are located in (i) Kakamega and (ii) Siaya in the Lake Region, (iii) Muguga and (iv) Penon in the Highlands, and (v) Gede and (iv) Jilore in the coastal region.

Some of the bamboo planting materials that were used in the trials were obtained in Kenya but most of the germplasm was imported from Rwanda, Tanzania, Zimbabwe, India, Thailand, and Japan in the form of seeds and vegetative material. The germplasm was mass propagated at the KEFRI nursery in Muguga and subsequently planted in the trial sites between 1988 and 1990.

An initial study of the trials was made by KEFRI in 1995 and published by Dr. B. N. Kigomo and Mr. G. O. Sigu (1996). Their study provides details of the characteristics of the planting sites, the form (i.e., seeds, rhizomes, offsets, or cuttings) and provenance of the germplasm, the species planted in each site, as well as success or failure, and growth performance of each species per site.

Objectives and Expected Results of the Plantation Analyses

The objective of studying the KEFRI trial plantations was to analyze the trial plantations in various regions Kenya in order to provide up to date information on species to site matching, with specific focus on identifying suitable species for developing bamboo plantations in the Lake Region, Highlands and coastal regions of Kenya.

Due to time limitations and logistical constraints, only 4 out of the 6 KEFRI trials sites were studied, namely: Kakamega, Muguga, Gede and Jilore.

Since the trial sites at Siaya in the Lake Region and Penon in the Highlands were not visited, it was therefore not possible to analyze and compare the results of the trials plots in Penon to those of Muguga, nor to compare the results of the Kakamega trials to those of Siaya.

The characteristics of these sites included in this study are shown in Table 1.

Table 1: Characteristics of KEFRI Bamboo Trial Sites

Site	**KAKAMEGA**	**MUGUGA**	**GEDE**	**JILORE**
Region	Lake Region	Highlands	Coastal (Malindi)	Coastal (Malindi)
Coordinates	0°14’S / 36°38’E	1°54’S / 34°15’E	3°20’S / 40°5’E	3°12’S / 39°55’E
Altitude	1,675 m asl	2,050 m asl	50 m asl	80 m asl
Temperature (min)	17°C	11°C	22°C	24°C
Temperature (max)	33°C	28°C	33°C	34°C
Annual Rainfall	1100-1950 mm	900-1500 mm	900-1400 mm	550-1000 mm
Soils	Dark Brown Loams	Deep Dark Red Clay Loams	Sandy White Loams	Sandy-red compact sandy soils

Source: Kigomo & Sigu, 1996.

The trial sites of Kakamega and Muguga both have very fertile soils and high annual rainfall and are suitable for agriculture. The performance of bamboo species in Kakamega can be used as a basis for species selection in the Lake Region.

At at elevation of just over 2000 m above sea level, Muguga lies in the lower elevation range of Kenya's highlands. In areas located between 2,500-3,400m above sea level, the only bamboo species observed in Kenya is the indigenous species *Yushania alpina*. At an altitude of up to 2,400m (e.g. Olenguruone) the species *Bambusa vulgaris* 'Vitatta' is cultivated and grows vigorously. No other exotic species have been observed in Kenya above this altitude. The performance of exotic bamboo species in Muguga therefore provides an indication of suitable species in the lower elevation range of Kenya's highlands.

The trial sites in Kenya's coastal region, namely Gede and Jilore, have a much lower rainfall, but they are nevertheless suitable for several tropical bamboos. Some bamboos that performed poorly at Kakamega and Muguga, showed much better results at the coast. Despite the fact that there are no natural bamboo resources in the coast, there are initiatives to plant bamboo, especially to meet demands by the tourism industry. The analysis of the performance of bamboo species under the conditions in Gede and Jilore may therefore be useful for private farmers in the area.

General Observations and Species Planted

The KEFRI trial plantations have been neglected for many years. Lack of management, clump maintenance and harvesting and is evident in the weeds between the rows of clumps, the abundance of old or rotting culms within clumps, the absence of any fertilizer and mulching regime. Each site appears more like a wild bamboo forest than what is properly called a 'trial plantation'. The 5m x 5m spacing of clumps provided clear evidence of the plantation structure, but the deficiency of management made the assessment and analysis of each site extremely difficult. The sites have not been systematically harvested to measure yield. Instead the sites have mainly been used as sources of germplasm for further propagation at KEFRI nurseries. Because of the conditions of the site, the analyses-and especially the assessments of potential yield-were made using conservative assumptions.

The following species and varieties were observed in the trial sites: (1) *Bambusa vulgaris*; (2) *Bambusa vulgaris* 'Vitatta'; (3) *Bambusa bambos*; (4) *Bambusa tulda*; (4) *Cephalostachyum pergracile*; (5) *Dendrocalamus asper*; (6) *Dendrocalamus brandisii*; (6) *Dendrocalamus giganteus*; (7) *Dendrocalamus hamiltonii*; (8) *Dendrocalamus membranaceus*; (9) *Dendrocalamus strictus*; (10) *Thyrsostachys siamensis;* (11) *Phyllostachys species.*

There is confusion about the identity of some species planted in the trials, especially in Muguga and Kakamega. There were in several cases clear differences between the plants in particular species plots. The author later learned from Dr. Bernard Kigomo that, at the time of establishing the trials, there was a mix of some plants during transport and planting. This is why plants differ significantly from the typical form of the species in some plots, which raised serious doubts regarding the identity of some species. A particular case in point is the plant referred to as "*Phyllostachys pubescens"* planted in Kakamega. The plants were grown from seeds obtained in Japan. Although the plants certainly belong to the Phyllostachys genus, they are extremely smaller in both height and diameter and do not resemble the species *Phyllostachys pubescens*. Due to doubts about

identification, apparent unsuitability of the species for the area, and the fact that this species was only planted in Kakamega, the species is not included in this analysis. Another case is that of *Dendrocalamus. asper*. The relatively good performance of this species under cultivation in Nairobi suggests that this species may be interesting for plantations. *D. asper* was planted in the Muguga trials but the species was not identified at the site, so no data was recorded for analysis. It is possible that *D. asper* was mixed up with *D. brandisii*. In Kakamega, a clump resembling *D. asper* was observed in the plot of *D. brandisii*. *D. asper* was however not originally included in the Kakamega trial site. Some elements of doubt therefore remain in the analyses and taxonomical clarifications are required.

Methodology

The method of analyzing the sites involved the following steps:

1) Observations were made on various clumps of each species and the number of culms and new shoots per clump was counted or estimated. In very dense clumps it was not possible to count the number of culms and therefore an estimate of the number of culms was made based on the number of culms counted for a particular area of the clump. Based on the counted and/or estimated number of culms of the sampled clumps of each species, average numbers of culms per clump per species was calculated.

2) The observation of the clumps involved visually identifying small, medium, and large culms and measuring the circumference of selected samples using a measuring tape. Based on the measured samples of various sizes of culms of each species, and taking into account the fact bamboo culms are tapered from the base towards the tip of the culm, an average culm diameter was calculated for each species.

3) The average height of the culms of each species was determined in many cases, roughly by observation, as well as accurately, by felling culms and measuring their precise length in meters. This method was applied by sampling culms in several clumps and an average height per species was calculated.

4) The wall thickness of the bamboo culms was calculated based on published information (as well as on unpublished information collected by the author over the years) regarding the ratio of wall thickness to culm diameter per species.

5) The dry weight of culms was calculated of the basis of the solid volume of the bamboo culm, using the specific gravity of bamboo to determine the mass. In calculating the volume of the culms, radial shrinkage of the culms is taken into account. Shrinkage ranges from 4-14% in the wall thickness and 3-12% in diameter. (Liese, 1985.) Culm shrinkage varies from species to species and depends very much on the moisture content of the culm at the time of harvesting. As a working assumption, the mean radial shrinkage factor of 9% in the wall thickness and 7.5% in diameter for tropical bamboos was assumed. The specific gravity of bamboo ranges from 0.5 to 0.8 (0.9) g/cm^3 (Liese, 1985). The value of 0.65 was taken as a working assumption for all species, which is the approximate value for most species of the *Bambusa* and *Dendrocalamus* genera. The mass to volume ratio of air dried bamboo with 11% moisture is about 0.7 g/m^3 and this was used as a working assumption for determining air dry weight of culms. The solid volume of bamboo is determined by multiplying the length of the culm by the solid cross section area of the culm. The solid cross section area is calculated by subtracting the culm cavity cross section area from the total cross section area. The cross section areas are calculated using the formula for the area of a circle (Area = Πr^2). Once the solid volume of the culm is estimated, the mass can be determined by means of the mass to volume ratio of bamboo. The method is purely mathematical but provides a rough estimation of culm weight. The actual average weight of the culms may vary by +/-20%. Clearly, the most accurate way of

determining culm weight is by physically weighing the dry culms, but this was not possible due to time and logistical constraints.

6) The estimated potential yield in tons (dry basis) per hectare per year was made with the assumption that, on average, 25% of the culms per clump are annually harvested. The figure of 25% or ¼ of the culms was used on the basis that only 3 year old mature culms are harvested and that new culms (year 0), as well as 1 and 2 year old culms are left to mature. There are variations in the number of new shoots that appear each year so the figure of 25% is a working assumption. There may be years when fewer culms are mature and ready for harvesting, while in other years the harvest will be much greater. Clump management and maintenance as well as climactic factors play a leading role in productivity. In this regard, bamboo is not different from most other crops.

7) Given the fact that the plantations are not well managed, it was assumed that the commercial yield would be lower than the potential yield. It was assumed that in a poorly managed plantation only 40% of the culms would be sellable.

8) To compare the performance of the species in the KEFRI trials, collected data on the average physical properties of the culms of the species in their natural range in Asia was used for benchmarking. Averages of culm height, diameter, wall thickness, and dry weight culm in the KEFRI plantations were calculated and compared to the benchmark values.

9) Analytic data per species and per location was sorted in order to rank the species in terms of three categories: (a) Estimated Potential Yield in Tons (Air Dry Basis) per ha/year; (b) Average dry weight of the culm; and (c) Height of the culm.

Analyses of the KEFRI Bamboo Trials

Abbreviations Used in the Analytic Tables:

- H = Average Height of mature culms in Meters
- D = Average Diameter of Mature Tapered Culms in Meters
- WT = Average Wall Thickness in millimeters
- DM = Estimated Average Air Dry Weight of Culm in Kilograms
- AC = Average number of culms per clump
- EY = Estimated Potential (air dried) Yield in Tons per hectare per year based on 5mX5m planting (400 plants/ha) with felling of only mature culms (25% of total culms) and extraction of dead or rotting culms.
- CY = Commercial yield refers to tons per ha per year of top quality culms. 40% of Estimated Potential Yield (EY) is assumed.
- RYS = Relative Yield Performance Ratio of a Species in Kenya. Each species with the highest Estimated Potential Yield (EY) is used as the basis for calculating the RYS ratio for the same species in different trial sites in Kenya. Thus, RYS = EY of a Species in Site X / EY of the same Species in the site where it obtains the highest EY. The RYS of the species with the highest yield in any of the various trial sites is therefore equal to 1.

Performance of Bamboo Species per Trial Site

Following the methodology outlined above, the performance of each observed species per trial site was assessed.

Table 2: Performance of *Bambusa bambos*

Species:	Bambusa bambos						
Trial Site	H	D	WT	DM	AC	EY	CY
Gede	9	5	7.5	3.8	25	9.4	3.8
Jilore	15	9	13.5	18.3	22	40.2	16.1
Kakamega	4	7	10	3.1	22	6.9	2.8
Muguga	4	6	9	2.4	22	5.3	2.1

Table 3: Performance of *Bambusa tulda*

Species:	Bambusa Tulda						
Trial Site	H	D	WT	DM	AC	EY	CY
Gede	No Data available						
Jilore	No Data available						
Kakamega	6	7	10	4.7	17	8.0	3.2
Muguga	6	7	10	4.7	17	8.0	3.2

Table 4: Performance of *Bambusa vulgaris* 'Vitatta'

Species:	Bambusa vulgaris 'Vitatta'						
Trial Site	H	D	WT	DM	AC	EY	CY
Gede	8	6	8	4.3	30	13.0	5.2
Jilore	No Data available						
Kakamega	8	7	9	5.7	28	16.0	6.4
Muguga	7	7	9	5.0	28	14.0	5.6

Table 5: Performance of *Cephalostachyum pergracile*

Species:	Cephalostachyum pergracile						
Trial Site	H	D	WT	DM	AC	EY	CY
Gede	Not Planted						
Jilore	No Data available						
Kakamega	Not Planted						
Muguga	10	6	5	3.5	17	5.9	2.4

Table 6: Performance of *Dendrocalamus asper*

Species:	Dendrocalamus asper						
Trial Site	H	D	WT	DM	AC	EY	CY
Gede	Not Planted						
Jilore	Not Planted						
Kakamega	Not Planted						
Muguga	No Data available / Possibly mixed with D. brandisii						

Table 7: Performance of *Dendrocalamus brandisii*

Species:	Dendrocalamus brandisii						
Trial Site	H	D	WT	DM	AC	EY	CY
Gede	15	10	18	29.7	6	17.8	7.1
Jilore	No Data available						
Kakamega	12	11	15	22.3	17	37.9	15.2
Muguga	10	10	18	19.8	17	33.7	13.5

Table 8: Performance of *Dendrocalamus membranaceus*

Species:	Dendrocalamus membranaceus						
Trial Site	H	D	WT	DM	AC	EY	CY
Gede	9	5	5	2.6	28	7.2	2.9
Jilore	12	7	10	9.4	39	36.8	14.7
Kakamega	7	7	8	4.5	17	7.6	3.0
Muguga	7	6	6	2.9	17	4.9	2.0

Table 9: Performance of *Dendrocalamus strictus*

Species:	Dendrocalamus strictus						
Trial Site	H	D	WT	DM	AC	EY	CY
Gede	9	3	11.3	3.0	25	7.5	3.0
Jilore	No Data available						
Kakamega	5	7	25	8.7	11	9.6	3.8
Muguga	5	6	23	6.7	11	7.4	3.0

Table 10: Performance of *Dendrocalamus hamiltonii*

Species:	Dendrocalus hamiltonii						
Trial Site	H	D	WT	DM	AC	EY	CY
Gede	9	5	7.5	3.8	30	11.3	4.5
Jilore	10	6	9	6.0	28	16.9	6.8
Kakamega	10	10	10	11.5	19	21.8	8.7
Muguga	9	10	10	10.3	28	29.0	11.6

Table 11: Performance of *Thyrsostachys siamensis*

Species:	Thyrsostachys siamensis						
Trial Site	H	D	WT	DM	AC	EY	CY
Gede	6	2.5	9.4	1.4	39	5.4	2.2
Jilore	No Data available						
Kakamega	5	2.5	9	1.1	28	3.1	1.2
Muguga	5	3	9	2.4	28	6.8	2.7

Benchmark Analysis

Table 12 to Table 15 below show the analyses of the performance of species at each KEFRI trial site. The average characteristics of species under cultivation within their natural range in Asia are used as a benchmark. The average weight and physical characteristics of the culm of the species in the trials are compared to data of the same species in Asia.

It is important to draw attentions to the limitations of this method of analysis. The benchmark analysis only provides a basis for comparing the characteristics of the culm, but it does not, by itself, allow for any conclusions regarding the suitability of a species for a particular site.

For instance, Table 12 shows that, in Gede, *D. brandisii* performed comparatively well in terms of culm diameter (D=83%) and culm weight (DM=49%). However, on the site, the clumps of *D. brandisii* were very sparsely populated with culms (AC=6). The high estimated potential yield (EY) of this species is due to the weight of the culms, but under better conditions and with good management, it can have a much better overall performance.

Bamboos are not created equal. In the family of woody bamboos, there are small, medium, large, and giant species. Apart from good climatic conditions, sufficient sunlight and rainfall, each species needs enough space to grow in order to reach its full size. This seriously has to be considered at the time of planting. In the KEFRI trials; all bamboo species were treated equally and planted at the spacing of 5m x 5m. This spacing was excessive for a small clumping species like *T. siamensis*, but insufficient for a giant like *D. brandisii* or large species like *D. hamiltonii* and *B. bambos*. Depending on the purpose of the plantation, large tropical bamboos with pachymorph rhizomes can be planted at distances of up to 10 m by 10m (100 clumps per hectare) to allow for the establishment of huge clumps. If the plantation is intended for the production of edible shoots, spacing can be reduced significantly, because the aim is to maintain thin clumps and harvest most of the shoots.

Table 12: Benchmark analysis of species in KEFRI Bamboo Trial in Gede

KEFRI Trial Site Location: Gede								**Ave. Performance in Natural Range in Asia**				**Comparative Performance in Gede**			
Species	H	D	WT	DM	AC	EY	CY	H	D	WT	DM	H	D	WT	DM
D. hamiltonii	9	5	7.5	3.8	30	11.3	4.5	20	10	15	33.6	45%	50%	50%	11%
B. tulda	No Data available							18	10	17	33.9	No Data available			
D. membranaceus	9	5	5	2.6	28	7.2	2.9	18	10	10	20.7	50%	50%	50%	12%
D. asper	Not Planted							22	12	20	58.5	No Data available			
B. vulgaris	8	6	8	4.3	30	13.0	5.2	15	7	10	11.8	53%	86%	80%	37%
D. brandisii	15	10	18	29.7	6	17.8	7.1	25	12	18	60.4	60%	83%	100%	49%
D. strictus	9	3	11.3	3.0	25	7.5	3.0	10	8	30	23.6	90%	38%	38%	13%
B. bambos	9	5	7.5	3.8	25	9.4	3.8	20	12	18	48.3	45%	42%	42%	8%
T. siamensis	6	2.5	9.4	1.4	39	5.4	2.2	9	4	15	5.3	67%	63%	63%	26%
D. giganteus	Not Planted							25	15	22	92.5	No Data available			
C. pergracile	Not Planted							18	8	6	10.1	No Data available			

Table 13: Benchmark analysis of species in KEFRI Bamboo Trial in Jilore

KEFRI Trial Site Location: Jilore								**Ave. Performance in Natural Range in Asia**				**Comparative Performance in Jilore**			
Species	H	D	WT	DM	AC	EY	CY	H	D	WT	DM	H	D	WT	DM
D. hamiltonii	10	6	9	6.0	28	16.9	6.8	20	10	15	33.6	50%	60%	60%	18%
D. membranaceus	12	7	10	9.4	39	36.8	14.7	18	10	10	20.7	67%	70%	100%	46%
B. bambos	15	9	13.5	18.3	22	40.2	16.1	20	12	18	48.3	75%	75%	75%	38%
T. siamensis	No Data available							9	4	15	5.3	No Data available			
D. giganteus	Not Planted							25	15	22	92.5	No Data available			
C. pergracile	No Data available							18	8	6	10.1	No Data available			

Table 14: Benchmark analysis of species in KEFRI Bamboo Trial in Kakamega

KEFRI Trial Site	Location: Kakamega							Ave. Performance in Natural Range in Asia				Comparative Performance in Kakamega			
Species	H	D	WT	DM	AC	EY	CY	H	D	WT	DM	H	D	WT	DM
D. hamiltonii	10	10	10	11.5	19	21.8	8.7	20	10	15	33.6	50%	100%	67%	34%
B. tulda	6	7	10	4.7	17	8.0	3.2	18	10	17	33.9	33%	70%	59%	14%
D. membranaceus	7	7	8	4.5	17	7.6	3.0	18	10	10	20.7	39%	70%	80%	22%
D. asper	No Data available				0			22	12	20	58.5	No Data available			
B. vulgaris	8	7	9	5.7	28	16.0	6.4	15	7	10	11.8	53%	100%	90%	48%
D. brandisii	12	11	15	22.3	17	37.9	15.2	25	12	18	60.4	48%	92%	83%	37%
D. strictus	5	7	25	8.7	11	9.6	3.8	10	8	30	23.6	50%	88%	83%	37%
B. bambos	4	7	10	3.1	22	6.9	2.8	20	12	18	48.3	20%	58%	56%	7%
T. siamensis	5	2.5	9	1.1	28	3.1	1.2	9	4	15	5.3	56%	63%	60%	21%
D. giganteus	Not Planted							25	15	22	92.5	No Data available			
C. pergracile	No Data available							18	8	6	10.1	No Data available			

Table 15: Benchmark analysis of species in KEFRI Bamboo Trial in Muguga

KEFRI Trial Site	Location: Muguga							Ave. Performance in Natural Range in Asia				Comparative Performance in Muguga			
Species	H	D	WT	DM	AC	EY	CY	H	D	WT	DM	H	D	WT	DM
D. hamiltonii	9	10	10	10.3	28	29.0	11.6	20	10	15	33.6	45%	100%	67%	31%
B. tulda	6	7	10	4.7	17	8.0	3.2	18	10	17	33.9	33%	70%	59%	14%
D. membranaceus	7	6	6	2.9	17	4.9	2.0	18	10	10	20.7	39%	60%	60%	14%
D. asper	No Data available				0			22	12	20	58.5	No Data available			
B. vulgaris	7	7	9	5.0	28	14.0	5.6	15	7	10	11.8	47%	100%	90%	42%
D. brandisii	10	10	18	19.8	17	33.7	13.5	25	12	18	60.4	40%	83%	100%	33%
D. strictus	5	6	23	6.7	11	7.4	3.0	10	8	30	23.6	50%	75%	77%	29%
B. bambos	4	6	9	2.4	22	5.3	2.1	20	12	18	48.3	20%	50%	50%	5%
T. siamensis	5	3	9	2.4	28	6.8	2.7	9	4	15	5.3	56%	75%	60%	46%
D. giganteus	Not Planted							25	15	22	92.5	No Data available			
C. pergracile	10	6	5	3.5	17	5.9	2.4	18	8	6	10.1	56%	75%	83%	34%

As the preceding tables show, the average culm size and weight of most of the species planted in Kenya are far below the benchmark values. Most likely this is not only because the species are planted outside their natural range, but also because they have not been managed. Under good management, where systematic harvesting of mature culms is carried out, it is likely that better results would be obtained for most species. Furthermore, despite the fact that most species are stunted in height, good climatic conditions-especially rainfall-coupled with a good management regime usually leads to vigorous shoot development, and hence, higher biomass productivity over time per unit area.

Species to Site Matching

Table 16: General Ranking of Species based on Estimated Potential Yield

Ranking of Species in the trial sites according to Estimated Potential Yield in Tons (Dry Matter) / Ha									
Rank	**Species**	**Trial Site**	**H**	**D**	**WT**	**DM**	**AC**	**EY**	**CY**
1	B. bambos	Jilore	15	9	13.5	18.3	22	**40.2**	16.1
2	D. brandisii	Kakamega	12	11	15	22.3	17	**37.9**	15.2
3	D. membranaceus	Jilore	12	7	10	9.4	39	**36.8**	14.7
4	D. brandisii	Muguga	10	10	18	19.8	17	**33.7**	13.5
5	D. hamiltonii	Muguga	9	10	10	10.3	28	**29.0**	11.6
6	D. hamiltonii	Kakamega	10	10	10	11.5	19	**21.8**	8.7
7	D. brandisii	Gede	15	10	18	29.7	6	**17.8**	7.1
8	D. hamiltonii	Jilore	10	6	9	6.0	28	**16.9**	6.8
9	B. vulgaris	Kakamega	8	7	9	5.7	28	**16.0**	6.4
10	B. vulgaris	Muguga	7	7	9	5.0	28	**14.0**	5.6
11	B. vulgaris	Gede	8	6	8	4.3	30	**13.0**	5.2
12	D. hamiltonii	Gede	9	5	7.5	3.8	30	**11.3**	4.5
13	D. strictus	Kakamega	5	7	25	8.7	11	**9.6**	3.8
14	B. bambos	Gede	9	5	7.5	3.8	25	**9.4**	3.8
15	B. tulda	Kakamega	6	7	10	4.7	17	**8.0**	3.2
16	B. tulda	Muguga	6	7	10	4.7	17	**8.0**	3.2
17	D. membranaceus	Kakamega	7	7	8	4.5	17	**7.6**	3.0
18	D. strictus	Gede	9	3	11.3	3.0	25	**7.5**	3.0
19	D. strictus	Muguga	5	6	23	6.7	11	**7.4**	3.0
20	D. membranaceus	Gede	9	5	5	2.6	28	**7.2**	2.9
21	B. bambos	Kakamega	4	7	10	3.1	22	**6.9**	2.8
22	T. siamensis	Muguga	5	3	9	2.4	28	**6.8**	2.7
23	C. pergracile	Muguga	10	6	5	3.5	17	**5.9**	2.4
24	T. siamensis	Gede	6	2.5	9.4	1.4	39	**5.4**	2.2
25	B. bambos	Muguga	4	6	9	2.4	22	**5.3**	2.1
26	D. membranaceus	Muguga	7	6	6	2.9	17	**4.9**	2.0
27	T. siamensis	Kakamega	5	2.5	9	1.1	28	**3.1**	1.2

Table 17: Ranking of Species Per Site based on Estimated Potential Yield

Ranking of Species per Trial Site according to Estimated Potential Yield in Tons (Dry Matter) / Ha									
Rank	Species	Trial Site	H	D	WT	DM	AC	**EY**	CY
1	D. brandisii	Gede	15	10	18	29.7	6	**17.8**	7.1
2	B. vulgaris	Gede	8	6	8	4.3	30	**13.0**	5.2
3	D. hamiltonii	Gede	9	5	7.5	3.8	30	**11.3**	4.5
4	B. bambos	Gede	9	5	7.5	3.8	25	**9.4**	3.8
5	D. strictus	Gede	9	3	11.3	3.0	25	**7.5**	3.0
6	D. membranaceus	Gede	9	5	5	2.6	28	**7.2**	2.9
7	T. siamensis	Gede	6	2.5	9.4	1.4	39	**5.4**	2.2
1	B. bambos	Jilore	15	9	13.5	18.3	22	**40.2**	16.1
2	D. membranaceus	Jilore	12	7	10	9.4	39	**36.8**	14.7
3	D. hamiltonii	Jilore	10	6	9	6.0	28	**16.9**	6.8
1	D. brandisii	Kakamega	12	11	15	22.3	17	**37.9**	15.2
2	D. hamiltonii	Kakamega	10	10	10	11.5	19	**21.8**	8.7
3	B. vulgaris	Kakamega	8	7	9	5.7	28	**16.0**	6.4
4	D. strictus	Kakamega	5	7	25	8.7	11	**9.6**	3.8
5	B. tulda	Kakamega	6	7	10	4.7	17	**8.0**	3.2
6	D. membranaceus	Kakamega	7	7	8	4.5	17	**7.6**	3.0
7	B. bambos	Kakamega	4	7	10	3.1	22	**6.9**	2.8
8	T. siamensis	Kakamega	5	2.5	9	1.1	28	**3.1**	1.2
1	D. brandisii	Muguga	10	10	18	19.8	17	**33.7**	13.5
2	D. hamiltonii	Muguga	9	10	10	10.3	28	**29.0**	11.6
3	B. vulgaris	Muguga	7	7	9	5.0	28	**14.0**	5.6
4	B. tulda	Muguga	6	7	10	4.7	17	**8.0**	3.2
5	D. strictus	Muguga	5	6	23	6.7	11	**7.4**	3.0
6	T. siamensis	Muguga	5	3	9	2.4	28	**6.8**	2.7
7	C. pergracile	Muguga	10	6	5	3.5	17	**5.9**	2.4
8	B. bambos	Muguga	4	6	9	2.4	22	**5.3**	2.1
9	D. membranaceus	Muguga	7	6	6	2.9	17	**4.9**	2.0

Table 18: General Ranking of Species based on Culm Weight

Ranking of Species in the various trial sites according to Weight (Kg) DM of Culms									
Rank	Species	Trial Site	H	D	WT	**DM**	AC	**EY**	CY
1	D. brandisii	Gede	15	10	18	**29.7**	6	**17.8**	7.1
2	D. brandisii	Kakamega	12	11	15	**22.3**	17	**37.9**	15.2
3	D. brandisii	Muguga	10	10	18	**19.8**	17	**33.7**	13.5
4	B. bambos	Jilore	15	9	13.5	**18.3**	22	**40.2**	16.1
5	D. hamiltonii	Kakamega	10	10	10	**11.5**	19	**21.8**	8.7
6	D. hamiltonii	Muguga	9	10	10	**10.3**	28	**29.0**	11.6
7	D. membranaceus	Jilore	12	7	10	**9.4**	39	**36.8**	14.7
8	D. strictus	Kakamega	5	7	25	**8.7**	11	**9.6**	3.8
9	D. strictus	Muguga	5	6	23	**6.7**	11	**7.4**	3.0
10	D. hamiltonii	Jilore	10	6	9	**6.0**	28	**16.9**	6.8
11	B. vulgaris	Kakamega	8	7	9	**5.7**	28	**16.0**	6.4
12	B. vulgaris	Muguga	7	7	9	**5.0**	28	**14.0**	5.6
13	B. tulda	Kakamega	6	7	10	**4.7**	17	**8.0**	3.2
14	B. tulda	Muguga	6	7	10	**4.7**	17	**8.0**	3.2
15	D. membranaceus	Kakamega	7	7	8	**4.5**	17	**7.6**	3.0
16	B. vulgaris	Gede	8	6	8	**4.3**	30	**13.0**	5.2
17	D. hamiltonii	Gede	9	5	7.5	**3.8**	30	**11.3**	4.5
18	B. bambos	Gede	9	5	7.5	**3.8**	25	**9.4**	3.8
19	C. pergracile	Muguga	10	6	5	**3.5**	17	**5.9**	2.4
20	B. bambos	Kakamega	4	7	10	**3.1**	22	**6.9**	2.8
21	D. strictus	Gede	9	3	11.3	**3.0**	25	**7.5**	3.0
22	D. membranaceus	Muguga	7	6	6	**2.9**	17	**4.9**	2.0
23	D. membranaceus	Gede	9	5	5	**2.6**	28	**7.2**	2.9
24	T. siamensis	Muguga	5	3	9	**2.4**	28	**6.8**	2.7
25	B. bambos	Muguga	4	6	9	**2.4**	22	**5.3**	2.1
26	T. siamensis	Gede	6	2.5	9.4	**1.4**	39	**5.4**	2.2
27	T. siamensis	Kakamega	5	2.5	9	**1.1**	28	**3.1**	1.2

Table 19: Ranking of Species Per Site based on average culm weight

Ranking of Species per Trial Site according to Weight (Kg) DM of Culms									
Rank	Species	Trial Site	H	D	WT	**DM**	AC	EY	CY
1	D. brandisii	Gede	15	10	18	**29.7**	6	17.8	7.1
2	B. vulgaris	Gede	8	6	8	**4.3**	30	13.0	5.2
3	B. bambos	Gede	9	5	7.5	**3.8**	25	9.4	3.8
4	D. hamiltonii	Gede	9	5	7.5	**3.8**	30	11.3	4.5
5	D. strictus	Gede	9	3	11.3	**3.0**	25	7.5	3.0
6	D. membranaceus	Gede	9	5	5	**2.6**	28	7.2	2.9
7	T. siamensis	Gede	6	2.5	9.4	**1.4**	39	5.4	2.2
1	B. bambos	Jilore	15	9	13.5	**18.3**	22	40.2	16.1
2	D. membranaceus	Jilore	12	7	10	**9.4**	39	36.8	14.7
3	D. hamiltonii	Jilore	10	6	9	**6.0**	28	16.9	6.8
1	D. brandisii	Kakamega	12	11	15	**22.3**	17	37.9	15.2
2	D. hamiltonii	Kakamega	10	10	10	**11.5**	19	21.8	8.7
3	D. strictus	Kakamega	5	7	25	**8.7**	11	9.6	3.8
4	B. vulgaris	Kakamega	8	7	9	**5.7**	28	16.0	6.4
5	B. tulda	Kakamega	6	7	10	**4.7**	17	8.0	3.2
6	D. membranaceus	Kakamega	7	7	8	**4.5**	17	7.6	3.0
7	B. bambos	Kakamega	4	7	10	**3.1**	22	6.9	2.8
8	T. siamensis	Kakamega	5	2.5	9	**1.1**	28	3.1	1.2
1	D. brandisii	Muguga	10	10	18	**19.8**	17	33.7	13.5
2	D. hamiltonii	Muguga	9	10	10	**10.3**	28	29.0	11.6
3	D. strictus	Muguga	5	6	23	**6.7**	11	7.4	3.0
4	B. vulgaris	Muguga	7	7	9	**5.0**	28	14.0	5.6
5	B. tulda	Muguga	6	7	10	**4.7**	17	8.0	3.2
6	C. pergracile	Muguga	10	6	5	**3.5**	17	5.9	2.4
7	D. membranaceus	Muguga	7	6	6	**2.9**	17	4.9	2.0
8	B. bambos	Muguga	4	6	9	**2.4**	22	5.3	2.1
9	T. siamensis	Muguga	5	3	9	**2.4**	28	6.8	2.7

Table 20: General Ranking of Species based on Average Culm Height

Ranking of Species in the various trial sites according to Height (m) of Culms									
Rank	Species	Trial Site	**H**	D	WT	DM	AC	**EY**	CY
1	B. bambos	Jilore	**15**	9	13.5	18.3	22	**40.2**	16.1
2	D. brandisii	Gede	**15**	10	18	29.7	6	**17.8**	7.1
3	D. brandisii	Kakamega	**12**	11	15	22.3	17	**37.9**	15.2
4	D. membranaceus	Jilore	**12**	7	10	9.4	39	**36.8**	14.7
5	D. brandisii	Muguga	**10**	10	18	19.8	17	**33.7**	13.5
6	D. hamiltonii	Kakamega	**10**	10	10	11.5	19	**21.8**	8.7
7	D. hamiltonii	Jilore	**10**	6	9	6.0	28	**16.9**	6.8
8	C. pergracile	Muguga	**10**	6	5	3.5	17	**5.9**	2.4
9	D. hamiltonii	Muguga	**9**	10	10	10.3	28	**29.0**	11.6
10	D. hamiltonii	Gede	**9**	5	7.5	3.8	30	**11.3**	4.5
11	B. bambos	Gede	**9**	5	7.5	3.8	25	**9.4**	3.8
12	D. strictus	Gede	**9**	3	11.3	3.0	25	**7.5**	3.0
13	D. membranaceus	Gede	**9**	5	5	2.6	28	**7.2**	2.9
14	B. vulgaris	Kakamega	**8**	7	9	5.7	28	**16.0**	6.4
15	B. vulgaris	Gede	**8**	6	8	4.3	30	**13.0**	5.2
16	B. vulgaris	Muguga	**7**	7	9	5.0	28	**14.0**	5.6
17	D. membranaceus	Kakamega	**7**	7	8	4.5	17	**7.6**	3.0
18	D. membranaceus	Muguga	**7**	6	6	2.9	17	**4.9**	2.0
19	B. tulda	Kakamega	**6**	7	10	4.7	17	**8.0**	3.2
20	B. tulda	Muguga	**6**	7	10	4.7	17	**8.0**	3.2
21	T. siamensis	Gede	**6**	2.5	9.4	1.4	39	**5.4**	2.2
22	D. strictus	Kakamega	**5**	7	25	8.7	11	**9.6**	3.8
23	D. strictus	Muguga	**5**	6	23	6.7	11	**7.4**	3.0
24	T. siamensis	Muguga	**5**	3	9	2.4	28	**6.8**	2.7
25	T. siamensis	Kakamega	**5**	2.5	9	1.1	28	**3.1**	1.2
26	B. bambos	Kakamega	**4**	7	10	3.1	22	**6.9**	2.8
27	B. bambos	Muguga	**4**	6	9	2.4	22	**5.3**	2.1

Table 21: Ranking of Species per Site based on Average Culm Height

Ranking of Species per trial site according to Height (m) of Culms									
Rank	Species	Trial Site	**H**	D	WT	DM	AC	EY	CY
1	D. brandisii	Gede	**15**	10	18	29.7	6	**17.8**	7.1
2	D. hamiltonii	Gede	**9**	5	7.5	3.8	30	**11.3**	4.5
3	B. bambos	Gede	**9**	5	7.5	3.8	25	**9.4**	3.8
4	D. strictus	Gede	**9**	3	11.3	3.0	25	**7.5**	3.0
5	D. membranaceus	Gede	**9**	5	5	2.6	28	**7.2**	2.9
6	B. vulgaris	Gede	**8**	6	8	4.3	30	**13.0**	5.2
7	T. siamensis	Gede	**6**	2.5	9.4	1.4	39	**5.4**	2.2
1	B. bambos	Jilore	**15**	9	13.5	18.3	22	**40.2**	16.1
2	D. membranaceus	Jilore	**12**	7	10	9.4	39	**36.8**	14.7
3	D. hamiltonii	Jilore	**10**	6	9	6.0	28	**16.9**	6.8
1	D. brandisii	Kakamega	**12**	11	15	22.3	17	**37.9**	15.2
2	D. hamiltonii	Kakamega	**10**	10	10	11.5	19	**21.8**	8.7
3	B. vulgaris	Kakamega	**8**	7	9	5.7	28	**16.0**	6.4
4	D. membranaceus	Kakamega	**7**	7	8	4.5	17	**7.6**	3.0
5	B. tulda	Kakamega	**6**	7	10	4.7	17	**8.0**	3.2
6	D. strictus	Kakamega	**5**	7	25	8.7	11	**9.6**	3.8
7	T. siamensis	Kakamega	**5**	2.5	9	1.1	28	**3.1**	1.2
8	B. bambos	Kakamega	**4**	7	10	3.1	22	**6.9**	2.8
1	D. brandisii	Muguga	**10**	10	18	19.8	17	**33.7**	13.5
2	C. pergracile	Muguga	**10**	6	5	3.5	17	**5.9**	2.4
3	D. hamiltonii	Muguga	**9**	10	10	10.3	28	**29.0**	11.6
4	B. vulgaris	Muguga	**7**	7	9	5.0	28	**14.0**	5.6
5	D. membranaceus	Muguga	**7**	6	6	2.9	17	**4.9**	2.0
6	B. tulda	Muguga	**6**	7	10	4.7	17	**8.0**	3.2
7	D. strictus	Muguga	**5**	6	23	6.7	11	**7.4**	3.0
8	T. siamensis	Muguga	**5**	3	9	2.4	28	**6.8**	2.7
9	B. bambos	Muguga	**4**	6	9	2.4	22	**5.3**	2.1

Table 22: Relative Yield Performance of Species per Site

Relative Performance and Ranking of Species in Each Site based on EY of Species with Highest Yield (EY)								
Species	Trial Site	H	D	WT	DM	AC	**EY**	RYS
B. bambos	Jilore	15	9	13.5	18.3	22	**40.2**	100%
B. bambos	Gede	9	5	7.5	3.8	25	**9.4**	23%
B. bambos	Kakamega	4	7	10	3.1	22	**6.9**	17%
B. bambos	Muguga	4	6	9	2.4	22	**5.3**	13%
B. tulda	Kakamega	6	7	10	4.7	17	**8.0**	100%
B. tulda	Muguga	6	7	10	4.7	17	**8.0**	100%
B. vulgaris	Kakamega	8	7	9	5.7	28	**16.0**	100%
B. vulgaris	Muguga	7	7	9	5.0	28	**14.0**	88%
B. vulgaris	Gede	8	6	8	4.3	30	**13.0**	81%
C. pergracile	Muguga	10	6	5	3.5	17	**5.9**	100%
D. brandisii	Kakamega	12	11	15	22.3	17	**37.9**	100%
D. brandisii	Muguga	10	10	18	19.8	17	**33.7**	89%
D. brandisii	Gede	15	10	18	29.7	6	**17.8**	47%
D. hamiltonii	Muguga	9	10	10	10.3	28	**29.0**	100%
D. hamiltonii	Kakamega	10	10	10	11.5	19	**21.8**	75%
D. hamiltonii	Jilore	10	6	9	6.0	28	**16.9**	58%
D. hamiltonii	Gede	9	5	7.5	3.8	30	**11.3**	39%
D. membranaceus	Jilore	12	7	10	9.4	39	**36.8**	100%
D. membranaceus	Kakamega	7	7	8	4.5	17	**7.6**	21%
D. membranaceus	Gede	9	5	5	2.6	28	**7.2**	20%
D. membranaceus	Muguga	7	6	6	2.9	17	**4.9**	13%
D. strictus	Kakamega	5	7	25	8.7	11	**9.6**	100%
D. strictus	Gede	9	3	11.3	3.0	25	**7.5**	78%
D. strictus	Muguga	5	6	23	6.7	11	**7.4**	78%
T. siamensis	Muguga	5	3	9	2.4	28	**6.8**	100%
T. siamensis	Gede	6	2.5	9.4	1.4	39	**5.4**	80%
T. siamensis	Kakamega	5	2.5	9	1.1	28	**3.1**	11%

Table 23: Species to Site - Benchmark Analysis and Relative Yield Performance

Species to Site Analysis Based on Combined Benchmark Comparison and Site Performance Data									
Rank	Species	Site	Benchmark Comparison Data				Site Performance Data		
			H	D	WT	DM	AC	EY	RYS
1	B. bambos	Jilore	75%	75%	75%	37.9%	22	40.2	100%
2	" "	Gede	45%	42%	42%	7.8%	25	9.4	23%
3	" "	Kakamega	20%	58%	56%	6.5%	22	6.9	17%
4	" "	Muguga	20%	50%	50%	5.0%	22	5.3	13%
1	B. tulda	Kakamega	33%	70%	59%	13.9%	17	8.0	100%
2	" "	Muguga	33%	70%	59%	13.9%	17	8.0	100%
1	B. vulgaris	Kakamega	53%	100%	90%	48.3%	28	16.0	100%
2	" "	Muguga	47%	100%	90%	42.3%	28	14.0	88%
3	" "	Gede	53%	86%	80%	36.7%	30	13.0	81%
1	C. pergracile	Muguga	56%	75%	83%	34.4%	17	5.9	100%
1	D. brandisii	Kakamega	48%	92%	83%	36.9%	17	37.9	100%
2	" "	Muguga	40%	83%	100%	32.8%	17	33.7	89%
3	" "	Gede	60%	83%	100%	49.2%	6	17.8	47%
1	D. hamiltonii	Muguga	45%	100%	67%	30.8%	28	29.0	100%
2	" "	Kakamega	50%	100%	67%	34.2%	19	21.8	75%
3	" "	Jilore	50%	60%	60%	18.0%	28	16.9	58%
4	" "	Gede	45%	50%	50%	11.2%	30	11.3	39%
1	D. membranaceus	Jilore	67%	70%	100%	45.6%	39	36.8	100%
2	" "	Kakamega	39%	70%	80%	21.6%	17	7.6	21%
3	" "	Gede	50%	50%	50%	12.5%	28	7.2	20%
4	" "	Muguga	39%	60%	60%	14.0%	17	4.9	13%
1	D. strictus	Kakamega	**50%**	88%	83%	**36.8%**	11	9.6	**100%**
2	" "	Muguga	**50%**	75%	77%	**28.6%**	11	7.4	**78%**
3	" "	Gede	**90%**	38%	38%	**12.7%**	25	7.5	**78%**
1	T. siamensis	Muguga	**56%**	75%	60%	**45.6%**	28	6.8	**100%**
2	" "	Gede	**67%**	63%	63%	**26.1%**	39	5.4	**80%**
3	" "	Kakamega	**56%**	63%	60%	**21.1%**	28	3.1	**11%**

Table 24: Species per Site - Benchmark Analysis and Relative Yield Performance

Ranking of Species per Site Based on Combined Benchmark Comparison and Site Performance Data									
Rank	Site	Species	Benchmark Comparison Data				Site Performance Data		
			H	D	WT	DM	AC	EY	RYS
1	Gede	B. vulgaris	53%	86%	80%	37%	30	13.0	81%
2	" "	T. siamensis	67%	63%	63%	26%	39	5.4	80%
3	" "	D. brandisii	60%	83%	100%	49%	6	17.8	47%
4	" "	D. strictus	90%	38%	38%	13%	25	7.5	78%
5	" "	D. hamiltonii	45%	50%	50%	11%	30	11.3	39%
6	" "	D. membranaceus	50%	50%	50%	12%	28	7.2	20%
7	" "	B. bambos	45%	42%	42%	8%	25	9.4	23%
1	Jilore	D. membranaceus	67%	70%	100%	46%	39	36.8	100%
2	" "	B. bambos	75%	75%	75%	38%	22	40.2	100%
3	" "	D. hamiltonii	50%	60%	60%	18%	28	16.9	58%
1	Kakamega	B. vulgaris	53%	100%	90%	48%	28	16.0	100%
2	" "	D. brandisii	48%	92%	83%	37%	17	37.9	100%
3	" "	D. strictus	50%	88%	83%	37%	11	9.6	100%
4	" "	B. tulda	33%	70%	59%	14%	17	8.0	100%
5	" "	D. hamiltonii	50%	100%	67%	34%	19	21.8	75%
6	" "	D. membranaceus	39%	70%	80%	22%	17	7.6	21%
7	" "	T. siamensis	56%	63%	60%	21%	28	3.1	11%
8	" "	B. bambos	20%	58%	56%	7%	22	6.9	17%
1	Muguga	T. siamensis	56%	75%	60%	46%	28	6.8	100%
2	" "	C. pergracile	56%	75%	83%	34%	17	5.9	100%
3	" "	D. hamiltonii	45%	100%	67%	31%	28	29.0	100%
4	" "	B. vulgaris	47%	100%	90%	42%	28	14.0	88%
5	" "	D. brandisii	40%	83%	100%	33%	17	33.7	89%
6	" "	B. tulda	33%	70%	59%	14%	17	8.0	100%
7	" "	D. strictus	50%	75%	77%	29%	11	7.4	78%
8	" "	D. membranaceus	39%	60%	60%	14%	17	4.9	13%
9	" "	B. bambos	20%	50%	50%	5%	22	5.3	13%

Conclusion

The comparative analysis of each species per site benchmarked to the performance of the species in their natural range is one criterion for species to site matching. In addition it is useful to compare the relative performance of species in the various trials by considering the number of culms per clump and estimated potential yield of the species per hectare.

Table 31 shows the species to site matching for Kakamega. The overall performance ranking is based on an analysis of the various criteria of each species as shown in Table 18 to Table 30. Table 31 shows for instance,

that although *D. brandisii* has a higher potential yield (see Table 23), the relative performance of *B. vulgaris* in terms of culm weight is better (see Table 30). It was observed that the culm production of *B. vulgaris* was the most vigorous in terms of culms per clump.

D. Brandisii, followed by *D. hamiltonii* and *D. strictus*, show better overall performance than the other species in Kakamega. *B. tulda* ranks fifth; despite its relatively low culm weight and height, the species shows a high potential yield due to the number of culms per clump.

T. siamensis is a small species but it showed very good relative performance in terms of culm height and number of culms per clump. However, the culms of this species are naturally small, and hence it ranked poorly in terms of potential yield. *T. siamensis* was planted using a spacing of 5m x 5m in the trials. However since it is small bamboo it may be planted at more proximate distances in order to maximize the biomass yield per hectare. The optimal plant spacing for *T. siamensis* is 4m x 4m (Dransfield & Widjaja, 1995). Had there been management and harvesting on the site, this species might have performed much better.

Table 25: Species to Site Matching for Kakamega (Lake Region)

		Ranking Criteria: Exotic Bamboos in Kakamega (Lake Region of Kenya)			
		Site Observation Analysis		Benchmark Comparative Analysis	
Species Rank	Overall Performance	Potential Yield (EY)	Culms per Clump (AC)	Culm Weight (DM %)	Culm Height (H %)
1	B. vulgaris	D. brandisii	B. vulgaris	B. vulgaris	T. siamensis
2	D. brandisii	D. hamiltonii	T. siamensis	D. brandisii	B. vulgaris
3	D. hamiltonii	B. vulgaris	D. hamiltonii	D. strictus	D. hamiltonii
4	D. strictus	D. strictus	B. bambos	D. hamiltonii	D. strictus
5	B. tulda	B. tulda	D. membranaceus	D. membranaceus	D. brandisii
6	T. siamensis	D. membranaceus	B. tulda	T. siamensis	D. membranaceus
7	D. membranaceus	B. bambos	D. brandisii	B. tulda	B. tulda
8	B. bambos	T. siamensis	D. strictus	B. bambos	B. bambos

If the purpose of the plantation is to obtain the highest culm yield in terms of tons per ha, then the selection of species to be recommended are *D. brandisii* followed by *D. hamiltonii*. However, these are merely provisionally recommended species. Culm yield, weight, and height are not the only criteria for selecting species for a bamboo plantation. It is essential to have a market and product or intended use for the bamboo. If the intended use is bioenergy, then planting species with the highest annual yield per hectare is recommended. However, species with a lower yield per hectare may be more suitable for splitting, weaving and basketry, which may have a ready market.

Muguga's altitude and climatic conditions are comparable to those of Lari. Species performance in Muguga can therefore be used as a basis for selection of species for the project sites in Lari. Olenguruone lies at a higher

altitude but has excellent growing conditions and high rainfall. *Y. alpina* was not analyzed in this study, but it is should be planted in Olenguruone and at high altitude areas where it can thrive.

The overall performance ranking is based on an analysis of the various criteria of each species shown in Table 18 to Table 30. The analysis of the Muguga trial site shows the following results.

Table 26: Species to Site Matching for Muguga

		Ranking Criteria			
		Site Observation Analysis		Benchmark Comparative Analysis	
Species Rank	Overall Performance	Potential Yield (EY)	Culms per Clump (AC)	Culm Weight (DM %)	Culm Height (H %)
1	T. siamensis	D. brandisii	D. hamiltonii	T. siamensis	T. siamensis
2	D. hamiltonii	D. hamiltonii	B. vulgaris	B. vulgaris	C. pergracile
3	B. vulgaris	B. vulgaris	T. siamensis	D. brandisii	D. strictus
4	D. brandisii	D. strictus	D. brandisii	D. hamiltonii	B. vulgaris
5	D. strictus	B. tulda	D. strictus	D. strictus	D. hamiltonii
6	B. tulda	C. pergracile	B. tulda	C. pergracile	D. brandisii
7	D. membranaceus	T. siamensis	D. membranaceus	B. tulda	B. tulda
8	C. pergracile	D. membranaceus	C. pergracile	D. membranaceus	D. membranaceus

In terms of its benchmark performance, *T. siamensis* is one of the species that did well in Muguga. In the trials it was planted in intervals of 5m x 5m but, as mentioned earlier, more proximate planting distances can be used to maximize its yield per hectare.

D. hamiltonii showed good performance in terms of the number of culms per clump as well as in potential yield. Vigorous shoot growth was observed in the trial in Muguga. Although it ranks second to *T. siamensis*, it should be regarded as a priority species for the production of large culms.

B. vulgaris produces a high number of culms per clump. It showed a very good relative performance in terms of average culm weight and a high estimated potential yield per hectare.

The potential yield of *D. brandisii* was the highest of the species planted in Muguga, but its relative performance in terms of height was low. As mentioned earlier in this report, there was some confusion in the Muguga site regarding species identification. *D. asper* does not appear in the above table but it was possibly mixed up with *D. brandisii*. The reasonably good performance of *D. asper* in Gigiri, Nairobi makes it a species to be considered in areas with similar conditions.

It was observed that *B. vulgaris* grows well in Olenguruone and therefore this species should be one of the main species in plantations in that area. Other tropical species may not grow as well due to the cool climate, but they should nevertheless be tested. The species that perform poorly in the highlands are *B. bambos*, followed by *D. strictus* and *B. tulda*. These species grow more favorably in warmer conditions.

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Succession of Bamboo (*Phyllostachys bambusoides* Sieb. et Zuc.) Riparian Forest Vegetation after Gregarious Flowering

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Abstract

Ecological research of *Phyllostachys bambusoides* riparian forest was practiced for 16 years from about 20 years after gregarious flowering. As a result it was indicated that the recovering vigorousness of *P. bambusoides* after flowering was continued at least for 25 years. Tree species were suppressed by bamboo again during the research. The bamboo forest vegetation is considered to need more than 25 years after bamboo flowering to stable the vegetation condition. Moreover, at the stable and unmanaged *P. bambusoides* forests, it is shown that a large amount of new culms is produced on every two or three years, and the culms of the following year are comparatively small and die young.

Introduction

In Japan, most of *Phyllostachys bambusoides* Siebold et Zuccarini flowered gregariously and died from the end of 1960's to the beginning of 1970's (Kasahara 1971). In this gregarious flowering, it was recorded that little seeds were produced and almost all the *P. bambusoides* populations regenerated by unique behavior. Although this report is not aimed to notice this regeneration system, this was asexual reproduction by the sprouting of next generation bamboo shoots from new rhizomes.

This flowering gave severe damages to the bamboo industries in Japan. After that, most of the bamboo industries abandoned to get bamboo timbers from their local areas. Notwithstanding most *P. bambusoides* forests recovered in a following decade, the new system to get bamboo timbers was not restored to its former state. At the same time, just after the flowering, many bamboo forests were converted to the other land uses. To obtain the materials for bamboo industries, much of them were not harvested in local areas and are purchased not only from other domestic areas but also from foreign countries. At present time, many recovering *P. bambusoides* forests in Japan are under unmanaged condition and scarce of constant management. As a result, in many bamboo forests the density control is not practiced, therefore, the quality of the produced bamboo timber from such kind of bamboo forests is very low.

Here, it is reported the results of the ecological research for 16 years at the unmanaged *P. bambusoides* riparian forest, which is very common condition in Japan now, and of the analyses of the vegetation succession in mixed bamboo forest with broad-leaved trees following to the recovery of bamboo after flowering.

Research Site and Method

Research is continuing at the riparian bamboo forest along Echi River, which is one of the main rivers in the east-coast plain of Lake Biwa, Shiga Prefecture, Japan. In 1990, the physiognomy survey between the middle part and lower part of river was carried out as the first step, and the change of land use and vegetation for about 100 years was traced using the topographical maps and aerial photographs (Yoshida et. al 1991). According to the results of this survey, four research sites were set. Vegetation research was started in 1992. Here, mainly, the results of one research site, which is located in the *P. bambusoides* forests sparsely mixed with broad-leaved trees, was analyzed.

Research site locates on the right bank of Echi River, 8 km upstream from the mouth. One quadrat of 40m*40m was set up. On this site, whole area was used for the research of tree species and a half of the area (20m*40m) was used for *P. bambusoides*. The research was executed in the fall of 1992 and 1994, and in the spring of 1997, 1999, 2001, 2003, 2005 and 2007. Species name, location, and diameter at breast height (d.b.h.) were surveyed for tree species, and location and d.b.h. for *P. bambusoides*.

Results

Physiognomy Survey of Vegetation along Echi River

The occurrence of *P. bambusoides* along Echi River was frequent as a whole, and the rate of occurrence in 1990 was 70% (Table 1). A lot of deciduous tree species belonging to Ulmaceae and Fagaceae, which are very popular as the component of riparian forest vegetation, appeared. As a common forest physiognomy, *P. bambusoides* with *Celtis sinensis*, *Aphananthe aspera* and *Zelkova serrata* occupy the canopy layer, and evergreen broad-leaved tree species, like *Quercus glauca*, appear as a component of the middle and shrub layer. Nevertheless *Pinus densiflora* is presumed to have occupied large area, it is decreasing their population because of pine wilt disease. This presumption was supported by the appearance of many dead pine trees. *Cryptomeria japonica* also appeared comparatively in high frequency as plantation. All the individuals of this species are inferred to be planted just after the flowering of *P. bambusoides* aiming the change of land use.

Vegetation Transition before and after the Flowering of P. bambusoides

Using two aerial photographs, taken before and after the bamboo flowering (1961 and 1982), the comparison of vegetation was carried out. The year of 1961 and 1982 are about ten years before and after bamboo flowering, respectively. The decrease of *P. bambusoides* crown caused by the flowering obviously promoted the expansion of the crowns of tree species. *P. bambusoides* forests took at least ten years to recover enough crowns after flowering. It means that, during the recovery process of bamboo forest, the seedlings and saplings of tree species on the forest floor get a chance to grow up without any suppression of bamboo.

The rate of expansion of tree species was compared using the change of crown density and occupied area of tree crown (Table 2). The result shows that they increased 450% and 400% in maximum, respectively.

Dynamics of P. bambuoides Forest during the Recent 16 years

Trees

Table 3 shows the change of main tree species number during recent 16 years in the research site. In 1992, 262 trees of 21 species (deciduous: 13, evergreen: 8) existed in 40m*40m quadrate, and 25 trees (9.5%) formed forest canopy with bamboo. Main tree species forming forest canopy was *Aphananthe aspera*, *Celtis sinensis* and *Zelkova serrata* etc.. The rest 237 trees, mainly evergreen broad-leaved species, were not the component of forest canopy, and existed as the component of forest floor vegetation.

In 1999, tree species number decreased to 177 of 12 species (deciduous: 6, evergreen: 6). However, the number of trees forming forest canopy was invariable (25 individuals) and the rate of them increased to 14%. The individuals of *Aphananthe aspera*, *Zelkova serrata* and *Ligustrum japonicum* did not decrease. The former two species are forming forest canopy, and the latter is the component of shrub layer. *Quercus glauca* showed comparatively dynamic change. In many cases, although its trunks which were alive in 1992 died during the following years, it produced coppice shoots again. This kind of ability to produce new shoots is superior on this species. But other species poor in this ability tend to decrease their individuals. All *Cryptomeria japonica*, planted species, died out during the research. The seedlings and saplings of tree species composing the forest canopy were seldom shown in the forest floor layer except a little amount of *Zelkova serrata* saplings.

In 2003, although the number of trees decreased a little to 165, tree species components and forest canopy forming trees did not change. Decrease of the number caused by the slow-down of decrease of *Camellia japonica*, *Neolitsea sericea* and *Cinnamomum sieboldii* after 1999. On the other hand, the decrease of *Celtis sinensis* was continuing. It is considered that the change of tree species tends to become stable.

Phyllostachys bambusoides

The density of new culms of *P. bambusoides* changes every year. In the research site, the number per hectare was 738, 788, 550 and 538 in 1995, 1998, 2000 and 2006 respectively, and in the other years it was from 200 to 390. This gives us a presumption that every two or three years this site produces a large number of new culms except the case of 2003 (Table 4). The distribution of new culms diameter (Figure 1) shows a lot of thin culms probably because of unmanaged condition. All of these culms are short and impossible to form forest canopy. The average of diameters was smaller on every following year of the year when bamboo forest produced large number of new culms.

The age structures of every diameter of surviving culms in the spring of 2003 and 2007 are shown on Figure 2 and Figure 3, respectively. The average diameters of all culms in each year were 6.39 cm and 6.34 cm respectively. The diameter of a large quantity of culms is from 6 to 8 cm, and there are a lot of culms more than 11 years old. The diameter of main culms forming the forest canopy was more than 6 cm. On the other hand, thinner the culm was, shorter its longevity was. The culms with comparatively long longevity were more than 3 cm culms in diameter, and the culms of diameter less than 2 cm had extremely short longevity. This is also understood by the smaller average diameter of new culms on every year than those of surviving culms in 2003 and 2007.

Discussion

As of the research in 1990, it was concluded that *P. bambusoides* forest did not finish the recovering process from flowering completely and that tree species tended to extend their territories (Yoshida et. al 1991). Nevertheless, the results of the following vegetation research in the mixed bamboo forest indicate that, in some cases, *P. bambusoides* does not continue to decline its territory and begins to defeat tree species again. This is clear from the decrease of the number of individuals and number of tree species during 16 years. Especially, the decline of planted trees, *Cryptomeria japonica* in this research site, caused by suppression of bamboo is conspicuous. Furthermore, even the evergreen broad-leaved shrub species tend to decline when they do not have enough capacity to make coppice shoots. Also the tall Ulmaceae species, which are forming forest canopy with bamboo, are presumed to decline because of the lack of succeeding seedlings and saplings, except in case with large disturbance.

P. bambusoides is thought that its activity was still increasing in comparison with the condition of 1990, and that the process of recovery from flowering had been continued for 25 years after flowering. However, it is estimated that the tendency of increase of its activity is slowing down after 1995. This presumption is followed by the increase of the percentage of small new culms and by the decrease of the number of large culms. Nevertheless, it is difficult to identify the cause whether to the end of process of recovery from flowering or to the careless management condition.

In this research it was indicated that the vigorousness of *P. bambusoides* after flowering was continued at least for 25 years. Tree species, which enlarged the territories during the recovery of bamboo, were suppressed by bamboo again. The bamboo forest vegetation is considered to need more than 25 years after bamboo flowering to stable the vegetation condition which means the coexistence of bamboo and trees. Moreover, at the stable *P. bambusoides* forest, it is shown that a large amount of new culms is recognized on every two or three years, and on each following year new culms are comparatively small and died young.

Now, in Japan, the resumption of management, like density control of bamboo culms, fertilizing and so on, is expected to set the domestic supply of materials for bamboo industry on the suitable way and to restore it in the stable condition before the flowering of *P. bambusoides*.

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Table 1. Tree species and their percentages occurred by physiognomy survey at riparian forests along Echi River, Shiga prefecture, Japan (from Yoshida *et al.* 1991)

Phyllostachys bambusoides	70	*Cornus controversa*	20
Quercus glauca	60	*Camellia japonica*	20
Celtis sinensis	40	*Castanea crenata*	10
Aphananthe aspera	30	*Quercus serrata*	10
Quercus aliena	30	*Quercus variabilis*	10
Quercus acutissima	30	*Pterocarya rhoifolia*	10
Pinus densiflora	30	*Kalopanax pictus*	10
Cryptomeria japonica	30	*Ulmus parvifolia*	10
Zelkova serrata	20	*Robinia pseudo-acacia*	10
Neolitsea sericea	20	*Persea thunbergii*	10
Meliosma myriantha	20	*Fraxinus sieboldiana*	10
Prunus grayana	20	f. *serrata*	

Table 2. Change of density and occupied area (%) of tree crown in *P. bambusoides* riparian forests along Echi River, Shiga prefecture, Japan. (comparison of 10 plots between 1961 and 1982 through aerial photograph) (from Yoshida *et al.* 1991)

Plot (size)	Distance from mouth of river (km)	Crown density (no./ha) 1961 to 1982	Occupied area of Tree crown (%) 1961 to 1982
A1(200m×200m)	2.1	0.50 to 2.25	3.51 to 12.06
A2(200m×200m)	2.4	1.00 to 2.00	6.78 to 8.78
A3(100m×400m)	2.9	4.00 to 8.50	16.47 to 34.60
A4(100m×400m)	3.3	3.50 to 6.25	14.34 to 17.45
A5(100m×400m)	4.0	1.50 to 2.50	4.64 to 8.00
A6(100m×400m)	4.8	3.00 to 4.50	8.19 to 15.45
A7(100m×400m)	5.7	2.00 to 4.25	2.82 to 11.45
A8(100m×400m)	7.5	2.00 to 5.50	3.55 to 7.39
A9(100m×400m)	8.1	4.75 to 17.75	10.10 to 40.48
A10(100m×200m)	8.4	3.50 to 10.50	6.44 to 19.56
Average	2.53 to 6.18	7.75 to 17.53	

Table 3. Change of main tree species number from 1992 to 2003 per hectare of *P. bambusoides* riparian forests along Echi River, Shiga prefecture, Japan (>=3cm)

	1992	1994	1997	1999	2001	2003	Layer
Quercus glauca	52	49	42	47	46	40	shrub
Camellia japonica	51	54	41	37	37	35	shrub
Neolitsea sericea	31	28	15	13	13	12	shrub, middle
Aphananthe aspera	30	30	29	29	28	28	top
Cinnamomum sieboldii	20	18	9	9	9	10	shrub, middle
Zelkova serrata	17	21	18	15	14	13	all
Ligustrum japonicum	13	14	13	14	14	13	shrub
Celtis sinensis	11	10	8	7	6	4	all
Cryptomeria japonica	9	6	-	-	-	-	(planted)

Table 4. Average diameter at breast height (cm) and total number of new culms in each year (/ha) of *P. bambusoides* riparian forest along Echi River, Shiga prefecture, Japan

	Before 1993	1993	1994	1995	1996	1997	1998	1999
d.b.h. of new culms	6.99	5.70	7.27	6.66	5.18	7.00	6.06	4.65
no. of new culms		---	275	350	738	250	363	788 350

	2000	2001	2002	2003	2004	2005	2006
d.b.h. of new culms	6.79	5.44	6.07	3.37	5.33	5.09	5.99
no. of new culms	550	350	200	225	388	263	538

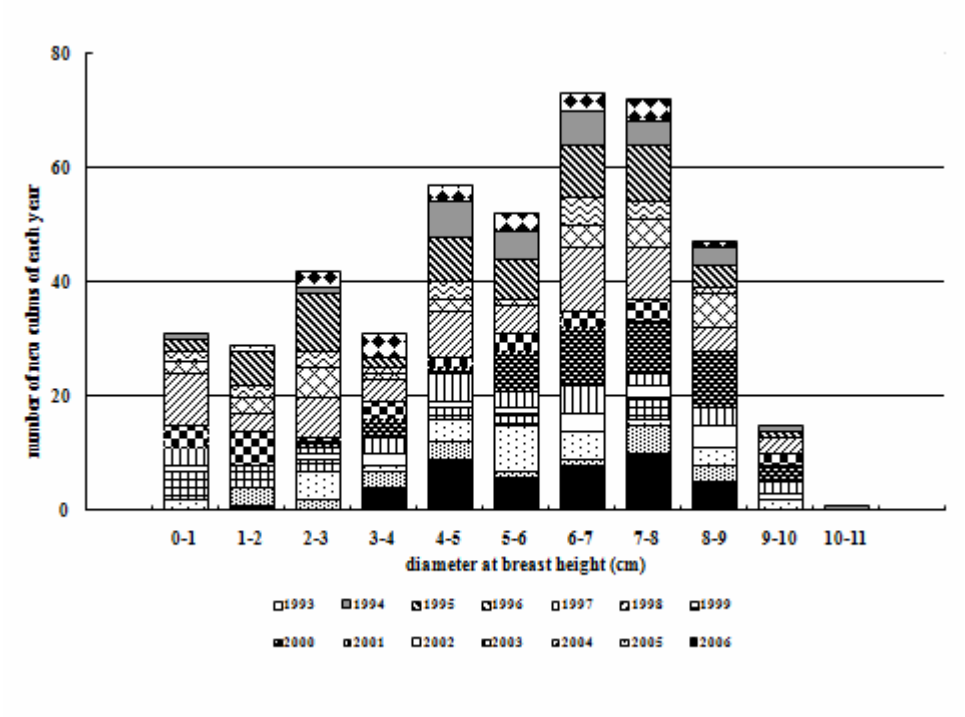

Figure 1. Distribution of diameter at breast height of new culms of each year in 800 m^2 of *P. bambusoides* riparian forests for ten years along Echi River, Shiga prefecture, Japan

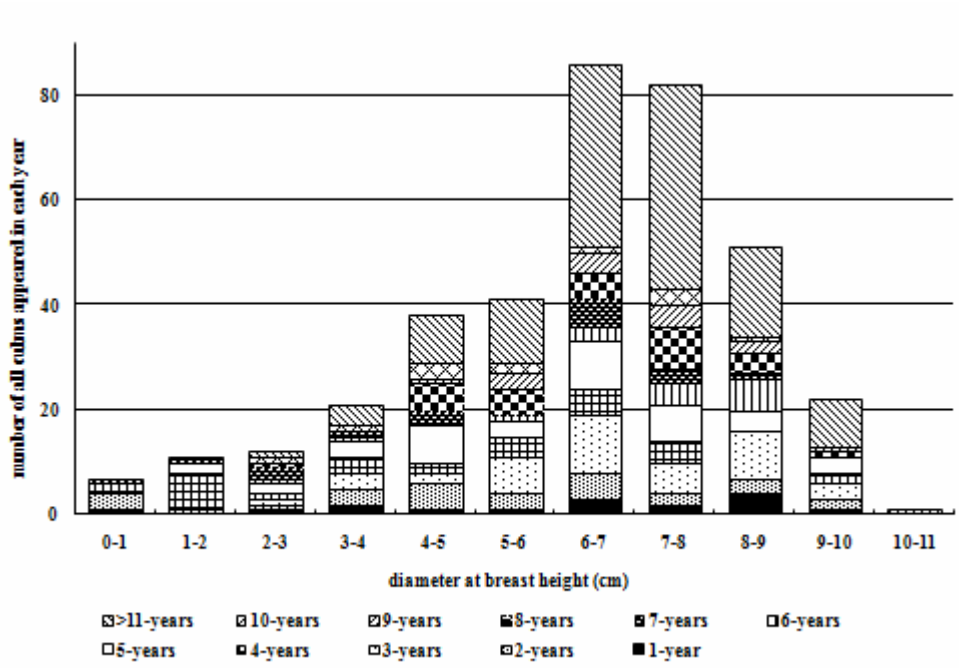

Figure 2. Distribution of diameter at breast height of all culms in 800 m^2 research site in spring, 2003

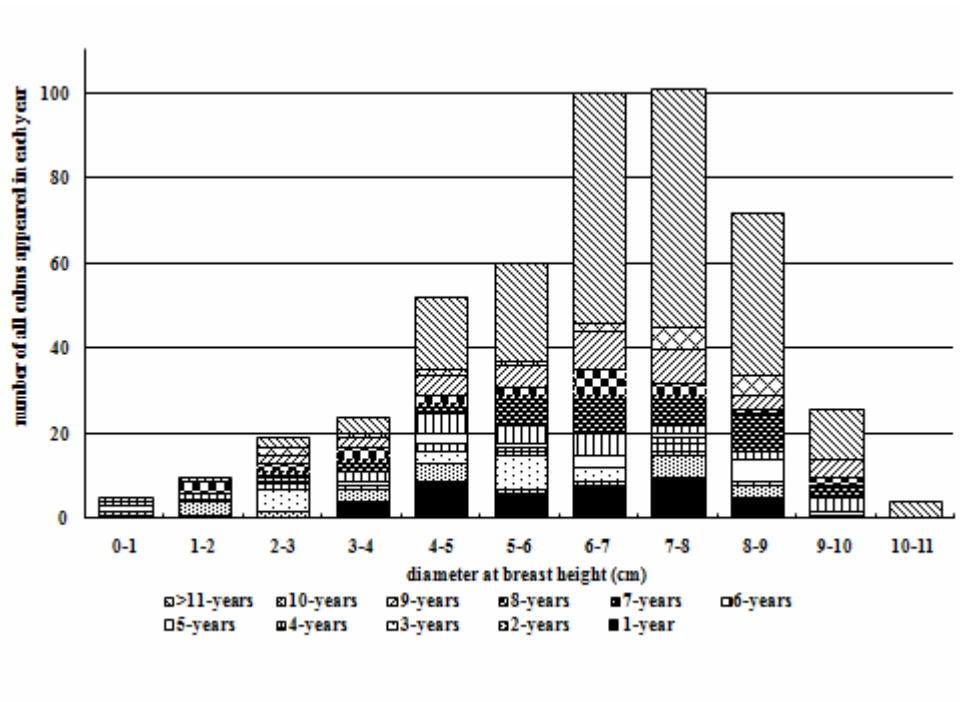

Figure 3. Distribution of diameter at breast height of all culms in 800 m^2 research site in spring, 2007

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Biology and Taxonomy

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Preface

Everyone knows how ecologically, economically and/or traditionally important bamboos are. They can be used as an alternative to wood in a variety of ways. To be able to study any more-advanced research topics or utilization, however, it is necessary to understand the fundamentals on bamboo biology and taxonomy, including systematics.

This session is contributing the most basic but the most important part among bamboo researches. It is chaired by De Zhu Li and co-chaired by Sarawood Sungkaew. D.Z. Li is a well-known bamboo taxonomist at Kunming Institute of Botany, Yunnan, who has contributed hundreds of papers for the world of bamboo taxonomy and biology. S. Sungkaew is regarded as a young-blood bamboo taxonomist who has been currently nominated to be a member of BPG (Bamboo Phylogeny Group, http://www.eeob.iastate.edu/research/bamboo/).

Cyanogenic Glycosides in Bamboo Plants Grown in Manipur, India

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Abstract

Bamboo cultivation is practiced in many tropical countries. In Manipur ,India the fresh succulent bamboo shoot slices, locally called '*Soibum*' is a highly prized vegetable item. Cyanogenic glycosides are phytotoxins which occur as secondary plant metabolites found in nature. . The cyanogenic glycosides present in bamboo shoots are Taxiphyllin. Taxiphyllin is hydrolysed to glucose and hydroxybenzaldehyde cyanohydrin. This benzaldehyde cyanohydrin then decomposes to hydroxy benzaldehyde and Hydrogen cyanide (HCN). By adequate processing like peeling ,slicing, fermenting, repeated washing, boiling,cooking ,roasting and canning, the cyanogenic glycosides and HCN can be reduced prior to consumption ,thus significantly reducing the potential health risk.

Keywords: Cyanogenic glycosides, Bamboo, Manipur

Introduction

Bamboo is a group of woody perennial evergreen plants in the grass family Poaceae, subfamily Bambusoideae, tribe Bambuseae. Some of its members are giant bamboo , forming by far the largest members of the grass family. Bamboo is the fastest growing woody plant in the world. Their growth rate (4.7inches/day)) is due to a unique rhizome-dependent system, but is highly dependent on local soil and climate conditions.

They are of economic and high cultural significance in East Asia and South East Asia where they are used extensively as a building material, in gardens, and as a food source. The shoots (new bamboo culms that come out of the ground) of bamboo (fig.1) are edible. They are used in numerous Asian dishes, and are available in markets in various sliced forms, both fresh and canned version. In Manipur, the fresh succulent bamboo shoots and the fermented preparation of bamboo shoot slices (fig.2), locally called "soibum" is a highly prized vegetable item. The "soibum" (fig.3) is manufactured traditionally by storing thin slices of fresh succulent and soft bamboo shoots in specialised containers/chambers for 2-3 months. The fermented chambers are either made of bamboo planks or roasted earthern pots. The inner surface of bamboo chambers are lined with banana leaves and a thin polythene sheets. There are different localities in Manipur where traditional fermentation of bamboo shoots is in progress (Khongkhang,Bishnupur, Andro,Noneh, Tengnoupal,Churachandpur,Kotha etc.). Bamboo shoots of many species like *Bambusa tulda,B. balcooa, Dendrocalamus hamiltonii, Melocanna bambusoides, Arundanaria callosa* were used for fermentation purpose.

Bamboo shoots are traditional component of Asian cuisine. Its consumption increase world wide expanding from oriental to western world and a health warning is appropriate as bamboo shoots contain cyanogenic glycosides that break down to produce hydrogen cyanide(HCN) , which can cause both acute and chronic toxicity in humans(Food Standards Australia, New Zealand,2005) . However, the cyanide content is reported to decrease substantially following harvesting. By adequate processing like peeling ,slicing, fermenting and cooking , the cyanogenic glycosides can be reduced prior to consumption ,thus significantly reducing the potential health risk.

Cyanogenic glycosides are phytotoxins which occur as secondary plant metabolites in at least 2000 plant species, of which a number of species are used as food in some areas of the world. Cassava and sorghum are especially important staple foods containing cyanogenic glycosides (Conn1979; Nartey 1980; Rosling 1994). There are approximately 25 cyanogenic glycosides known. The major cyanogenic glycosides found in the edible parts of plants being; amygdalin (almonds); dhurrin(sorghum); linamarin& lotaustralin (cassava,lima beans); prunasin(stone fruit);and taxiphyllin(bamboo shoots). The potential toxicity of a cyanogenic plant depends primarily on the potential that its consumption will produce a concentration of HCN that is toxic to exposed animals or humans . Several factors are important in this toxicity: The first aspect is the processing of plant products containing cyanogenic glycosides. When the edible parts of the plants are macerated, the catabolic intracellular enzyme ß-glucosidase can be released, coming into contact with the glycosides. This enzyme hydrolyzes the cyanogenic glycosides to produce hydrogen cyanide and glucose and ketones or benzaldehyde(Harborne1972,1993). The hydrogen cyanide is the major toxic compound causing the toxic effects. The cyanogenic glycosides present in bamboo shoots is Taxiphyllin. Taxiphyllin is hydrolysed to glucose and hydroxybenzaldehyde cyanohydrin. This benzaldehyde cyanohydrin then decomposes to hydroxy benzaldehyde and HCN (Schwarzmair 1997).

Plant products , if not adequately detoxified during the processing or preparation of the food, are toxic because of the release of this preformed hydrogen cyanide. The second aspect is the direct consumption of the cyanogenic plant. Maceration of edible parts of the plants as they are eaten can release ß-glucosidase. The ß-glucosidase is then active until the low pH in the stomach deactivates the enzyme. Additionally, it is possible that part of the enzyme fraction can become reactivated in the alkaline environment of the gut. At least part of the potential hydrogen cyanide is released, and may be responsible for all or part of the toxic effect of cyanogenic glycosides in the cases of some foods (WHO,1993).

In the intact plant, the enzyme and the glycosides remain separated , but if the plant tissue is damaged both are put in contact and cyanohydric acid is released (Bell 1981;Grunert et al.,1994). Cyanohydric acid is extremely toxic to a wide spectrum of organism, due to its ability of linking with metals(Fe++, Mn++ andCu++) that are functional groups of many enzymes inhibiting the reduction of oxygen in the cytochrome respiratory chain, electron transport in the photosynthesis and the activities of enzymes such as catalase ,oxidaes(Cheeke 1995). The level of cyanogenic glycosides produced is dependent upon the age and variety of the plant, as well as environmental factors(Cooper-Driver & Swain1976;Woodhead&Bernays, 1977). Although there are reports elsewhere of bamboo species containing significant potentially very toxic amounts of cyanogenic glycosides in their shoots, however the available materials does not confirm that some bamboo species do indeed contain very

high level of cyanogenic glycosides in their shoots .There are no clear differences between species and sufficient information to generalised.

The present work is undertaken to assess cyanogenic glycosides in fresh and fermented succulent bamboo shoots to stimulate new uses of bamboo shoots in existing markets and to assist developing foods security in food poor areas.

Materials and Methods

The emerging young fresh succulent bamboo shoots (about 20cm in diameter and 15cm in height) of the species of *Bambusa balcooa, B. tulda, Dendrocalamus halmiltonii, Arundinaria callosa, , Bambusa pallida* etc., were collected during the growing season(month of May–September 2008) from different districts/localities of Manipur(Churachandpur, Khongkang, Tengnoupal,Phalbung, Kangpokpi and Bashikhong) . Different portions of the fresh succulent bamboo shoots (outer hard sheath, inner soft shoots and other parts of the bamboo plants) were assessed for cyanide content

The traditionally fermented samples were collected from different districts/localities in Manipur where traditional fermentation of bamboo shoots is done in large scales (Khongkhang , Andro,Noneh, Tengnoupal,Churachandpur,Kotha etc.). Bamboo shoots of many species like *Bambusa tulda, B. balcoa, Dendrocalamus hamiltonii, Melocanna bambusoides, Arundanaria callosa* were used for fermentation

Estimation of Cyanogenic Glycosides:

Cyanogenic glycosides estimation was done using the technique of the picrate-impregnated paper according to Bradbury et al., 1999. Fresh plant material (bamboo shoots) was cut into small thin slices and placed into a small flat bottomed vial. Phosphate buffer (0.5ml of 0.1M at pH7) was added followed by brief crushing the materials with a glass rod. A picrate paper (fig.4) attached to a plastic backing strip was added and the vial immediately closed with a screw stopper. After about 16h at 30° C, the picrate paper was removed and immersed in 5.0ml water for not less than 30 min. The absorbance was measured at510nm and the total cyanide content was determined

Results and Discussions

The results in table. 1 give the total cyanide content of tip, middle, and base of the outer hard sheath (discarded portion) covering the soft inner tissues and the inner soft bamboo shoots samples taken for consumption as food determined by the picrate method. The results showed an average of 0.02 to 0.17mg/g of HCN in the outer hard sheath and 0.03 to 1.7 mg/g of HCN in the soft portion of the bamboo shoots. The total cyanide levels are highest at the tip and lowest at the base of the soft inner shoot but just the reverse for the hard cover sheath. Table 2 represents the total cyanide content in different portion of the bamboo plants(*Melocanna bambusoides and Bambusa pallida).* The fleshy fruits of muli- *Melocanna bambusoides (fig.5)a*re eaten raw or cooked –its seeds are also eaten by the people as a substitute for rice.It also content low concentration of HCN(0.01mg/g) which renders it toxic free for consumption. The rhizome ,which is not utilized contain high content of

HCN(0.14mg/g). The acute lethal dose of HCN for human beings is 0.5-3.5 mg/kg body weight, animals is 0.66 to 15mg/kg body weight .Cyanide inhibits the action of cytochrome oxidase, carbonic anhydrase & other enzyme system. It blocks the final step of oxidative phosphorylation and prevents the formation of ATP and its use as energy source.It reduce the oxygen carrying capacity of the blood by combining with the ferric iron atom (Harborne1972,1993) .

Bamboo shoots may contain significantly higher levels of HCN, however ,the HCN content is reduced substantially during fermentation processing prior to consumption as in Table 3 . Since HCN are highly volatile ,the loss of HCN during the fermentation processes like peeling,slicing,cutting ,repeated washing(3-4 times) is quite rapid. During cooking/parboiling ,roasting and canning reduces the HCN below the toxic level . Boiling bamboo shoots for 20 min. at 98^0 C removed nearly 70% of the total HCN content but higher temperature and longer intervals removed progressively up to 96%(Ferreira et al., 1995). Thus it may perhaps not present a problem for consumers. However, due care in preparation remain necessary.

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Table.1: Total cyanide content in bamboo plants determined by Picrate method

Name of the Species	Portion of the fresh bamboo shoots	Conc. of HCN (mg/g) in outer hard sheath covering the soft shoots	Conc. of HCN (mg/g) in inner soft bamboo shoots
Bambusa balcooa	Tip	0.02	2.15
	Middle	0.036	1.38
	Base	0.086	0.62
Dedrocalamus hamiltonii	Tip	0.043	2.42
	Middle	0.063	0.86
	Base	0.104	0.15
Arundanaria callosa	Tip	0.02	0.14
	Middle	0.01	0.05
	Base	0.07	0.03
Bambusa tulda	Tip	0.08	0.17
	Middle	0.10	0.83
	Base	0.13	0.28
Melocanna bambusoides	Tip	0.06	1.81
	Middle	0.10	0.68
	Base	0.17	0.35
Bambusa palli	Tip	0.04	0.27
	Middle	0.08	0.17
	Base	0.12	0.13

Table.2: Total cyanide content in different parts of the bamboo plants determined by Picrate method

Name of the species	Portion of the Plant	Conc. of HCN (mg/g)
Melocanna bambusoides	Fruit	0.01
	Leaves	0.09
	Inflorescence	0.07
	Rhizome	0.14
Bambusa pallida	Leaves	0.09
	Inflorescence	0.07
	Rhizome	0.04

Table.3: Total cyanide content in fermented bamboo shoot slices (soibum)

Sl.No	Fermented bamboo shoots collected from different districts of Manipur	Conc. of HCN (mg/g)
1	B. Salvaphai -CCpur District	0.21
2	Khongkang- CDL District	0.28
3	Tengnoupal -CDL District	0.29
4	Exudate (khongkang fermentation)	13.22

Fig.1 : Emmerging Young Succulent Bamboo Shoots

Fig.2 : Bamboo Shoot Slices for Fermentation process

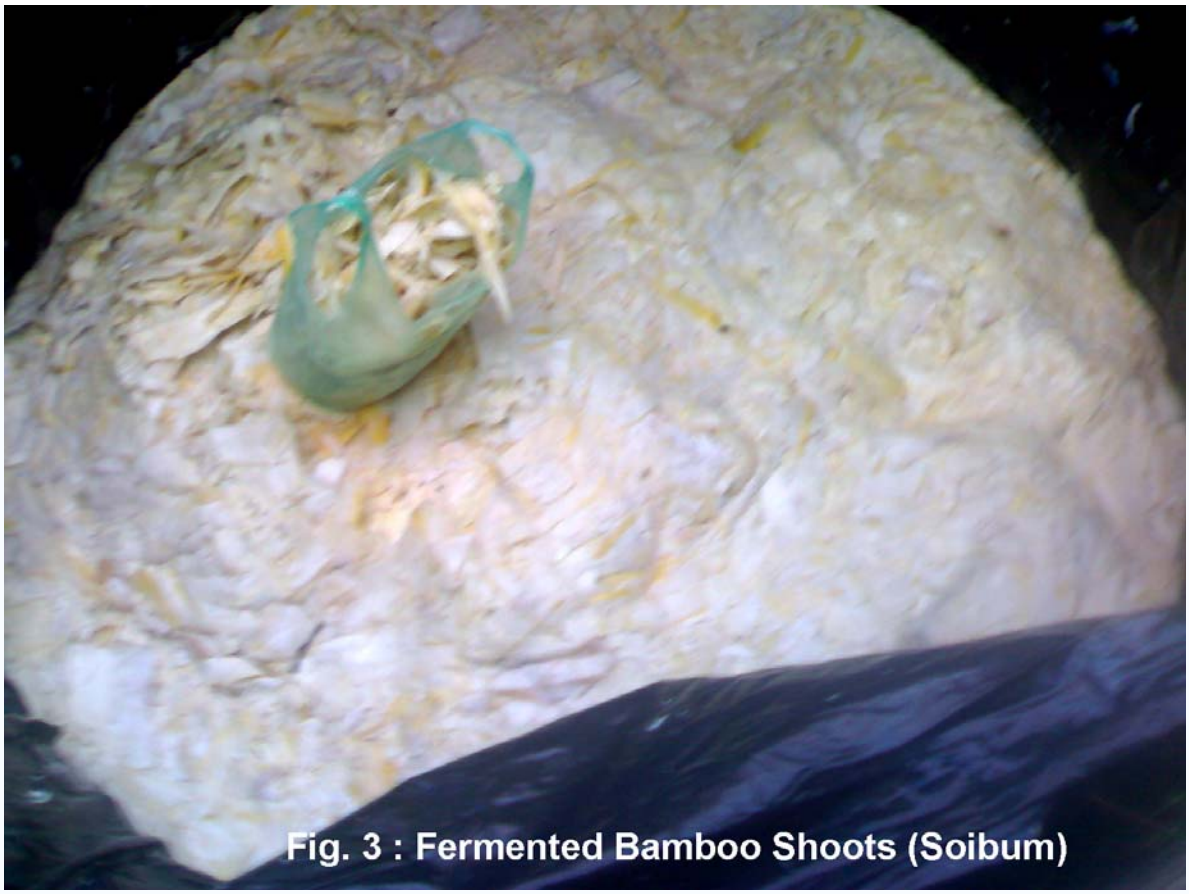

Fig. 3 : Fermented Bamboo Shoots (Soibum)

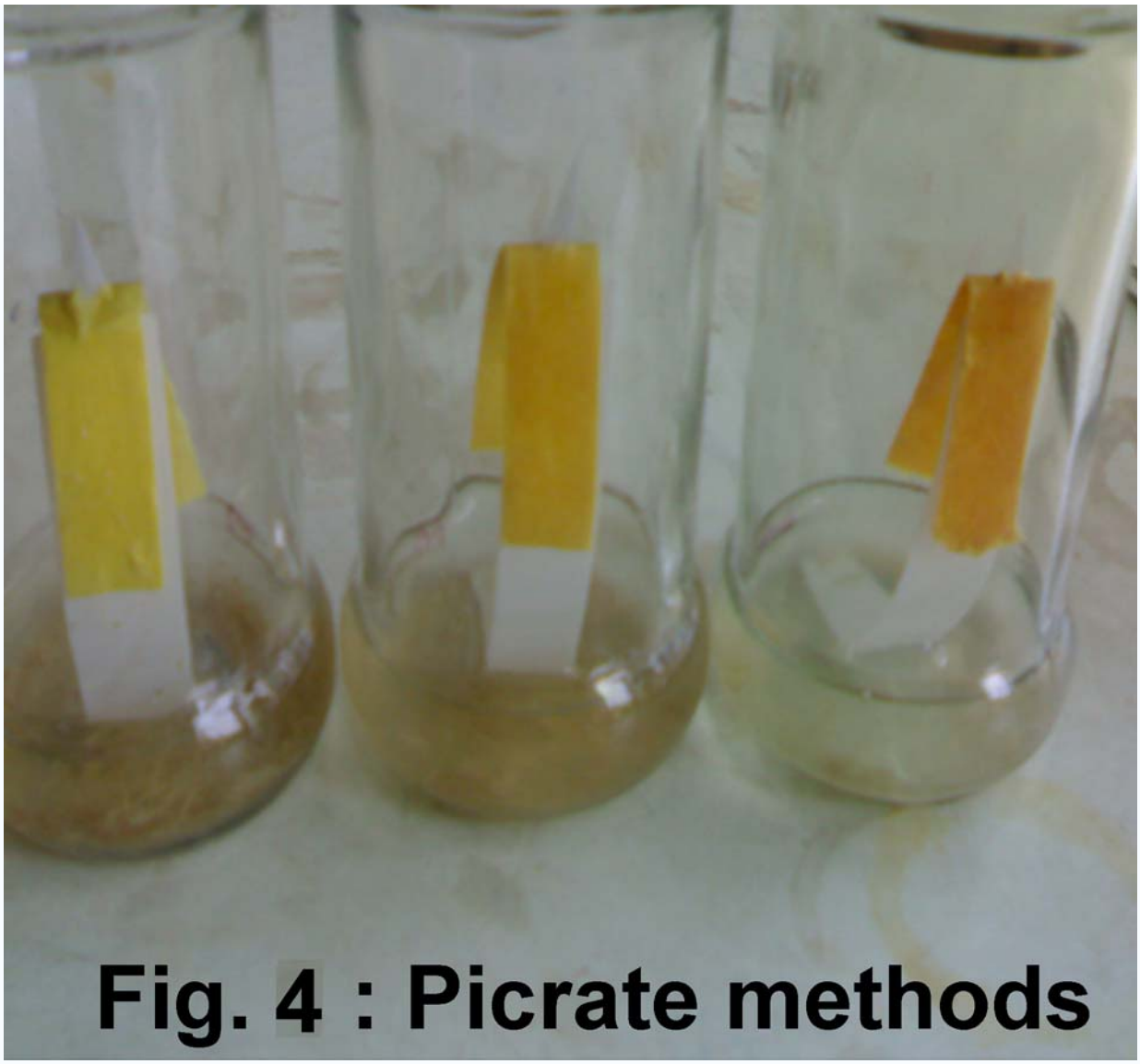
Fig. 4 : Picrate methods

Fig. 5 : Bamboo Seeds of Melocanna bambusoides

The First Report of Flowering and Fruiting Phenomenon of Melocanna baccifera in Nepal

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Abstract

Melocanna baccifera is a bamboo species found in eastern, central and western part of Nepal. Least information is available about this bamboo in Nepal so far. This bamboo showed sporadic flowering for the first time in Nepal in 2007-2008. Flower showed dimorphism, upper part being sterile where as the lower part is fertile bearing numerous pear shaped fruits. This paper deals with the flowering, fruiting phenomenon and ethnobotanical use of this bamboo species in Nepal.

Introduction

Nepal is a small country in the world occupying about 0.09 percent of the earth's surface with the area of 147,181 sq.km. Due to topographical variation within a short range starting from 64 m of elevation to the highest altitude of 8,848 m, Nepal is regarded as a high biodiversity zone and possesses 6500 species of higher plants including Bamboo species. Nepal possesses 81 species of bamboo out of 1,573 species worldwide. It comes to be about 24 percent in world's ratio.

In Nepal, bamboo occupies about 62,890 hectares of land. The natural forest hosts 38,000 hectares and rest is agricultural land. The total standing stock has been estimated at 15 million cubic meters with biomass value of 1,060 metric tons. The annual production of bamboo is estimated at 3.01 million cubic of which 2.64 million culms are consumed locally and 0.64 million culms are exported to India (Kesari, 2005).

Nepal has 5 genera and 27 species under large bamboo species which are commonly called *Bans* in local language and come in Bambusae tribe. Small bamboos include 15 genera and 35 species. On the other hand 3 genera and 4 species fall under dwarf bamboo species. Of them, 45 species are indigenous and rest is exotic. *Melocanna baccifera* is a large bamboo species found in Nepal.

Methodology

Eastern and Central Nepal were visited in course of regular plant survey from Natural History Museum, likewise a private visit was also arranged to study the fruiting phenomenon. Informations were gathered from the local people. Interviewing with local inhabitants and collection of the samples were done during the flowering and non-flowering seasons. Relevant literatures (Poudyal, 2006, Keshari (2005), Shrestha 1998, 200; Stapleton

1994, Gamble 1896 and Shibata personal communication 2008) were consulted. Help from sketching and photographs were also taken. Other associated plants were also recorded with their local names

Result

There are altogether five species of *Melocanna*, but Nepal represents only one described species so far. The author for the first time found this species from east Nepal in 1996. This species is very interesting in terms of culms, rhizomes and fruits, but there is no report of fruiting of this species till 2008.

The author found the species in Bahundangi and Sanischare village of Jhapa district in east Nepal in 1996. The culms were found growing along the edge of the paddy field where it formed a line of culms surrounding the agricultural land. The bamboo was erect, smooth without any branches and was cylindrical (Fig. 1). The erect shoot has uniform culms whose diameter was almost 5.0 cm and culm height ranges from 15.0 to 18.3 cm, the culms were green and spiny, occasionally with yellowish-green internodes and white cuticles below the nodes. The culm-wall was thin and non durable. Culm-sheaths were persistent and brittle. Sheath blade was very long and narrow. Half of the culms were without branches. Almost similar sized branches arose from every node. The leaves were large.

Flowers: For the first time in Nepal flowers appeared in 2007. The flower started to appear in 2007 and lasted till the summer of 2008. Thereafter large sized fruiting resembling a pear appeared in early 2008. Its fruiting attracted many peoples of that area.

Inflorescence: The inflorescence was large compound panicle. Spikelets were acuminate fasciculate and one sided (Fig. 2). There were two types of flowers; one was in fertile stage and the next on sterile nodes in the same culm. The fertile flowers were at the lower nodes whereas sterile were at the upper nodes of the culms. There were several sterile and fertile flowers arising from the same nodes and were hanging down from the nodes (Fig. 3,4).

Empty sterile glumes were indefinite, acuminate, and striate. Flowering glumes similar to empty glumes, palea also similar, not keeled.

Lodules two and narrow
Stamens five to seven
Filaments free or irregularly joined
Ovary glabrous
Style elongated
Stigma two to four, short and hairy
Fruit caryopsis, very large and pear shaped (Fig 5) with long beaked pericarp very thick, Greenish-yellowish-white skin externally. Small whitish ovules were embedded in a cavity filled with liquid (Fig.6)

Ethnobotany: *Melocanna baccifera* are reported in many parts of Nepal except the far west region. In the eastern Jhapa, Central in Rautahat and Chitwan and Pokhara, Syangja and Palpa districts in the west.

Locally the species is known as *Philinge Bans* in the eastern and *Lahure Bans* in the western Nepal. In central Nepal, it does not have any common name.

Since the fruiting was not observed but most of the peoples believe that the bamboo has never a big fruit like *Melocanna* and the fruiting is due to some misfortune. Due to this ignorancy, villagers cut all the culms and throw them away (Fig. 7).

The fruits are used as game ball for children. Hundreds of people visited this place to see this unique body of fruit (Fig. 8). Children generally cut the fruit and taste the sap inside which they liked most due to its sweet test like that of coconut-fluid. People do not have idea that the shoots are edible, but villagers before fruiting used the culm for basketry, mat, house wall, roof gum or fluid and leaves as fodder. The bamboos were planted nearby their houses or huts and kitchen garden. Other species of bamboo like *Dendrocalamus strictus, Bambusa nutans, and Dendrocalamus gigantean* were also noticed in central and east Nepal. They are used as hedge to boarder paddy fields and consider ornamental due to its beautiful poles and amphimorph or metamorph nature. Due to its more publicity, media were also attracted to the village and made interesting telecast in television also. Popular newspapers are looking for more information about this bamboo species. The author made clear of the rumors that such phenomena with this bamboo occur once in 7-51 years in other countries like India, Bangladesh, China, Indonesia, Myanmar and Sri Lanka. This was the first observation in Nepal; this bamboo has many values and should be conserved effectively.

Table 1. Associate Species around *Melocanna baccifera* Grove in Pourai Village, Rautahat District

1. *Ficus semicordata* (Kanyu)
2. *Morus macroura* (Kimbu)
3. *Zingiber*
4. *Anthocephalus chinensis* (Kadam)
5. *Zizyphus mauritiana* (Bayer)
6. *Bauhinia variegata* (Koiralo)
7. *Syzygium cumini* (Jamun)
8. *Piper longum* (Pipla)
9. *Solanum surrattense* (Kantakari)
10. *Cissampelos pareira* (Jaluko)
11. *Musa paradisiaca* (Kera)
12. *Ageratum conyzoides* (Gande)
13. *Amaranthus spinosus* (Lunde kanda)
14. *Shorea robusta* (Sal)
15. *Dioscorea bulbifera*
16. *Colebrookea oppositifolia* (Gittha)
17. *Thysanolaena maxima* (Amliso)
18. *Ficus racemosa* (Dumri)
19. *Tinospora sinensis* (Gurjo)
20. *Annona squamata* (Saripha)
21. *Dalbergia sisso* (Sisau)
22. *Eupatorium odoratum* (Tite hawi)
23. *Moringa oleifera* (Sahijan)
24. *Bombax ceiba*
25. *Caesalpinia dicapeta* (Arile kanda)
26. *Mimosa pudica* (Lajwanti)
27. *Ricinus communis* (Ander)
28. *Cynodon dactylon* (Dubo)
29. *Stellaria monosperma* (Jethi madhu)
30. *Bambusa nutans* (Mal bans)
31. *Dendrocalamus strictus* (Lathi bans)
32. *Dendrocalamus hookeri* (Bhalu bans)
33. *Bambusa multiplex*
34. *Schleichera oleosa* (Kusum)
35. *Prunus persica* (Aru)
36. *Anogeissus latifolia* (Bhanjhi)
37. *Litchi chinensis* (Litchi)
38. *Perilla frutescens* (Silam)
39. *Lagerstoemia parviflora* (Botdhaiyaro)
40. *Cannabis sativa* (Bhang)
41. *Persicaria pentagyna* (Pire)
42. *Polygonum hidropiper*
43. *Diplazium esculentum* (Pani nyuro)

Ethnic people of the area in Pourai Village: Tamang, Thing, Bhote, Bamjang (Fig. 9), Jimba, Pakhin, Gurung, Magar, Yonzon, Majhi, Gongaba, Thokar, Syanba, Kami, Damai, Danuwar, Rai, Shrestha

Others: Mainali, Nyoupane (Brahmins) and Chhetri.

Occupation: Agriculture and forestry.

Conclusion

Flowering in *Melocanna beccifera* occurs after a period of 30-40 years, but the propagation of this bamboo is as easy as other species. Seeds if available propagates easily and from propagates this species can easily be proliferated even in Kathmandu. The fruits very easily fall down on ground even by a gentle breeze or wind and germinate quickly.

Large pear shaped fruiting makes the bamboo very attractive, the villagers in Nepal have no idea about the importance of this species and believe on misfortune when the plant blossom. They also destroyed all the calms after flowering and fruiting due to ignorancy. Fruits and young shoots are eaten in Bangladesh and India. Culms are strongly used to different purposes including paper making and scaffolding.

This plant if used under sustainable way may help to reduce poverty to some extent. This plant adds beautifying orchard, control erosion and help to bring prosperity in the society. Conservation education has been felt essential so to conserve bamboos like *Melocanna* species in Nepal.

Acknowledgement

The author is thankful to the Natural History Museum, Tribhuvan University for all the necessary permission for this study. Thanks are due to the local and media peoples of that area for encouragement and remarks on the conservation of the bamboo. Last but not the least thank is due to Mr. Bhaiya Khanal, Associate Professor for his constant help in the field and reading this manuscript.

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Fig.1.Melocanna baccifera in the paddy field

Fig.2. Flowering spikelet

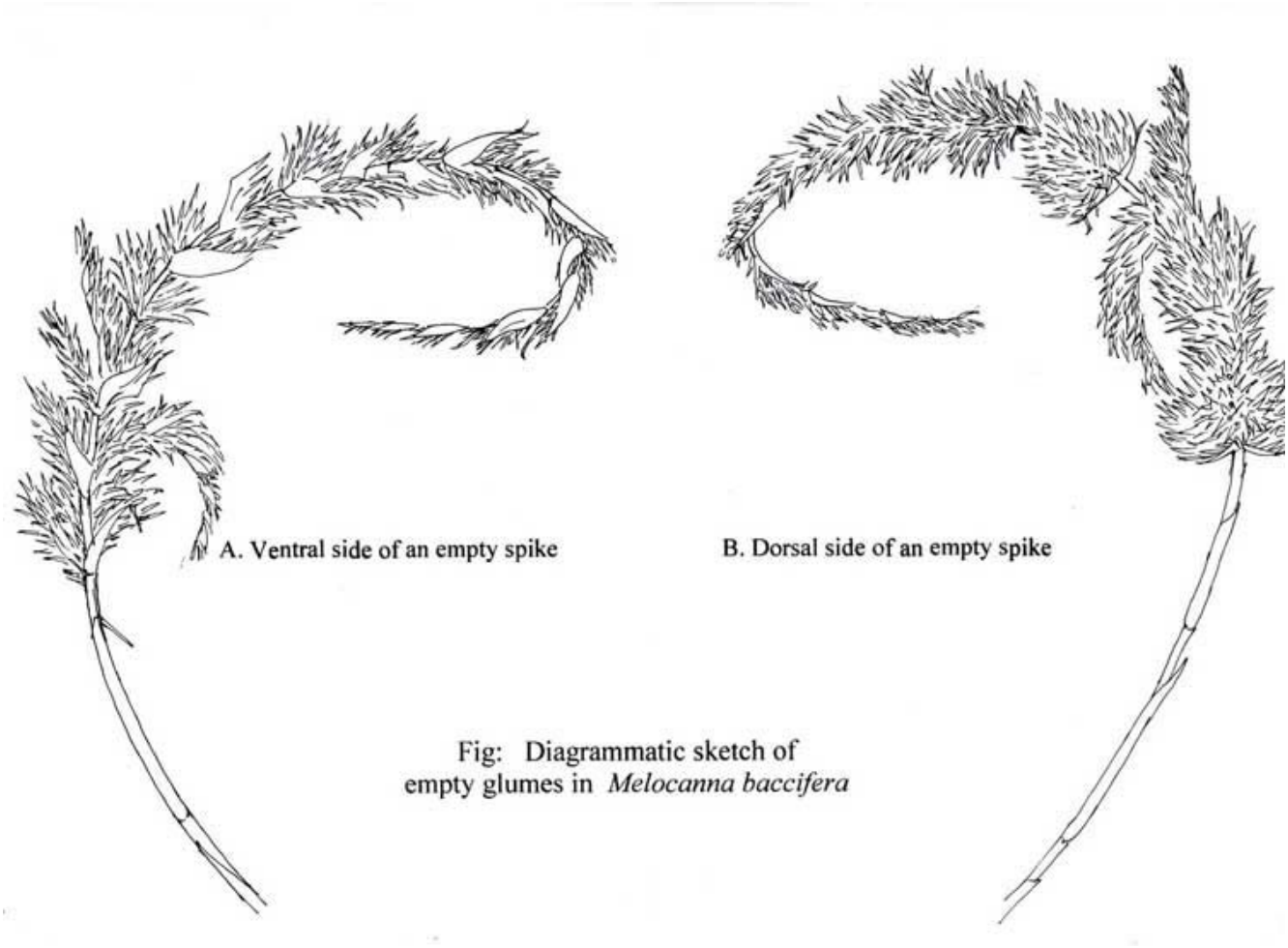

Fig.3 Empty glume

Fig. 4 Sterile flowers

Fig.5. Fruits and flowers together

Fig. 6. Ovule in the cavity

Fig.7. Removing culm with fruits by the villagers

Fig.8. Villagers play with the fruits and flowers

Fig. 9. Melocanna culm in basketary and cage in the village

Species Relationships in *Dendrocalamus* Inferred from AFLP Fingerprints

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Abstract

Species of *Dendrocalamus* are characterized by their sympodial rhizomes and large sized dense clumps. The genus contains over fifty species from tropical and subtropical region of the old world, many of which are economically exploited by rural communities in south and southeast Asia. The original description of the genus was based on the type species *Dendrocalamus strictus*, which was subsequently expanded to include pericarp characters that were used to distinguish between *Dendrocalamus* and *Bambusa* (Munro 1868; Bentham 1883; Gamble 1896). While at present it is taxonomically convenient for *Dendrocalamus* to be recognized in a broad sense (its species being distinguished by the presence of single-keeled prophylls throughout the inflorescence - Stapleton 1991), the limits between *Bambusa* and *Dendrocalamus* are not satisfactorily defined. In the present study amplified fragment length polymorphism markers (AFLPs) were used to investigate phylogenetic relationships among ten included *Dendrocalamus* and five out group species. Neighbour-Joining and Maximum parsimony analyses of AFLP dataset suggested the current circumscription of *Dendrocalamus* to be polyphyletic. Further, the analyses did not find support for the various earlier infrageneric classifications within *Dendrocalamus*. The implications of the findings are discussed.

Introduction

Dendrocalamus is a woody bamboo genus placed in the subtribe Bambusinae and tribe Bambuseae (Ohrnberger 1999). Species referred to the genus are characterized by their sympodial rhizomes and large sized dense clumps. The genus contains over fifty species, naturally distributed in the tropical and subtropical region of the old world, many of which are economically exploited by the communities in south and southeast Asia. The original description of the genus was based on the type species *D. strictus*. The description was expanded subsequently to include pericarp characters, which were used to distinguish between *Dendrocalamus* and *Bambusa* (Munro 1868, Bentham 1883, Gamble 1896). While at present it is taxonomically convenient for *Dendrocalamus* to be recognized in a broad sense, the limits between *Bambusa* and *Dendrocalamus* are not satisfactorily defined thus creating confusion in their systematic classification. And lack of sound taxonomy is acting as hindrance in the scientific conservation and management of the woody bamboos belonging to this genus.

Since *Dendrocalamus* was separated from *Bambusa* by Nees von Esenbeck in 1834, over 70 species names have been assigned to the genus although Ohrnberger (1999) retains only 51 of these. Most of the species that have not been maintained by Ohrnberger have been reduced to synonymy or to infraspecific rank. A few are transferred to, or sunk into, other genera: *Ampelocalamus* (subtribe Thamnocalaminae); *Gigantochloa* and *Pseudoxytenanthera* (Bambusinae).

Various infrageneric classifications of *Dendrocalamus* have been adopted by Chinese botanists. Hsueh and Li (1988) proposed the first infrageneric classification of *Dendrocalamus* by recognizing two subgenera and five sections, limiting the assignments to only those species reported from China. Ohrnberger (1999) assigned species only to sections *Dendrocalamus*, *Bambusoidetes*, *Sinocalamus* and *Draconicalamus*. Out of the 51 taxa recognized by Ohrnberger, 22 were assigned to particular sections while 29 taxa were unplaced. A more recent taxonomic revision of Chinese *Dendrocalamus* (Li and Stapleton 2006) retains the subgenera proposed by Hsueh and Li (1988) but disregards sectional assignments, merging sections *Dendrocalamus* and *Bambusoidetes* as subgenus *Dendrocalamus,* and sections *Sinocalamus* and *Draconicalamus* as subgenus *Sinocalamus*. Li and Stapleton (2006) transferred 11 taxa previously referred to subgenus *Sinocalamus* to subgenus *Dendrocalamus*. The major problem faced in the infrageneric classification of *Dendrocalamus* is the paucity of published morphological character information for many of the species. Twenty seven species do not appear to have been referred to any subgenus or section under any of the proposed schemes.

Bamboos have always been a taxonomically challenging group of plants because, while the classification of flowering plants depends largely on the characteristics of reproductive organs, flowering is rare in many bamboo species. Some bamboo species flower at intervals as long as 120 years and for some there is no report of flowering to date. Because of apparent paucity of morphological characters in bamboos, taxonomists have long sought different sources of taxonomically informative data. The availability of molecular data in the final decade of the twentieth century enabled taxonomists to review phylogenetic concepts of the Poaceae more objectively. Initially DNA products *viz.*, isozymes and secondary compounds like phenolics were used in exploring relationships among taxa (Chou and Hwang 1985), species identification (Alam *et al.* 1997) and assessment of infraspecific polymorphism (Biswas 1998). In a study involving five *Dendrocalamus* taxa, *Arthrostylidium naibunensis* W.C. Lin and *Chimonobambusa quadrangularis* Makino, a *Dendrocalamus* cluster could be differentiated from the other two genera using phenolic compounds and isozyme patterns of esterase and peroxidase. Within *Dendrocalamus* two clusters were recognized: *Dendrocalamus asper* associated with *D. giganteus,* while *D. latiflorus* associated with its variety *D. latiflorus* var. *mei-nung*. However, *Dendrocalamus strictus* was distant from these two clusters. Later on, variation in DNA itself was the subject of investigations. The more pertinent studies involving named *Dendrocalamus* taxa are those of Loh *et al.* (2000) and Sun *et al*. (2005) but these studies entailed only limited sampling of the genus. In the first, two *Dendrocalamus* taxa were sampled, with *D. brandisii* clustering with taxa from *Bambusa,* and *D. giganteus* appearing genetically distant from all other taxa included. In the second study three *Dendrocalamus* taxa were sampled. These three taxa did not form a separate clade but clustered within *Bambusa,* which was split into two distinct clades. *D. membranaceus* showed close affinity to *D. strictus* and both were placed within one *Bambusa* clade, whereas *D. latiflorus* was associated with the other *Bambusa* clade. The study reported wide genetic variation within *Dendrocalamus* and raised questions about its monophyly.

These earlier molecular studies included limited samples from *Dendrocalamus* and did not throw much light on the infrageneric relationships within the genus. In the present investigation there was wider provision within *Dendrocalamus* with ten putative taxa, and five outgroup taxa from the subtribe Bambusinae. Amplified fragment length polymorphism (AFLP) markers were used to (i) test the monophyly of *Dendrocalamus,* and (ii) assess the molecular support for various infrageneric assignments proposed in *Dendrocalamus.*

Materials and Methods

Site Description

Genetic material was collected from the bambuseta of five botanical gardens in India: Forest Research Institute, Dehra Dun; National Botanical Garden of Botanical Survey of India, Howrah; State Forest Research Institute, Chessa; ICAR research complex for northeastern hill region, Basar; Rain Forest Research Institute, Jorhat. The genetic material of the monotypic African bamboo *Oxytenanthera abyssinica* was available as the result of previous research work in Bangor, UK (Inada 2004).

Genetic Material

Leaves were collected from ten *Dendrocalamus* and five outgroup taxa from subtribe Bambusinae. The leaves were dried using silica gel as per the procedure of Chase and Hills (1991) and then transported from the field sites in India to the laboratory at CAZS - Natural Resources, Bangor University, for DNA extraction and analysis. Six of the *Dendrocalamus* taxa (*D. strictus, D. hamiltonii, D. membranaceus, D. brandisii, D. sikkimensis, D. asper*) represented subgenus *Dendrocalamus* and two other taxa (*D. giganteus* and *D. calostachyus*) represented subgenus *Sinocalamus*, in the infrageneric classification of *Dendrocalamus* by Li and Stapleton (2006). No information was available regarding the infrageneric assignment of *D. sahnii* and *D. somdevai.* The outgroup taxa were from the genera *Bambusa, Melocalamus, Oxytenanthera, Dinochloa* and *Thyrsostachys*, all of which belong, like *Dendrocalamus,* to subtribe Bambusinae as recognized by Ohrnberger (1999).

DNA Extraction

DNA was extracted from 50 mg of dried leaf tissue using a modified CTAB protocol of Doyle and Doyle (Doyle and Doyle 1990). The DNA extractions were checked for quality by running a 1% agarose mini-gel (run at 50 V for 30 minutes) in TBE buffer (1 X) containing 0.5 µg/ml ethidium bromide. The genomic DNA was visualized and photographed under a ultra-violet light source. Quantitation of genomic DNA was done using the fluorescent dye Pico green in the Fluostar Galaxy Fluorometer.

Generation of AFLP Markers

The AFLP assay was performed following the protocol of Vos *et al*. (1995), adapted for the Beckman Coulter Sequencer. The process was carried out in four steps. In the first step, two restriction enzymes *Eco*RI and *Mse*I (*Tru*9I) were used to digest the genomic DNA of the samples. In the second step, double stranded adapters

complementary to the cut ends (overhangs) produced by enzymes *Eco*RI and *Mse*I were ligated to the cut DNA fragments. In the third step, a PCR (pre-selective PCR) was performed with universal primers E00 and M00. The thermocycler conditions included 30 cycles consisting of 30 seconds denaturation at 94°C, 60 seconds annealing at 56°C, 60 seconds extension at 72°C and finally 600 seconds extension at 72°C. In the fourth step, a second PCR (selective PCR) was done with selective primers, each with three nucleotide extensions (E00+3; M00+3). The selective primer E00+3 was end-labelled with fluorescent dye D4 instead of the radioactive labelling described in the original protocol of Vos *et al.* (1995). The thermocycler conditions included 13 touchdown cycles to avoid amplifying non-specific sequences (30 seconds denaturation at 94°C, 30 seconds annealing at 65°C which was then reduced by 0.7°C per cycle, 60 seconds extension at 72°C), 23 normal cycles (30 seconds denaturation at 94°C, 30 seconds annealing at 56°C, 60 seconds extension at 72°C) and 420 seconds final extension at 72°C.

A primer screening experiment was done to select five primer sets, which were then used to amplify AFLP markers from the fifteen taxa included in the present investigation. A negative control (without template DNA) was run in each batch of PCRs to confirm that no contamination had occurred. The reproducibility of AFLP peaks was checked by repeating the whole process a number of times.

Separation and Scoring of AFLP Markers

The selective PCR products were separated through capillary gel electrophoresis in the CEQ 8000 Genetic Analysis System (Beckman Coulter, Inc.) and analysed with the fragment analysis software. During fragment analysis the separated fragments were sized with the use of internal size standards (PA400). Following this, the sized fragments were subjected to an AFLP binning analysis that converted the AFLP peak profiles into binary matrix. The presence of a peak was scored 1 and its absence scored 0. Peaks of size ranging from 60 bp to 400 bp were scored.

Data Analysis

Phenetic Analysis

The binary matrix (470 X 15) of multilocus peak patterns generated by the scoring software in CEQ 8000 was converted to a matrix of pairwise distances between OTUs expressed as Jaccard's (Jaccard 1908) distance coefficient using the software package NTSYSpc 2.11X (Rohlf 2000).

Jaccard's distance coefficient was derived as

$D_J = 1 – [a / (n - d)]$,

where:
n, total sample size (a + b + c + d).
a, number of peaks common to both taxa
b, number of peaks for the first taxon
c, number of peaks for the second taxon
d, number of peaks absent from both taxa

Cluster analysis was carried out using the neighbour-joining (NJ) algorithm of Saitou and Nei (Saitou and Nei 1987) in NTSYSpc 2.11X (Rohlf 2000). The generated tree was rooted using the outgroup option, taking *Oxytenanthera abyssinica* as the outgroup taxon. The statistical support for the internal branches was assessed by performing a bootstrap analysis with 1000 replicates in the software package FREETREE (Pavlicek *et al.* 1999). A Mantel test was performed to test how well the phenogram represented the inter-OTU distances, following the procedure described by Koopman *et al.* (2001).

Phylogenetic analysis

Cladistic analysis of the AFLP dataset (470 X 15) was performed under maximum parsimony criterion with PAUP 4.0b10 (Swofford 2002). The large number of includedtaxa (>12) ruled out an exhaustive search. So, heuristic search was used to identify the most parsimonious tree. Heuristic search was performed with the following criteria -1000 replicates, random additions of sequence, tree-bisection-reconnection (TBR) branch swapping, character optimizations using accelerated transformation (Perrie and Brownsey 2005). Output trees were rooted using the outgroup option with *Oxytenanthera abyssinica* as the outgroup taxon. Statistical support for internal branches was assessed using the bootstrap analysis (Felsenstein 1985) in PAUP 4.0b10 with following criteria – 1000 replicates, heuristic search and a 50% confidence level.

Results

The five AFLP primer sets used in the present investigation generated 609 marker loci, out of which 99.2 % (604) loci were polymorphic and only 0.8 % (5) loci were monomorphic across the 15 OTUs. The dataset also contained 134 (22.0 %) loci where only one peak was detected. The number of AFLP marker loci generated by the individual primer sets varied from 101 to 133 with a mean of 121.8.

The genetic distance estimates based on Jaccard's measure varied from 0.47 to 0.92 (Table 1). Although referred to the Bambusinae, the monotypic African bamboo *Oxytenanthera abyssinica* shared very few peaks with other taxa included in the study and was found genetically distant from them (distance ranged from 0.77 to 0.92). However, even within *Dendrocalamus* there was wide genetic variation. *Dendrocalamus strictus* appeared isolated with a minimum distance of 0.77 (from *D. somdevai*) and a maximum distance of 0.85 (from *D. asper*). Among the outgroups included in the present investigation *Bambusa balcooa* was found to be the closest to *Dendrocalamus sensu lato* with a mean distance of 0.60.

Cluster analysis with the neighbour-joining algorithm resulted in a single tree (Figure 1) with high co-phenetic correlation coefficient (r = 0.971). A well-supported (85% bootstrap support) major cluster was recovered containing all *Dendrocalamus* taxa (except *D. strictus*) with *Melocalamus compactiflorus* as sister lineage. *D. strictus* was recovered near the root of the tree distant from the major cluster containing other *Dendrocalamus.* Three clusters could be recognized within the major cluster that had varying degree (above 50%) of bootstrap support. Cluster 1 (partially supported with bootstrap support of 93%) consisted of *Dendrocalamus membranaceus, D. somdevai* and *D. brandisii.* Cluster 2 (89% bootstrap support) consisted of *Dendrocalamus sikkimensis, Bambusa balcooa* and *D. hamiltonii.* Cluster 3 consisted of *D. giganteus* and *D. asper*.

Table 1 Half-matrix of pairwise Jaccard's distance coefficients between 15 operational taxonomic units. Rows are labelled with taxon name (D. = *Dendrocalamus*). Columns are labelled with accession code only.

Operational taxonomic units	S3	S4	S9	S10	S11	S15	S30	S13	S14	S23	S27	S52	S6	31	S32
(S3) *D. membranaceus*	0														
(S4) *D. somdevai*	**0.51**	0													
(S9) *D. brandisii*	**0.55**	**0.55**	0												
(S10) *D. giganteus*	0.66	0.65	0.60	0											
(S11) *D. sikkimensis*	0.68	**0.59**	**0.59**	0.64	0										
(S15) *D. sahnii*	0.61	**0.56**	**0.57**	**0.58**	**0.56**	0									
(S30) *D. calostachyus*	0.63	0.60	**0.53**	**0.57**	**0.57**	**0.55**	0								
(S13) *Dinochloa*	0.66	0.63	0.61	0.69	0.64	0.62	**0.58**	0							
(S14) *Thyrsostachys*	0.69	0.68	0.70	0.75	0.74	0.73	0.71	0.73	0						
(S23) *Bambusa*	0.65	**0.59**	**0.57**	0.61	**0.51**	**0.54**	**0.54**	0.63	0.74	0					
(S27) *Melocalamus*	0.69	0.67	0.68	0.66	0.67	0.63	0.63	0.70	0.73	0.66	0				
(S52) *D. strictus*	0.79	0.77	0.84	0.84	0.85	0.84	0.82	0.82	0.83	0.87	0.85	0			
(S6) *D. asper*	0.70	0.69	**0.59**	0.62	0.65	0.64	0.63	0.73	0.76	0.66	0.71	0.85	0		
(31) *D. hamiltonii*	0.65	**0.54**	**0.58**	0.62	**0.52**	**0.53**	**0.55**	0.66	0.72	**0.47**	0.68	0.83	0.60	0	
(S32) *Oxytenanthera*	0.83	0.83	0.82	0.83	0.82	0.81	0.80	0.84	0.84	0.83	0.83	0.92	0.82	0.77	0

However, the relative relationship among these three clusters was not clear due to polytomy. Further, the affinity of *D. sahnii, D. calostachyus* and *Dinochloa macclellandii* remained unresolved.

Maximum parsimony analysis of the AFLP dataset (consisting of 470 characters out of which 460 were parsimony informative) with heuristic search yielded two equally parsimonious trees [Figure 2(a) and (b)], giving two alternate but equally likely hypotheses of evolutionary relationships among the OTUs. Each tree was 1468 steps (character state changes) long with consistency index (CI) = 0.320, retention index (RI) = 0.298 and rescaled consistency index (RC) = 0.095. The two most parsimonious trees were congruent for most part of the trees but differed with the placement of *Dendrocalamus calostachyus*. Strict consensus of the parsimonious trees resulted in a polytomy (Figure 3). Three clades were recovered that were identical to the clusters in Neighbour-Joining tree. Because of polytomy the relationship among these three clades was not clear. Bootstrap analysis with 1000 bootstrap replicates showed partial support for the three clades. Only part of clade 1, part of clade 2 and clade 3 had above 50% bootstrap support.

Discussion

Neither the phenetic nor the phylogenetic approach adopted in the present investigation supported the monophyly of *Dendrocalamus* as currently circumscribed. The placement of *Bambusa balcooa* and *Dendrocalamus strictus* in the cladogram (Figure 3) and the placement of *Bambusa balcooa, Dendrocalamus strictus* and *Dinochloa macclellandii* in the phenogram (Figure 1), suggested otherwise. *Bambusa balcooa,* instead of forming a separate lineage, was recovered in a clade/cluster shared with *Dendrocalamus hamiltonii* and *D. sikkimensis*. This supports the findings of Stapleton (1994a) who had reported the closeness of *Bambusa balcooa* to *Dendrocalamus* species on morphological grounds, stressing similarity in the profuse aerial roots at the culm nodes, the large rhizomatous branch bases and the culm wax. Further similarities between *Bambusa balcooa* and *Dendrocalamus hamiltonii* can be found in the reproductive parts with both species having 3 stigmas each. *Dinochloa macclellandii* whose affinity was unresolved in the neighbour-joining phenogram (Figure 1), was recovered as a sister lineage to the clades containing *Dendrocalamus* in the most parsimonious trees (Figures 2a and b). The placement of *Dendrocalamus strictus* near the root of the tree away from rest of the *Dendrocalamus sensu lato* was not entirely unexpected considering the findings of Chou and Hwang (1985), who had reported the isolation of *D. strictus* from other *Dendrocalamus* taxa based on studies involving isozymes and phenolics.

Morphologically, the isolation of *D. strictus* could be explained by presence of inflorescence comprising of fascicular pseudospikelets (2.2–2.5 cm in diam.) on each node of flowering branches, distinguishing them from other species included in the study (Yang *et al.* 2008). Ecologically also, *D. strictus* is very distinct from the other *Dendrocalamus* taxa included in the present investigation. *Dendrocalamus strictus* naturally occurs in dry deciduous open forests, receiving as little as 750 mm annual rainfall and exposed to low relative humidity. The other *Dendrocalamus* taxa included in the present investigation are confined to moister areas (moist deciduous to wet evergreen forests), with an annual rainfall in excess of 1500 mm.

There was congruence between neighbour-joining cluster analysis and the maximum parsimony analysis as far as three monophyletic clusters/clades were concerned. The first of congruent groups consisted of

Dendrocalamus membranaceus, D. somdevai and *D. brandisii.* The second congruent group consisted of *Bambusa balcooa, Dendrocalamus hamiltonii* and *D. sikkimensis*. The third congruent group consisted of *Dendrocalamus giganteus* and *D. asper.* The placement of *Dinochloa macclellandii* differed in the two analyses. The affinity of *Dendrocalamus sahnii* and *D. calostachyus* were inconclusive in both the analyses. The three monophyletic clusters/clades did not agree to the sectional assignments within *Dendrocalamus sensu lato* circumscribed by Hsueh and Li (1988), Ohrnberger (1999), and Li & Stapleton (2006).

Bambusinae as circumscribed by Ohrnberger (1999) is an Old World tropical subtribe with its centre of diversity in southeast Asia. It contains seventeen genera, the relationships among which are not fully understood. In the present investigation *Bambusa balcooa* was placed within *Dendrocalamus sensu lato* supporting the closeness, or even inseparability of these two genera. *Melocalamus* and *Thyrsostachys* were recovered as sister lineages to *Dendrocalamus* and *Bambusa.* Watanabe *et al.* (1994), the first to study phylogenetic relationships among Asian bamboos using restriction fragment length polymorphism of chloroplast DNA, recovered a clade representing subtribe Bambusinae *sensu* Ohrnberger (1999), containing *Bambusa, Dendrocalamus, Gigantochloa* and *Thyrsostachys*. Internally, however, Watanabe's clade was poorly resolved in terms of relationships among *Bambusa, Gigantochloa* and *Dendrocalamus,* suggesting close relationships among these genera. *Thyrsostachys* had emerged as a sister lineage to the other genera included in Watanabe's study. The study of Loh *et al.* (2000) and Ramanayake *et al.* (2007), using AFLPs and RAPDs respectively, also indicated a close relationship between *Bambusa* and *Gigantochloa.* The combined evidence from these earlier molecular studies and the present investigation suggest that taxa belonging to *Bambusa*, *Dendrocalamus* and *Gigantochloa* form a close complex but are relatively distant from *Melocalamus, Thyrsostachys* and *Oxytenanthera.*

The phylogenetic trees generated in the present study are plausible hypotheses for relationships within *Dendrocalamus*, but need validation from other evidences. The low statistical support for some of the clusters/clades might improve with inclusion of more informative characters, which could be generated by using more selective primer sets. The study confirms that the current taxonomic treatment of *Dendrocalamus* is unsatisfactory and needs revision. A broader study encompassing a wider selection of taxa from *Bambusa, Dendrocalamus* and *Gigantochloa*, and inclusion of evidence from multiple data source (including AFLP and sequencing of fast evolving genes) might be expected to produce a robust phylogenetic tree for this suite of closely related taxa.

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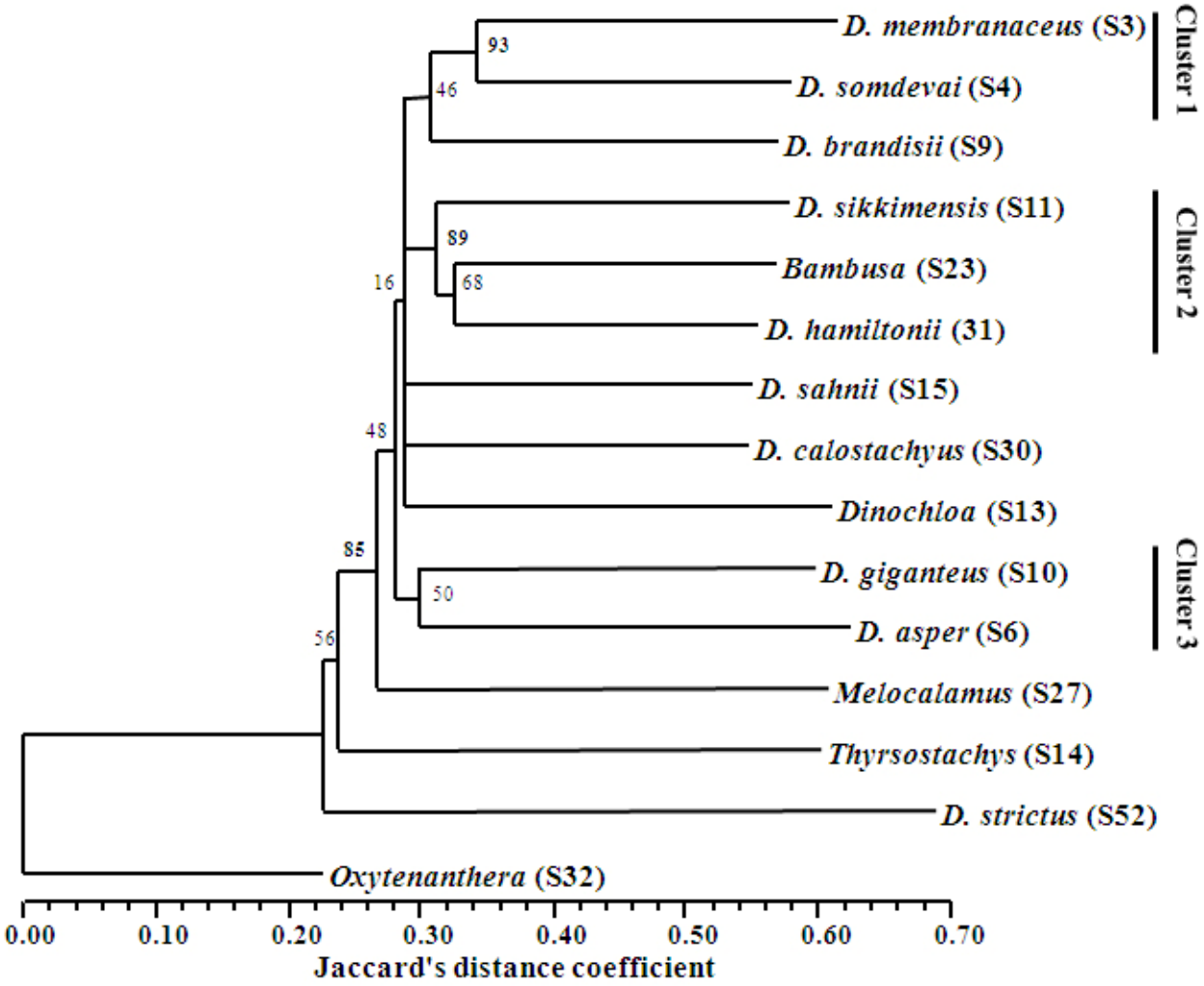
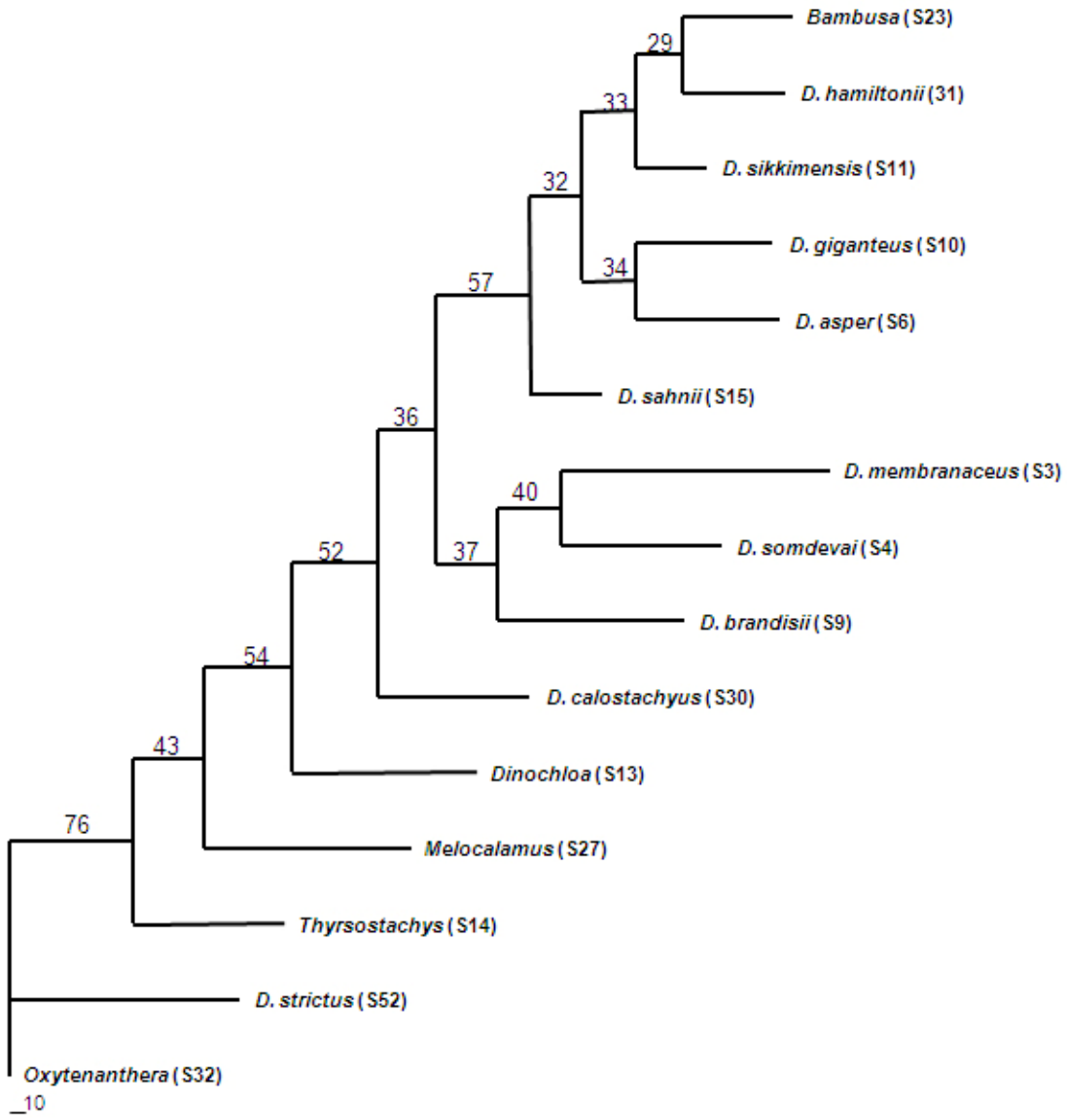
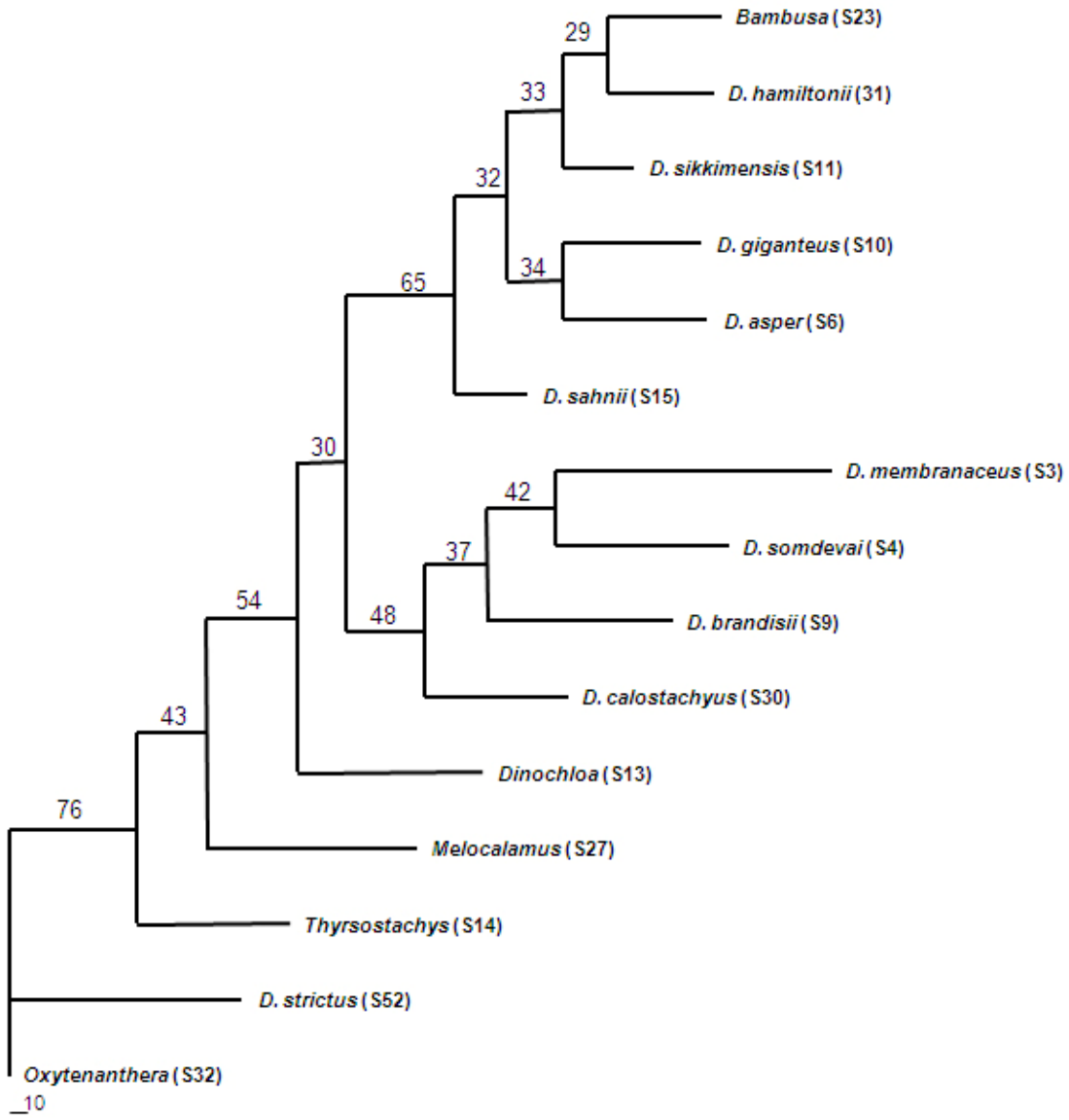


Figure 1. Neighbour-joining phenogram showing phenetic relationships among the 15 sampled taxa from *Dendrocalamus* and the subtribe Bambusinae.

Numbers at the nodes indicate bootstrap (%) support for the respective clusters. Bar scale indicates additive distance between pairs of taxa.


Bambusa (S23)
D. hamiltonii (31)
D. sikkimensis (S11)
D. giganteus (S10)
D. asper (S6)
D. sahnii (S15)
D. membranaceus (S3)
D. somdevai (S4)
D. brandisii (S9)
D. calostachyus (S30)
Dinochloa (S13)
Melocalamus (S27)
Thyrsostachys (S14)
D. strictus (S52)
Oxytenanthera (S32)
29
33
32
34
57
36
40
37
52
54
43
76
10

(a)



(b)

Figure 2a & b. Phylograms depicting two equally parsimonious trees resulting from the maximum parsimony analysis of a character matrix of 470 AFLP markers.

Each tree has a length of 1468 steps, CI = 0.320, RI = 0.298, RC = 0.095. Values above segments indicate character state changes (gains/losses of AFLP bands) supporting respective nodes. Accession codes are indicated within brackets. The horizontal bars below trees represent 10 character state changes.

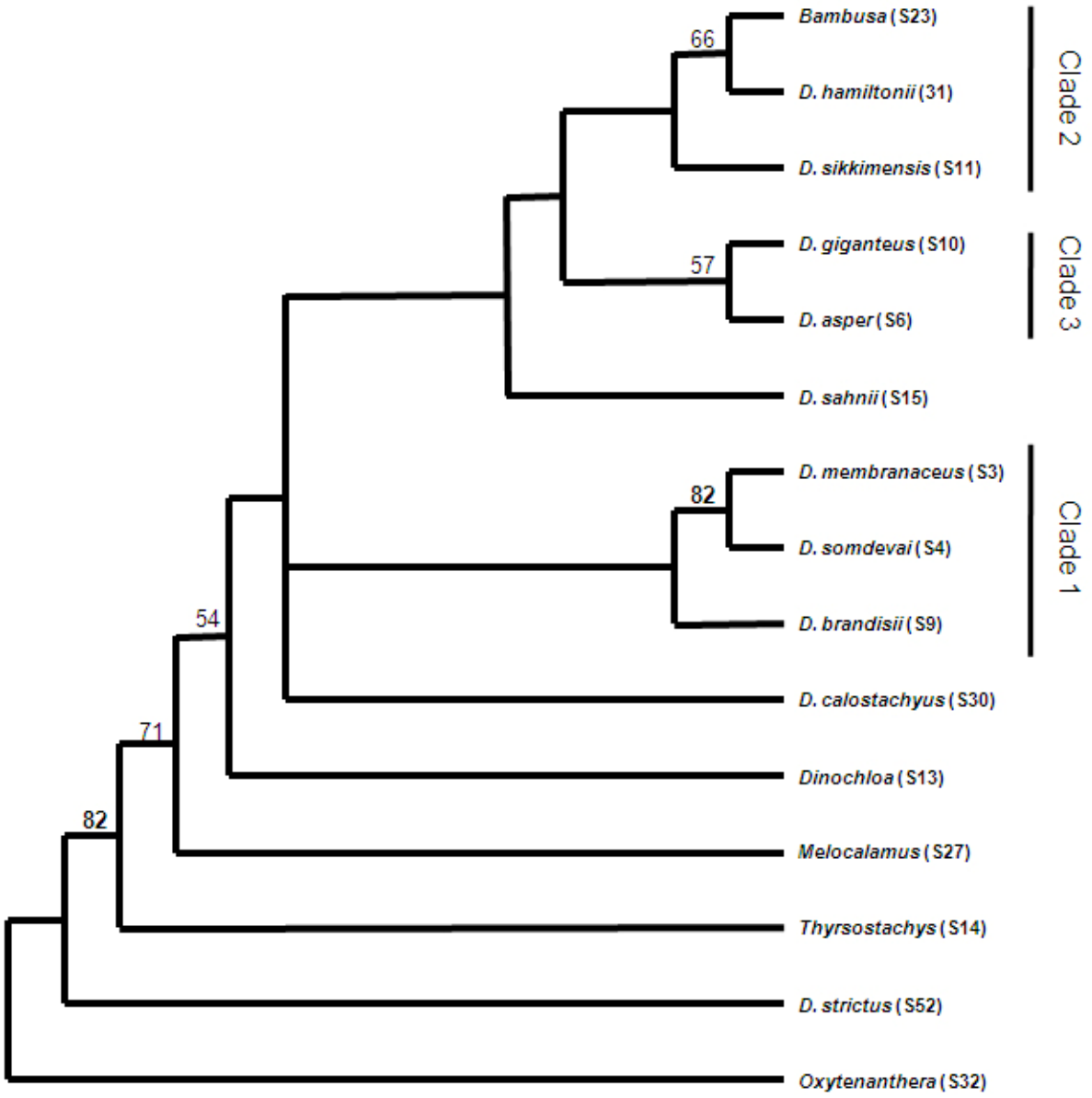


Figure 3. Cladogram depicting strict consensus of the two parsimonious trees obtained in the maximum parsimony analysis of a character matrix of 470 AFLP markers.

Length =1480 steps (character state changes), CI = 0.317, RI = 0.289, RC = 0.092. Values above segments indicate bootstrap support for the respective nodes. Bootstrap support for nodes with less than 50% support and which collapse under the 50% majority rule tree is not shown. Accession codes are indicated within brackets. Clades conforming to the clusters of neighbour-joining analysis are indicated.

Flowering gene expression in the life history of two mass-flowered bamboos, *Phyllostachys meyeri* and *Shibataea chinensis* (Poaceae: Bambusoideae)

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Abstract

A total of 4 copies of the flowering promoting gene *FLOWERING LOCUS T* (*FT*) homolog *PmFT* were cloned and sequenced, and 2 fragment copies of the flowering repressing gene *CENTRORADIALIS* (*CEN*) homolog *PmCEN* were amplified. The average identities of amino acid sequences among the copies of *PmFT* and *PmCEN* were 97% and 95%, respectively. The orthologous regions were used with a real-time RT PCR method for gene expression analyses in stages of the life history of *Phyllostachys meyeri* McClure and *Shibataea chinensis* Nakai, with emphasis on their mass flowering behaviors. Both genes were expressed during the reproductive phase and in sterile leaves in the vegetative phase, whereas *PmCEN* alone was expressed in seedlings and juvenile clones. *PmFT* expression was strongest in leaves of the flowering culm. Relatively weak expression of both gene homologs in *S. chinensis*—*ScFT* and *ScCEN*— was detected during the reproductive phase; the expression of *ScFT* was highest in mature leaves. Only *ScFT* was detected at a low level in the vegetative phase after flowering. The expression of *FT* homologs in the vegetative phase in both bamboo species suggested that sporadic flowering would occur in the following year(s). The highest expression level of *FT* homologs were detected in the flowering culms in both bamboo species, suggesting that the same molecular mechanism of flowering promoting genes discovered in model plants might underlie the mass flowering process of the bamboo plants.

Introduction

Many bamboos have a life history trait of monocarpic mass flowering and death (Janzen 1976), suggesting that cross-breeding to produce a new genetic cultivar would be difficult in bamboos. If the molecular mechanism of bamboo flowering could be clarified and genetic modification made feasible, bamboo propagation technology might be fundamentally reformed.

A number of genes that control flowering time have been isolated and characterized in *Arabidopsis* (Komeda 2004). Corbesier et al. (2007) discovered that the *FLOWERING LOCUS T* (*FT*) gene is a candidate for encoding florigen and that the *FT* protein moves from an induced leaf to the shoot apex and causes flowering. On the other hand, *TERMINAL FLOWER 1* (*TFL1*)/*CENTRORADIALIS* (*CEN*) acts as a flowering repressing gene to

delay the flowering time and alters the inflorescence architecture in *Arabidopsis* (Alvares et al. 1992) and in *Antirrhinum* (Bradley et al. 1996). Rice *TFL1/CEN* orthologs, *RCN1* and *RCN2*, delay transition into flowering and alter panicle morphology (Nakagawa et al. 2002).

We have investigated the relationships between various flowering behaviors in the genus *Phyllostachys* and have examined the nucleotide sequence variation in the *FT* homolog *PmFT* (Hisamoto and Kobayashi 2007). In the present study, we first cloned 4 copies of *PmFT* and amplified 2 fragment copies of the *CEN* homolog *PmCEN* from *Phyllostachys meyeri* McClure. Then, we analyzed their expression patterns in the life history, including mass flowering and death and the recovery of a grove of *P. meyeri*, as well as in mass-flowering *Shibataea chinensis* Nakai.

Materials and Methods

Plant Materials

Phyllostachys meyeri and *Shibataea chinensis* were cultivated in the Fuji Bamboo Garden, Japan. The life histories of *P. meyeri* and *S. chinensis* are summarized in Figure 1. *P. meyeri* bloomed in high synchrony with determinate inflorescences of the capitate type (Figure 1; LF, IF), and then the culms died. Two months after the mass flowering, slender, short regenerated culms emerged and bear indeterminate inflorescences of the lax type (Figure 1; LR, IR), whereas the flowered culms died. Caryopses matured in June and seedlings emerged in July 2004 (Figure 1; SS). One year after the mass flowering, several slender vegetative culms emerged (Figure 1; LS). The juvenile clumps formed a clone with monopodial rhizomes in 2007 (Figure 1; LJ).

S. chinensis bore young inflorescences in February 2008 (Figure 1; LY, IY). The grove was in full bloom with green leaves in March (Figure 1; LM, IM). This stage was considered to correspond with the mass-flowering stage in *P. meyeri*. Flowering terminated around April 20. All the inflorescences withered, but did not bear any caryopses. Even after flowering, the flowered culms remained verdant with green foliage leaves (Figure 1; LW), and bore new leaf buds on the axils.

We collected samples of *P. meyeri* and *S. chinensis* in various stages of flowering as follows: in *P. meyeri*, leaves (LF) and inflorescences (IF) of the mass-flowered culms, inflorescences (IR) and leaves (LR) of the regenerated culms in flower, leaves (LS) of the regenerated sterile culms, leaves of the juvenile clumps (LJ), and young stems of the seedlings (SS); in *S. chinensis*, leaves (LY) and inflorescences (IY) in the young stage, leaves (LM) and inflorescences (IM) in the mature stage, and leaves (LW) remaining after flowering.

Isolation and Sequencing of FT and CEN Homologs from Phyllostachys meyeri

Genomic DNA was isolated from the leaves of *Phyllostachys meyeri* by the modified CTAB method (Hasebe and Iwatsuki 1990). Full-length *PmFT* and partial *PmCEN* sequences were amplified using the primer pairs shown in Table 1.

Table 1 Primer pairs used for PCR amplification

Primer name	Derivation	Position	Sequence of primer (5□-3□)	Designed for
PmFT_5end	*PmFT* (AB240578)	1□21	ATGGTCGGCGGGGACAGGGAT	cloning and sequencing
PmFT_3end		897□919	TCACCAGGGGTACATCCTTCTTC	
PmCEN_F	rice *FDR2* (AF159882)	211□231	GGTCATGAGCTCTACCCATCA	
PmCEN_R		592□610	GCCTCCTGGCTGCAGTCTC	
FT_F	*PmFT1 4* (AB240578; AB498760□ AB498762)	185□371 (intron: 202□ 366)	GGACATTTTACACACTCGTGAT	real-time RT-PCR
FT_R		418□562 (intron: 429□ 551)	CAGTGACCAGCCAGTGTAGATA	
CEN_F	*PmCEN1 2* (AB498763; AB498764)	71□193 (intron: 89□189)	CGGTCTTTCTTCACATTGGTTA	
CEN_R		371□391	AGCATCTGTTGTCCCAGGTAT	
GAPDH_F	rice *GAPDH* mRNA (AF546879)	244□261	GCTACCCAGAAGACTGTT	
GAPDH_R		371□391	GTGCTGCTAGGAATGATGTTGA	

Each PCR reaction was performed in a volume of 25 µl containing 1 ng of the template DNA, 1.25 U Takara LA *Taq*, 20 pmol of each primer, 2 × GC buffer II, and 0.25 mM dNTP (Takara). Amplification was performed in a GeneAmp PCR system 9700 programmed for the following sequence of steps: (A) initial denaturation of 1 s at 95°C; (B) 14 cycles of 15 s at 95°C and 12 min at 68.5°C; (C) 8 cycles of 15 s at 95°C followed by 12 min at 68.5°C, wherein the time for each successive cycle increased by 5 s; and (D) post-elongation for 10 min at 72°C. The PCR products were subcloned into pSTBlue-1 (Novagen) and sequenced using the BigDye Terminator v. 3.1 Cycle Sequencing Kit (Applied Biosystems).

Analysis of Gene Expression

Total RNA was extracted from the samples using the RNA Plant Mini Kit (Qiagen) and treated with DNase according to the manufacturer's protocol. First-strand cDNA was synthesized from 3 µg of the total RNA by SuperScript III reverse transcriptase (Invitrogen) with an oligo $(dT)_{20}$ primer and dNTP mixture according to the manufacturer's instructions.

We performed real-time PCR for a volume of 25 µl containing 1×, 10^{-1}×, or 10^{-2}× cDNA, 10 pmol of each primer, and 2×QuantiTect SYBR Green PCR Master Mix using the QuantiTect SYBR Green RT-PCR Kit (Qiagen). We used the same gene-specific primers for both *Phyllostachys meyeri* and *Shibataea chinensis*, and we employed rice *GAPDH* gene primers as the control (Table 1). Amplification was performed in a 7500 Real Time PCR System (Applied Biosystems) programmed for an initial denaturation of 15 min at 95°C, followed by 41 cycles of 15 s at 94°C, 30 s at 56°C, and 35 s at 72°C. The final cycle was 15 s at 95°C, 1 min at 60°C, and 15 s at 95°C for a dissociating stage to check the specificity of the PCR amplification. All experiments were repeated at least 3 times.

Results

Cloning of FT and CEN Homologs in Phyllostachys meyeri

In a preliminary study, we identified full-length *PmFT* based on the rice *RFT1* gene (AB240578; Hisamoto et al. 2008), and we detected 4 copies of *PmFT* by a Southern blot analysis and determined complete sequences of 2 copies. In the present study, we cloned a total of 4 genomic copies among 28 clones of PCR products amplified using primer pairs designed from the 5′- and 3′-end sequences of *PmFT* (Figure 2a). The 4 copies, *PmFT1* to *PmFT4*, were composed of 4 exons and 3 introns. Exon 1 of *PmFT2* was 204 bp in length including a 3 bp-insertion, whereas those of the other copies were 201 bp.In all the copies, the lengths of exons 2, 3, and 4 were 61 bp, 41 bp, and 233 bp, respectively. The lengths of the introns were 165–169 bp, 123–162 bp, and 91 bp in introns 1, 2, and 3, respectively. Four-bp and 36-bp insertions were found in introns 1 and 2 of *PmFT4*. The nucleotide sequence identities among the 4 copies were 92–98%.

We obtained two partial *PmCEN* sequences, *PmCEN1* and *PmCEN2*, which were amplified using primer pairs designed from the rice *FDR2* gene (Figure 2b). The sequences started from the nucleotide corresponding to the 232nd nucleotide of *FDR2* mRNA and were composed of 4 exons and 3 introns. Exon 1 of *PmCEN1* was 88 bp in length including a 3-bp insertion, whereas exon 1 of *PmCEN2* was 85 bp in length. In both copies, the lengths of exons 2, 3, and 4 was 62 bp, 42 bp, and 213 bp, respectively. The lengths of the introns were 101 or 105 bp, 106 or 190 bp, and 95 bp in introns 1, 2, and 3, respectively. A total of 84 bp of insertions was found in intron 2 of *PmCEN1*. The nucleotide sequence identity between the 2 copies was 80%.

We aligned the putative amino acid sequences of the 4 copies of *PmFT* and the 2 copies of *PmCEN* with *FT* and *TFL1* in *Arabidopsis*, and the homologs in rice and poplar (Figure 3). Amino acid sequence identity among the 4 copies was 96–98%, whereas the identities between *PmFT* and the other *FT* proteins were low: 71% in *Arabidopsis*, 82% in poplar, and 88% in rice. The amino acid sequence identity between the 2 copies of *PmCEN* was 95%, but the amino acid identities between *PmCEN* and the other *TFL1/CEN* proteins were low: 75% in *Arabidopsis*, 81% in poplar, and 86% in rice.

Expression Patterns of FT and CEN Homologs in Two Bamboo Species

As shown above, the nucleotide and amino acid sequences were highly conserved among the 4 copies of *PmFT*, as well as the 2 copies of *PmCEN*. We carried out gene expression analyses of all the copies of *PmFT* and *PmCEN* in the life history of *Phyllostachys meyeri* and the flowering process of *Shibataea chinensis* by real-time RT-PCR using primers specific for each gene and normalized by reference to the *GAPDH* gene (Figure 4).

In *P. meyeri*, *PmFT* was strongly expressed in the leaves of mass-flowered culms and regenerated culms in flower, while it was weakly expressed in their inflorescences (Figure 4a). In particular, the level of expression was almost 45 times higher in the leaves than in the inflorescence of mass-flowered culms. Expression of *PmFT* was not detected in seedlings or juvenile plants, but it was detected in regenerated sterile culms even though they did not flower. On the other hand, the expression of *PmCEN* was stronger in the inflorescences than in the leaves. The expression level in seedlings was 15 times as high as that in the inflorescences of regenerated flowered culms. Expression was also detected in regenerated sterile culms and juvenile plants. For a detailed

investigation of the mass-flowered stage, we analyzed the expression levels in mass-flowered *S. chinensis* from young to withered stages. Similar to *PmFT*, the expression level of the *FT* homolog, *ScFT* was higher in leaves than in inflorescences (Figure 4b), in which the expression level increased as the inflorescences matured. *ScFT* was weakly expressed in the withered leaves remaining after flowering. On the other hand, expression of the *TFL1/CEN* homolog *ScCEN* was highest in mature inflorescences. Its second highest expression was in leaves of the young stage, followed by leaves in the mature stage. *ScCEN* expression was not detected in the leaves remaining after flowering.

Discussion

We amplified *PmFT* and *PmCEN* using primers designed for rice *FT* and *CEN* homologs (Table 1). The *FT* and *TFL1* genes belong to the same gene family, and exert opposing effects on flowering time. These effects have been related to the presence of critical amino acid residues: tyrosine at position 85 and glutamine at position 140 in *FT*; and histidine at position 88 and aspartic acid at position 144 in *TFL1* (Hanzawa et al. 2005, Ahn et al. 2006). The amino acid residues in *PmFT* and *PmCEN* copies match these amino acid residues, except that *PmFT4* has glutamic acid at position 140 (Figure 3). High homology was detected in amino acid sequences rather than in nucleotide sequences among the 4 copies of *PmFT* and between the 2 copies of *PmCEN* (Figures 2 and 3), suggesting that these copies were functionally homologous in *Phyllostachys meyeri*. Therefore, we designed primers for expression analysis at positions conserved in the 4 copies of *PmFT* as well as between the 2 copies of *PmCEN* (Table 1; Figure 2, arrows). In addition, the position of the critical tyrosine at 85 was included in the forward primer of *PmFT* to avoid confusion between *PmFT* and *PmCEN*.

In *Arabidopsis*, activation of *FT* transcription in leaf vascular tissue induces flowering (Corbesier et al. 2007). They provided evidence that *FT* does not activate an intermediate messenger in leaves and concluded that the *FT* protein acts as a long-distance signal that induces *Arabidopsis* flowering. Tamaki et al. (2007) also reported that a protein encoded by a rice *FT* ortholog, Hd3a, moves from the leaf to the shoot apical meristem and induces flowering, and suggested that the Hd3a protein may be the rice florigen. In the present study, the highest expressions of *PmFT* and *ScFT* were detected in leaves rather than inflorescences, suggesting that these two bamboo *FT* homologs have roles similar to their genes in *Arabidopsis* and rice. However, expression of *PmFT* continued in regenerated sterile culms, and *ScFT* expression continued in withered leaves remaining after their full-bloom stage. We have investigated the regeneration process of bamboo clumps every year, and confirmed that *P. meyeri* exhibited sporadic flowering for 4 years from 2004 to 2008 and that *S. chinensis* extensively flowered this year and the culms did not die (data not shown). Thus, we suggest that the *PmFT* expression in regenerated culms indicates sporadic flowering after monocarpic mass-flowering in *P. meyeri*, while the *ScFT* expression in withered leaves shows not monocarpic but polycarpic mass flowering in *S. chinensis*. From this result, if the expression of *FT* homolog is analyzed in a sterile clump, it might be possible to predict whether the clump will bloom or not.

The recessive mutants of *TFL1* produced determinate rather than indeterminate inflorescences in *Arabidopsis* (Alvarez et al. 1992) and *Antirrhinum* (Bradley et al. 1996); it was proposed that the *TFL1/CEN* gene product supports the activity of an inhibitor of flower initiation. Overexpression of the rice *TFL1/CEN* homologs, *RCN1*and *RCN2*, caused a delay in the flowering transition and altered the panicle morphology (Nakagawa et al.

2002). *RCN1* expression was observed in all the tissues of leaves, roots, flowers, vegetative meristems, and reproductive meristems. *RCN2* expression was also detected in all the tissues, but its level was higher in vegetative and reproductive meristems than in other tissues. In the present study, expression of *PmCEN* and *ScCEN* was detected in all tissues, except for withered leaves of *S. chinensis* (Figure 4). In the reproductive phase, *PmCEN* expression was strongest in the inflorescences of regenerated flowering culms, followed by inflorescences of mass-flowered culms in *P. meyeri*. The *ScCEN* expression level was highest in mature inflorescences, and it was lower in young inflorescences in *Shibataea chinensis*. We have investigated the inflorescence architecture of these two bamboos: in *P. meyeri*, determinate inflorescences are borne in mass-flowered culms, whereas indeterminate inflorescences are borne in regenerated culms in flower (data not shown). *S. chinensis* bears indeterminate inflorescences (Hisamoto et al. 2009). The sufficient expected amount of *ScCEN* expression in the inflorescences suggested that this gene promotes indeterminate inflorescence architecture. In the seedlings and juvenile clumps, only *PmCEN* was detected and strongly expressed. This result suggests that not only introduction of *PmFT* but also inhibition of *PmCEN* is necessary in order to force sterile bamboos to flower.

Recently, several flowering genes were isolated from woody plants, such as poplar *FT/TFL1* homologs (Igasaki et al. 2008), grapevine *FT/TFL1* homologs (Carmona et al. 2007), rubber tree *LEAFY* homolog (Dornelas et al. 2005), citrus *FT* homolog (Endo et al. 2005), citrus *LEAFY* homologs (Pillitteri et al. 2004), and apple *LEAFY* homologs (Wada et al. 2002). The apple *FT* homolog was strongly expressed and forced flowers to occur ectopically (Wada's personal communication). These studies aim to develop new breeding technologies for the acceleration of flowering by genetic modification, because woody plants have a very long juvenile phase that is an obstacle in their breeding. Woody bamboos constitute important resources that are used as foods and materials for building construction or crafts without any emissions. They also have a very long vegetative phase and exhibit monocarpic mass flowering and death (Janzen 1976). Therefore, it is important to elucidate the molecular mechanisms of flowering in woody bamboos to develop a new technology for controlling their sexual reproduction. Thus, we now intend to exploit a new vector system to induce such a *FT* gene.

Acknowledgments

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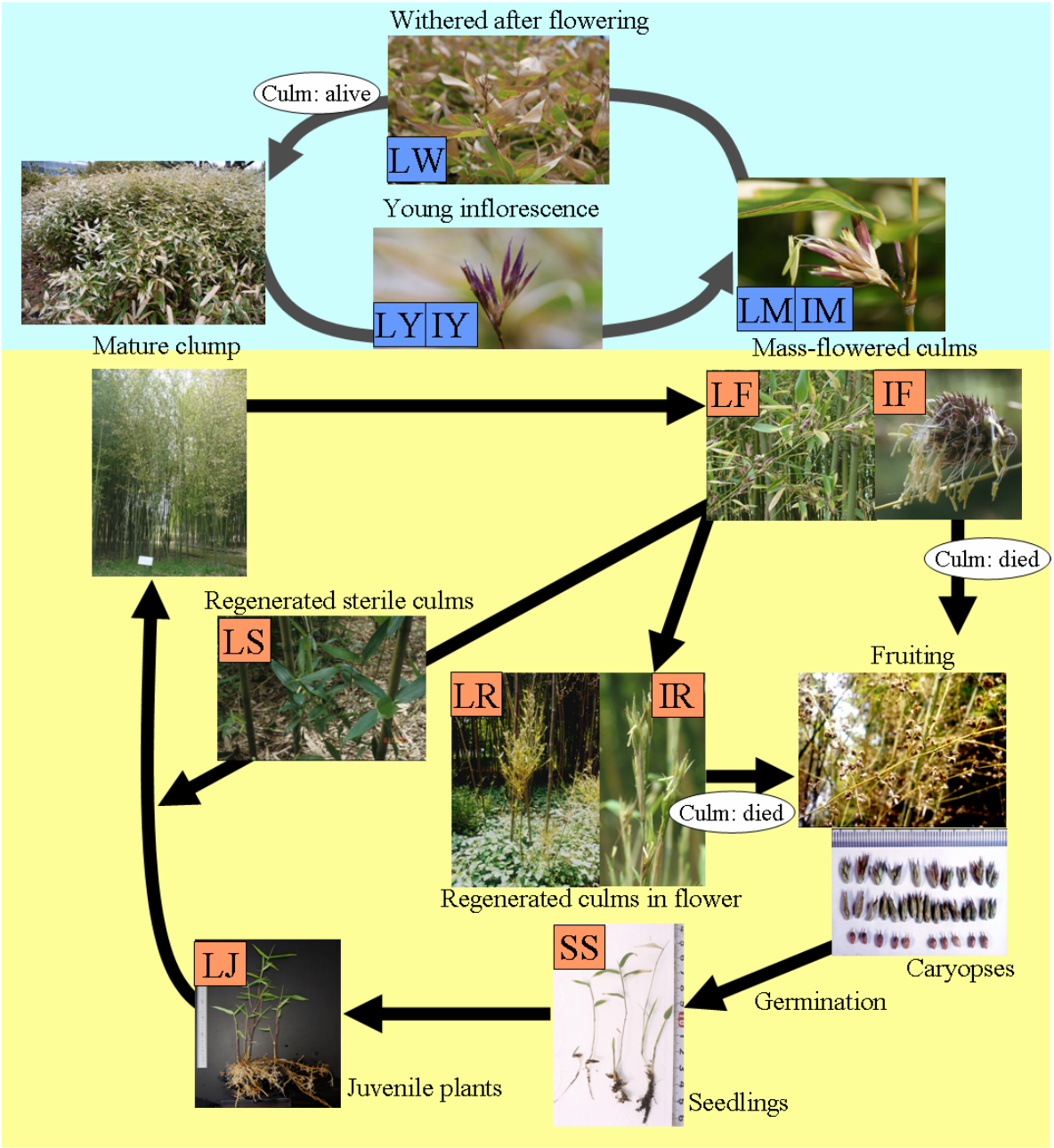

Figure 1 Combined diagram of the life histories of *Phyllostachys meyeri* (yellow region) and *Shibataea chinensis* (blue region). Each symbol shown on the photograph corresponds to Figure 4: in *P. meyeri*, leaves (LF) and inflorescences (IF) of mass-flowered culms, leaves (LR) and inflorescences (IR) of regenerated culms in flower, leaves (LS) of sterile regenerated culms, leaves of juvenile clumps (LJ), and young stems of the seedlings (SS); in *S. chinensis*, leaves (LY) and inflorescences (IY) in the young stage, leaves (LM) and inflorescences (IM) in the mature stage, and leaves (LW) remaining after flowering.

a

```
PmFT1  ATGGTCGGCGGGGACAGGGATCCGCTGGTGGTTGGTAGGGTTGTGGGCGACGTGCTCGAC  60
PmFT2  ......................A...........C....................A.....  60
PmFT3  ...............................C.......................A.....  60
PmFT4  ...............................C.......................A.....  60

PmFT1  CCCTTCGTCCGAACCACCAACCTCAGGGTGAGCTACGGGCCGAGGACGAT---ATCCAAC  117
PmFT2  ....................C....C....C........C............GAT.......  120
PmFT3  ....................G...........................C...........  117
PmFT4  ...............................C.......................A.....  117

PmFT1  GGCTGCGAGCTCAAGCCGTCCATGGTCGTGCACCAGCCCAGGATCGAGGTTGGCGGCAAT  177
PmFT2  ....................................T.G.....................  180
PmFT3  ....................................T.G.....................  177
PmFT4  ....................................G.....................  177

PmFT1  GACATGAGGACATTTTACACACTCGTACGTATAAGCACACGCAAGATCTGT----GCTAA  233
PmFT2  ....................................T.G.....................  236
PmFT3  ....................................T.G.....................  233
PmFT4  ..A.......G.....................T.............ACGT.....  237

PmFT1  TTAATCACAACAGTAGCGCCATTTTCGATGTTTCTCCTTGTCTTAAGAAGGACTAATCAG  293
PmFT2  ....................................T.G.....................  296
PmFT3  ....C...............................T.G.....................  293
PmFT4  ....................................T.G.....................  297

PmFT1  CTTACATGCGTGCAAAATGGCTTATTAATAACAGCATATATCGATCATGTTGTGCATGCG  353
PmFT2  ....................................T.G.....................  356
PmFT3  ....................................T.G.....................  353
PmFT4  ....................................T.G.....................  357

PmFT1  TAACTAACTGCAGGTGATGGTAGACCCAGATGCTCCAAGCCCAAGCGAGCCCAATTTTAG  413
PmFT2  ....................................T.G.....C...............  416
PmFT3  ....................................T.G.....C...............  413
PmFT4  ....................................T.G.....C...............  417

PmFT1  GGAATATCTACACTGGTAAATACGTACTAATGCTAGCCAGCTCT--CTCTTTT-------  464
PmFT2  ...G................................T.G.....C...............  467
PmFT3  ...G.....C.....C....................T.G.....C...............  464
PmFT4  ...G..C.....C.......TT.....ACGTACT.T.G.....C...............  477

PmFT1  ---------------------------TT---TGCCACACTCACCGCTGATTCGTCCAGC  494
PmFT2  ....................................T.G.....C...............  497
PmFT3  ...................CCA.......T.G.....C...............  497
PmFT4  AGTGCTAGCCAGCTCTTTCTCGATCTT..CCA.....T.G.....C...T..  537

PmFT1  ATATATATATGCATCATATCGATCTTGACATGGTGGATCGATCTTTACTTTCTGCAGGCT  554
PmFT2  ....T.G.....C...............T.G.....C...............  557
PmFT3  ....T.G.....C...............T.G.....C...............  557
PmFT4  ....T.G.....C...............T.G.....C...............  597

PmFT1  GGTCACTGATATTCCTGGTACTACTGGAGCAGCGCTTGGTCACTACTCCTCCCTCTCTTA  614
PmFT2  ....T.G.....C...............T.G.....C...............  617
PmFT3  ....T.G.....C...............T.G.....C...............  617
PmFT4  ....T.G.....C...............T.G.....C...............  657

PmFT1  ATTAATTTATCTCTTCCTTTCCTGCATGTTTTAACTTGCATGCATGCGATGTGCTCTGAA  674
PmFT2  ....T.G.....C...............T.G.....C...............  677
PmFT3  ....T.G.....C...............T.G.....C...C...........  677
PmFT4  ....T.G.....C...............T.G.....C...C...........  717

PmFT1  CTTCTGCAGGGCAAGAGGTGGTGTGCTACGAGAGCCCAAGGCCGACCATGGGGATCCATC  734
PmFT2  ....T.G.....C...............T.G.....C...............  737
PmFT3  ....T.G.....C...............T.G.....C...............  737
PmFT4  ....T.G.....C...............T.G.....C...............  777

PmFT1  GCTTCGTGTTCGTGCTGTTCCAGCAGCTGGGCCGGCAGACGGTTTATGCCCCCGGTTGGC  794
PmFT2  ....T.G.....C...............T.G.....C...............  797
PmFT3  ....T.G.....C...............T.G.....C...............  797
PmFT4  ....T.G.....C...G.....C...C...G.....C...............  837

PmFT1  GCCAGAACTTCAACACCAGGGA-CTTCNCCGAGCTCTACAACCTCGGCCAGCCGGTCGCC  853
PmFT2  ....T.G.....C...-.....A....G.....C...............  856
PmFT3  ....T.G.....C...G.....A.....C...C...G.....C...C....  856
PmFT4  ..G.T.G.....C...G.T.C.....C...G.....C...C...G.....  896

PmFT1  GCCGTTTACTTCAACTGCCAGCGTGAGGCTGGCTCTGGGGGAAGAAGGATGTACCCCTGG  913
PmFT2  ....T.G.....C...G.....C...G.....C...G.....  916
PmFT3  ....T.G.....C...G.....C...G.....C...G.....  916
PmFT4  ....T.G.....C...G.....C...G.....C...G.....  956

PmFT1  TGA  916
PmFT2  ...  919
PmFT3  ...  919
PmFT4  ...  959
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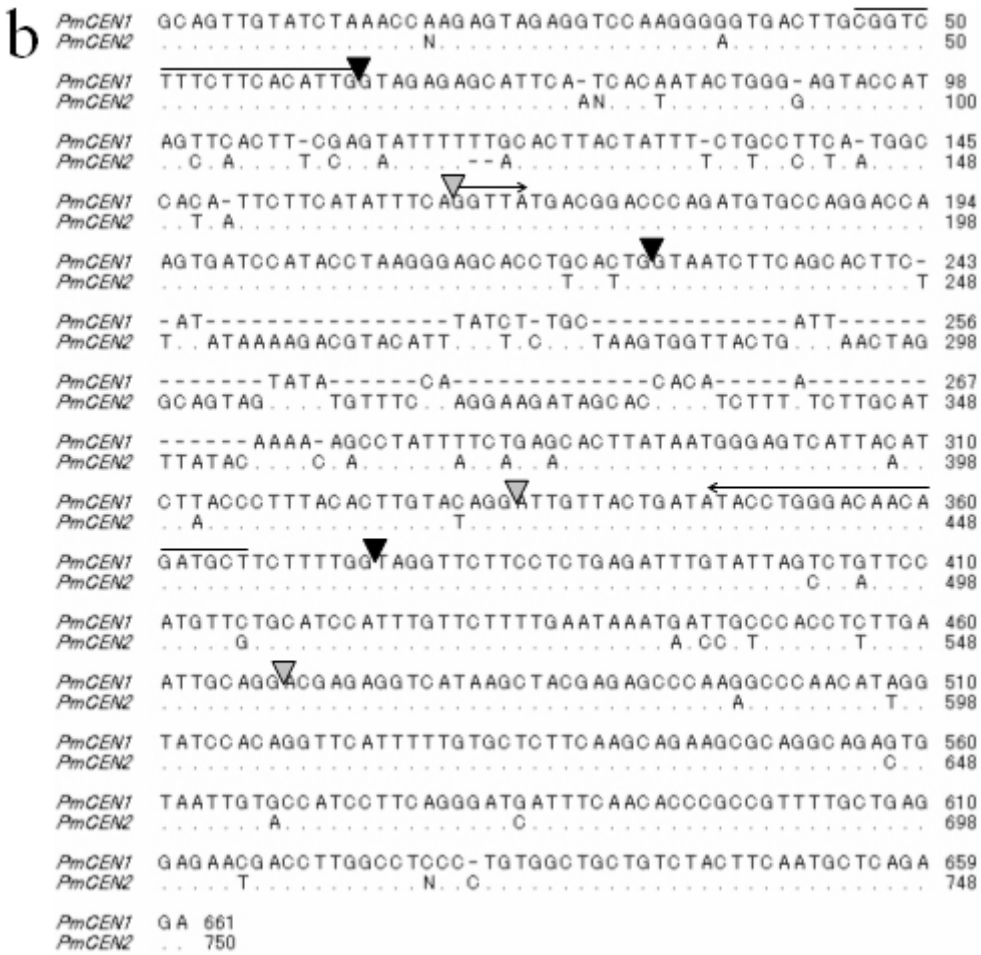

Figure 2 Alignment of nucleotide sequences between (a) 4 copies of *PmFT* and (b) 2 copies of *PmCEN*. A dot indicates a nucleotide identical to the *PmFT1* sequence. An insertion/deletion is shown with a dash and a stop codon with an asterisk. Black and gray arrowheads indicate the start and end of introns, respectively. Arrows show the positions of primers designed for gene expression analysis; the positions correspond with Table 1.

```
PmFT1    MVGGDRD---PLVVGRVVGDVLDPFVRTTNLRVSY-GPRT-ISNGCELKPSMVVHQPRIEVGGNDMRTFY 65
PmFT2    MVGGDRD---PLVVGRVVGDVIDPFVRTTTLRVSY-GPRTMISNGCELKPSMVVHQPRIEVGGNDMRTFY 66
PmFT3    MVGGDRD---PLVAGRVVGDVLDPFVRTTDLRVSY-GPRT-ISNGCELKPSMVVHQPRLEVGGNDMRTFY 65
PmFT4    MVGGDRD---PLVVGRVVGDVIDPFVRTTNLRVSY-GPRT-TSNGCELKPSMVVHQPRVEVGGNEMRTFY 65
RFT1     MAGSGRD-D-PLVVGRIVGDVLDPFVRITNLSVSY-GARI-VSNGCELKPSMVTQQPRVVVGGNDMRTFY 66
Hd3a     MAGSGRDRD-PLVVGRVVGDVLDAFVRSTNLKVTY-GSKT-VSNGCELKPSMVTHQPRVEVGGNDMRTFY 67
FT       MSINIRD---PLIVSRVVGDVLDPFNRSITLKVTY-GQRE-VTNGLDLRPSQVQNKPRVEIGGEDLRNFY 65
PnFT1    MPRDRE----PLSVGRVIGDVLDPFTRSISLRVNY-NSRE-VNNGCELKPSHVVNQPRVDIGGEDLRTFY 64
PmCEN1   ----------------------------------------------------------AVVSKPRVEVQGGDLRSFF 26
PmCEN2   ----------------------------------------------------------AVVSK?RVEVQGSDLRSFF 26
FDR1     MSRSVE----PLVVGRVIGEVLDSFNPCTKMIVTY-NSNKLVFNGHEFYPSAVVSKPRVEVQGGDMRSFF 65
FDR2     MSRSVE----PLVVGRVIGEVLDTFNPCMKMIVTY-NSNKLVFNGHELYPSAVVSKPRVEVQGGDLRSFF 65
TFL1     MENMGTRVIEPLIMGRVVGDVLDFFTPTTTKMNVSY--NKKQVSNGHELFPSSVSSKPRVEIHGGDLRSFF 68
PnTFL1   MAKMS----EPLVVGRVIGDVIDHFTANVKMTVTYQSSRKQVFNGHELFPSAVTNKPKVEVHGGDMRSFF 66
         ▽                   *   ▽           ▽
PmFT1    TLVMVDPDAPSPSEPNFREYLHWLVTDIPGTTGAALGQEVVCYESPRPTMGIHRFVFVLFQQLGRQTVYA 135
PmFT2    TLVMVDPDAPSPSEPNFREYLHWLVTDIPGTTGAAFGQEVVCYESPRPTMGIHRFVFVLFQQLGRQTVYA 136
PmFT3    TLVMVDPDAPSPSEPNLREYLHWLVTDIPGTTGAAFGQEVVCYESPRPTMGIHRFVFVLFQQLGRQTVYA 135
PmFT4    TLVMVDPDAPSPSEPNLREYLHWLVTDIPGTTGAAFGQEVVCYESPRPTMGIHRFVFVLFQQLGRRTVHA 135
RFT1     TLVMVDPDAPSPSNPNLREYLHWLVTDIPGTTGATFGQEVMCYESPRPTMGIHRLVFVLFQQLGRQTVYA 136
Hd3a     TLVMVDPDAPSPSDPNLREYLHWLVTDIPGTTAASFGQEVMCYESPRPTMGIHRLVFVLFQQLGRQTVYA 137
FT       TLVMVDPDVPSPSNPHLREYLHWLVTDIPATTGTTFGNEIVCYENPSPTAGIHRVVFILFRQLGRQTVYA 135
PnFT1    TLVMVDPDAPSPSNPNLREYLHWLVTDIPATTGANFGQEVMCYESPRPTAGIHRFVFVLFRQLGRQTVYA 134
PmCEN1   TLVMTDPDVPGPSDPYLREHLHWIVTDIPGTTDASF?REVISYESPRPNIGIHRFIFVLFKQKRRQSVIV 96
PmCEN2   TLVMTDPDVPGPSDPYLREHLHWIVTDIPGTTDASF?REVISYESPKPNIGIHRFIFVLFKQKRRQTVIV 96
FDR1     TLVMTDPDVPGPSDPYLREHLHWIVTDIPGTTDASFGREIISYESPKPSIGIHRFVFVLFKQKRRQAVVV 135
FDR2     TLVMTDPDVPGPSDPYLREHLHWIVTDIPGTTDASFGREVISYESPKPNIGIHRFIFVLFKQKRRQTVIV 135
TFL1     TLVMIDPDVPGPSDPFLKEHLHWIVTNIPGTTDATFGKEVVSYELPRPSIGIHRFVFVLFRQKQRR-VIF 137
PnTFL1   TLVMTDPDVPGPSDPYLREHLHWIVTDIPGTTDATFGREVMNYEMPRPNIGIHRFVFLLFKQKGRQTVTT 136
             *
PmFT1    P--GWRQNFNTRDF?ELYNLGQPVAAVYFNCQREAGSGGRRMYPW----- 178
PmFT2    P--GWRQNFTPGNFAELYNLGQPVAAVYFNCQREAGSGGRRMYPW----- 179
PmFT3    P--GWRQNFNTRDFAELYNLGQPAAAVYFNCQREAGSGGRRMYPW----- 178
PmFT4    P--GRRENFNTRDFAALYNLGQPVAAVYFNCQREAGSGGRRMYPW----- 178
RFT1     P--GWRQNFSTRNFAELYNLGSPVATVYFNCQREAGSGGRRVYP------ 178
Hd3a     P--GWRQNFNTKDFAELYNLGSPVAAVYFNCQREAGSGGRRVYP------ 179
FT       P--GWRQNFNTREFAEIYNLGLPVAAVFYNCQRESGCGGRRL-------- 175
PnFT1    P--GWRQNFNTRDFAELYNLGSPVAAVYFNCQRESGSGGRRP-------- 174
PmCEN1   P--SFRDDFNTRRFAEENDLGLPVAAVYFNAQRETAARRQSEFVDKLG?A 144
PmCEN2   P--SFRDHFNTRRFAEENDLGLPVAAVYFNAQRETAARRQSEFVDKL?RA 144
FDR1     P--SSRDHFNTRQFAEENELGLPVAAVYFNAQRETAARRR---------- 173
FDR2     P--SFRDHFNTRRFAEENDLGLPVAAVYFNAQRETAARRR---------- 173
TFL1     PNIPSRDHFNTRKFAVEYDLGLPVAAVFFNAQRETAARKR---------- 177
PnTFL1   P--ASRDKFNTRKFAEENELGLPVAAVFFNAQRETAARKR---------- 174
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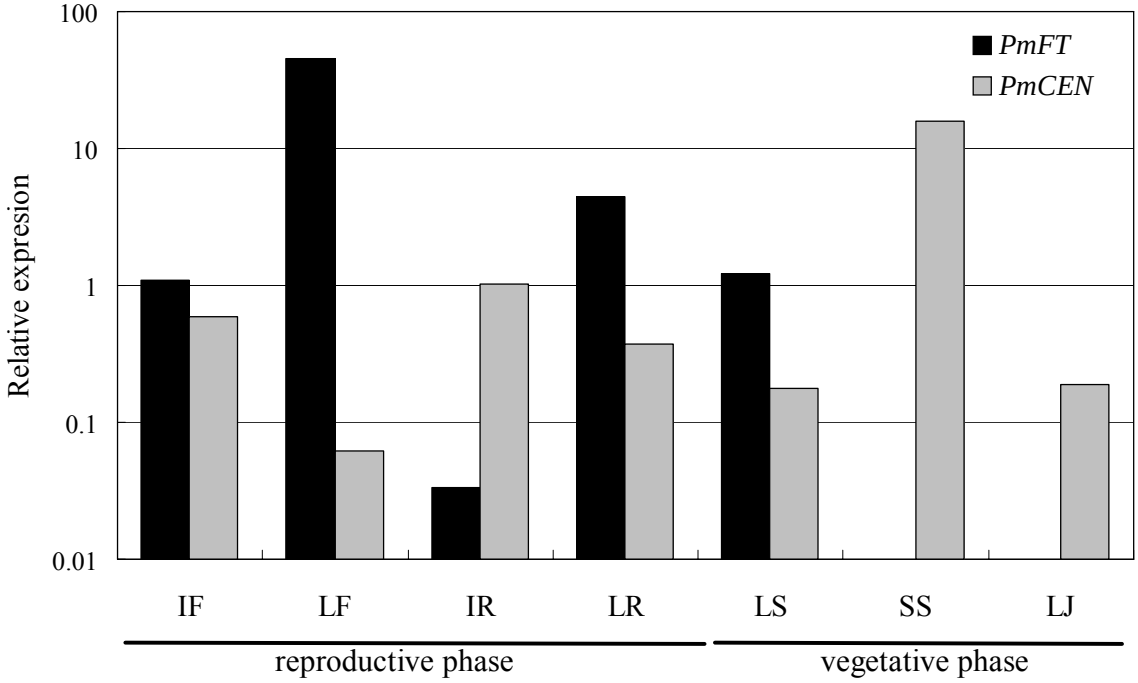
Figure 3 Alignment of the putative amino acid sequences of 4 copies of *PmFT* and partial sequences of 2 copies of *PmCEN* with *FT* (AB027504) and *TFL1* (U77674) in *Arabidopsis*; *RFT1* (AB062676) and *Hd3a* (AB433508) for *FT* homologs and *FDR1* (AF159883) and *FDR2* (AF159882) for *CEN* homologs in *Oryza sativa*; and *PnFT1* (AB369069) and *PnTFL1* (AB369067) in poplar. Amino acids in black and gray are identical and similar, respectively. A dash indicates gaps introduced to maximize the alignment among sequences. In *PmCEN1* and *2*, amino acid residues from 1 to 51 have not been determined yet. Arrowheads indicate the positions of introns. Asterisks indicate amino acids that are critical to the definition of proteins in the *FT* and *TFL1* families.

a


100
10
1
0.1
0.01
Relative expresion
PmFT
PmCEN
IF
LF
IR
LR
LS
SS
LJ
reproductive phase
vegetative phase

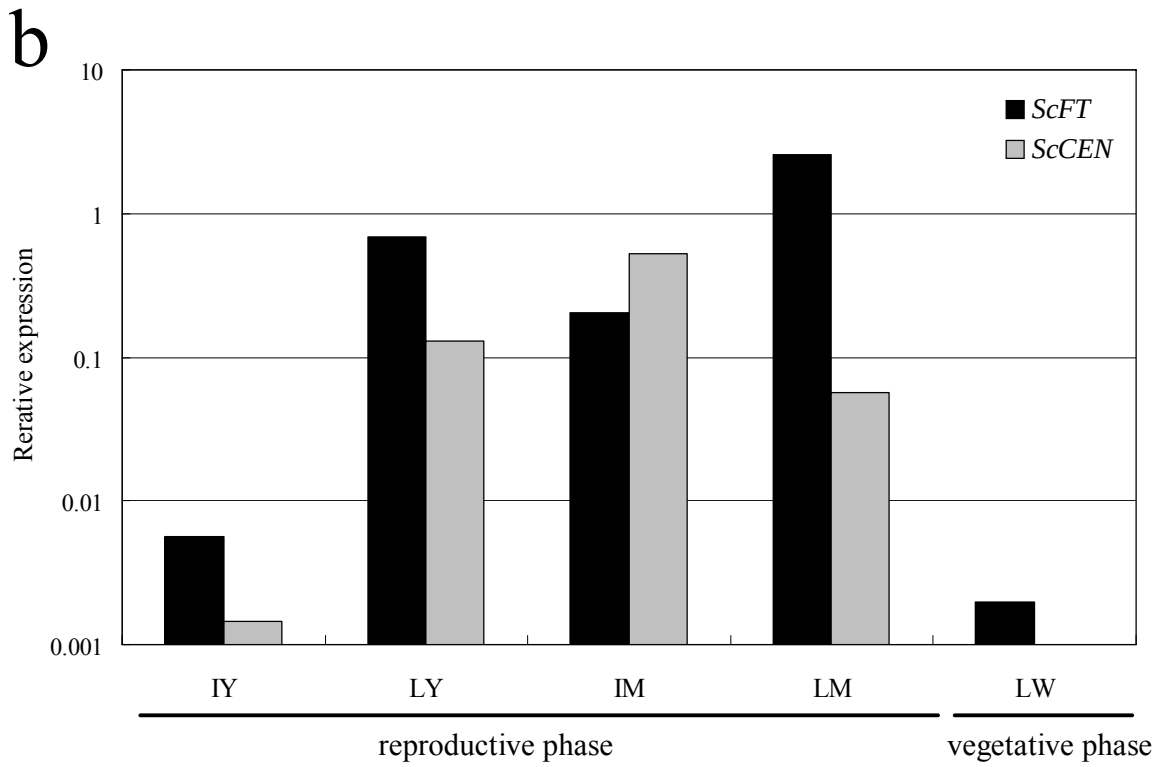


Figure 4 Expression of *FT* and *CEN* homologs in various organs of (a) *Phyllostachys meyeri* and (b) *Shibataea chinensis* in different stages of flowering. Expression levels were measured by real-time RT-PCR and normalized by reference to the *GAPDH* gene. a: IF, LF, inflorescences and leaves of mass flowered culms; IR, LR, inflorescences and leaves of regenerated culms in flower; LS, leaves of sterile regenerated culms; SS, young stems of seedlings; LJ, leaves of juvenile plants in *P. meyeri*. b: IY, LY, young inflorescences and leaves accompanying them; IM, LM, mature inflorescences and leaves; LW, leaves remaining after flowering in *S. chinensis*.

Relationships between *Phuphanochloa* (Bambuseae, Bambusoideae, Poaceae) and its related genera

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Abstract

Morphological and molecular relationships between a newly established bamboo genus *Phuphanochloa* and it related genera are discussed. Morphologically, *Phuphanochloa* is superficially similar to several bamboo genera e.g. *Bambusa*, *Bonia*, *Dendrocalamus*, *Gigantochloa*, and *Thyrsostachys*. It is, however, somewhat vegetatively similar to either *Gigantochloa* or *Thyrsosstachys*, particularly on the basis of the culm-sheath. In contrast, it is more reproductively similar to *Bambusa* in having distinct and disarticulating rachilla of the spikelet. However, the peculiar syndrome in breaking up of the spikelets at maturity is the best character to set *Phuphanochloa* apart from *Bambusa*. Phylogenetic analysis based on combined five plastid DNA regions; *trnL intron*, *trnL-F* intergenic spacer, *atpB-rbcL* intergenic spacer, *rps16* intron, and *matK*, showed that *Phuphanochloa* is, with high support, sister to the group consisting of eight *Bambusa* species representing all its four subgenera; subg. *Bambusa* (*B. malingensis*), subg. *Dendrocalamopsis* (*B. oldhamii* and *B. beecheyana*), subg. Leleba (*B. tuldoides*, *B. pachinensis*, and *B. dolichomerithalla*), and subg. *Lingnania* (*B. emeiensis* and *B. chungii*). According to morphology and molecular results, *Phuphanochloa* can not be included in any of these subgenera. These eight species of *Bambusa* can not be treated as members of *Phuphanochloa* either. This is because there are some conflicts between morphology and molecular on *Bambusa*. And also, the generic delimitation of such large genus is systematically problematic. There is therefore, *Phuphanochloa* is best regarded as a distinct genus being closely related to *Bambusa* sensu lato.

Keywords: Bambuseae, Morphological and molecular relationships, *Phuphanochloa*

Introduction

Phuphanochloa Sungkaew & Teerawat. is a bamboo genus newly established (Sungkaew et al. 2008). It is apparently a monotypic genus, consisted of a single species, *P. speciosa* Sungkaew & Teerawat. The type locality of this genus is Phu Phan National Park, in Sakon Nakhon Province, north-eastern Thailand where the generic name was named after. Formerly, *Phuphanochloa* was only known from its type locality. After more investigations were carried out, it is found that *Phuphanochloa* also occurs in Loei Province, north-eastern Thailand, especially in Phu Kradung National Park. Sungkaew et al. 2008 reported that *Phuphanochloa* looked

morphologically similar to other four bamboo genera namely *Bambusa*, *Bonia*, *Dendrocalamus*, and *Gigantochloa*.

This study is a step-forward for a better understanding on *Phuphanochloa*. More information from another ally, *Thyrsostachys*, which is also superficially similar to *Phuphanochloa*, was added. The greater sample size of related genera, especially *Bambusa*, *Dendrocalamus* and *Gigantochloa*, for molecular analysis was conducted. The aim of this study is primarily to study morphology and molecular relationships between *Phuphanochloa* and its allies. It also aims to discuss the status of this genus.

Materials and Methods

Morphological relationship

A comparison on morphological characters between *Phuphanochloa* and its allies based on former study (Sungkaew et al. 2008) and more information from this study were compiled. Herbarium specimens of some species of these allies from the Forest Herbarium (BKF) and the Faculty of Forestry, Kasetsart University Herbarium were examined.

Molecular relationship

Using DNA sequences, the relationships of *Phuphanochloa* in comparison with its related genera was investigated. Single and combined genes of five plastid DNA regions, *trnL intron*, *trnL-F* intergenic spacer, *atpB-rbcL* intergenic spacer, *rps16* intron, and *matK*, were phylogenetically analyzed. Combined analysis of plastid DNA regions are often useful for improving phylogenetic resolution and support (Reeves et al. 2001). These five regions have shown to be useful for phylogenetic study of grasses and bamboos for both lower and higher taxonomic ranks (Sungkaew et al. 2009). Twenty-nine bamboo species of the subtribe Bambusinae sensu Soderstrom and Ellis (1987) and Sungkaew (2008) were sampled (Table 1) as the ingroup. Three species of the subtribe Melocanninae according to Ohrnberger (1999) were selected to be the outgroup because they lie outside the ingroup species which are the members of the core Bambusinae (Sungkaew et al. 2009). DNA extractions and relevant processes, including DNA sequencing which performed on an ABI Prism^{TM} 310 Genetic Analyzer (Applied Biosystems), were carried out in Trevor's Molecular Laboratory in the Department of Botany, School of Natural Sciences, Trinity College Dublin, University of Dublin, Dublin 2, Ireland (all molecular protocols see Sungkaew et al. 2009). Successful DNA sequences were edited and assembled using AutoAssembler Software, version 2.1. The sequences were then imported to PAUP 4.0* Beta 2 (Swofford 1998) for alignment. Sequences were aligned by eye. Gaps were scored as additional binary characters (scoring gaps of identical size and position only). The resulting sequences were subjected to maximum parsimony analysis using the heuristic search options in PAUP 4.0* Beta 2 (Swofford 1998). Searches included 1,000 replicates of random stepwise addition saving no more than 100 trees for tree bisection reconstruction (TBR) branch swapping per replicate. Bootstrapping included 1,000 replicates and the same heuristic search settings as the individual searches except that simple addition sequence was used instead of random stepwise addition.

Table 1 Taxa and vouchers of all sequences

Taxon	Voucher/Herbarium	Source
Bambusinae		
Bambusa bambos (L.) Voss	SS&AT 030704-16/THNHM&KUFF	Thailand
Bambusa beecheyana Munro	Stapleton 1313/KEW	USA[1], cultivated
Bambusa chungii McClure	Stapleton 1320/KEW	USA[1], cultivated
Bambusa dolichomerithalla Hayata	Stapleton 1343/KEW	USA[1], cultivated
Bambusa malingensis McClure	Stapleton 1332/KEW	USA[1], cultivated
Bambusa oldhamii Munro	SS&AT 111/THNHM&KUFF	Thailand, cultivated
Bambusa oliveriana Gamble	Stapleton 1321/KEW	USA[1], cultivated
Bambusa pachinensis Hayata	Stapleton 1333/KEW	USA[1], cultivated
Bambusa tulda Roxburgh	Stapleton 1328/KEW	USA[1], cultivated
Bambusa tuldoides Munro	Stapleton 1327/KEW	USA[1], cultivated
Dendrocalamus asper (J.H. Schultes) Backer ex K.Heyne	BAM1[2]	Malaysia, cultivated
Dendrocalamus asper (J.H. Schultes) Backer ex K.Heyne	SS&AT 110704-1/THNHM&KUFF	Thailand, cultivated
Dendrocalamus brandisii (Munro) Kurz	SS&AT 260903-8/THNHM&KUFF	Thailand
Dendrocalamus copelandii (Gamble ex Brandis) N.H.Xia & Stapleton	SS&AT 20/THNHM&KUFF&TCD	Thailand
Dendrocalamus dumosus (Ridley) Holttum	SS&AT 389/THNHM&KUFF&TCD	Thailand
Dendrocalamus giganteus Munro	BAM45[2]	Malaysia, cultivated
Dendrocalamus hamiltonii Nees & Arnott ex Munro	SS&AT 787/THNHM&KUFF	Thailand
Dendrocalamus khoonmengii Sungkaew, A. Teerawatananon & Hodk.	SS&AT 257/THNHM&KUFF&TCD	Thailand
Dendrocalamus latiflorus Munro	SS&AT 113/THNHM&KUFF	Thailand, cultivated
Dendrocalamus membranaceus Munro	SS&AT 020704-4/THNHM&KUFF	Thailand
Dendrocalamus pendulus Ridley	SS&AT 231/THNHM&KUFF	Thailand
Dendrocalamus sinicus Chia & J.L. Sun	SS&AT 127/THNHM&KUFF	Thailand, cultivated
Dendrocalamus strictus (Roxburgh) Nees	SS&AT 718/THNHM&KUFF	Thailand
Gigantochloa albociliata Munro	SD 1436/KEW	Thailand
Gigantochloa atroviolacea Widjaja	Stapleton 1311/KEW	USA[1], cultivated
Gigantochloa ligulata Gamble	SS&AT 090704-4/THNHM&KUFF	Thailand
Gigantochloa scortechinii Gamble	SS&AT 309/THNHM&KUFF	Singapore, cultivated
Bambusa emeiensis L.C.Chia & H.L.Fung	SS&AT 624/THNHM&KUFF	China, cultivated
Phuphanochloa speciosa Sungkaew & Teerawat.	SS&AT 191/THNHM&KUFF&TCD	Thailand
Thyrsostachys siamensis Gamble	SS&AT 020704-3/THNHM&KUFF	Thailand
Melocanninae		
Cephalostachyum pergracile Munro	SD 1435/KEW	Thailand
Pseudostachyum polymorphum Munro	SS&AT 176/THNHM&KUFF	Thailand
Schizostachyum zollingeri Steudel	SS&AT 090704-1/THNHM&KUFF	Thailand

Remarks; Abbreviations are as follows; KEW, Kew herbarium, England; KUFF, Herbarium of Faculty of Forestry, Kasetsart University, Bangkok, Thailand; THNHM, Thailand Natural History Museum, National Science Museum, Techno Polis, Pathum Thani, Thailand; TCD, Herbium, School of Botany, Trinity College, Dublin, Ireland; SS, S. Sungkaew; AT, A. Teerawatananon; SD, S. Dransfield.

[1] California, United States of America

[2] Bambusetum, Rimba Ilmu Botanic Garden, University of Malaya, Kuala Lumpur, Malaysia; specimen collected by K.M. Wong

Results

Morphological relationship

A morphological character of *Phuphanochloa* in comparison to its allies based on former study (Sungkaew et al. 2008) together with more information from this study were compiled and is presented in Table 2.

Molecular relationship

The justification to combine datasets in the analyses in this study was based on an examination of groupings (and support for these) found in the single-gene analyses (data not shown). No major and well supported incongruences were found between the results from single gene region analyses and it was deemed appropriate to combine datasets.

The aligned metrix of the combined five plastid DNA regions (*trnL intron*, *trnL-F* intergenic spacer, *atpB-rbcL* intergenic spacer, *rps16* intron, and *matK*) was 4,243 bp long. 13 characters were excluded and of the remaining 4,230 characters, 4,153 were constant, 29 were variable but parsimony-uninformative, and 48 were parsimony informative. The tree search using maximum parsimony found three equally most parsimonious trees, of 81 steps. CI and RI were 0.97 and 0.98 respectively. One of the three equally most parsimonious trees is shown as a phylogram with bootstrap values and strict consensus information in Figure 1. Bootstrap (BS) percentages (≥50%BS) are described as low (50–74%), moderate (75–84%), and high (85–100%).

Phuphanochloa is sister to the group consisting of *Bambusa* species; *B. emeiensis*, *B. oldhamii*, *B. malingensis*, *B. tuldoides*, *B. pachinensis*, *B. dolichomerithalla*, *B. chungii*, and *B. beecheyana* with high bootstrap support (85%BS, Figure 1). These eight *Bambusa* species is highly supported as a monophyletic group (83%BS). Within this *Bambusa* group, more groupings are found. *B. pachinensis* is sister to *B. dolichomerithalla* and *B. chungii* is sister to *B. beecheyana*, both with low bootstrap support of 63% and 65% respectively. A subgroup comprising five species; *B. tuldoides*, *B. pachinensis*, *B. dolichomerithalla*, *B. chungii*, and *B. beecheyana*, was formed but collapsed in the strict consensus analysis.

Thyrsostachys groups with some species of other two genera with high support (85%BS); *Gigantochloa* (*G. ligulata* and *G. albociliata*) and *Bambusa* (*B. tulda* and *B. bambos*).

Dendrocalamus species bunch together with some representatives from other two genera with high support (100%BS); *Bambusa* (*B. oliveriana*) and *Gigantochloa* (*G. scortechinii* and *G. atroviolacea*). Two representatives of *D. asper* group with two species of *Gigantochloa*, *G. scortechinii* and *G. atroviolacea*, with low support (63%BS). In addition, these two *Gigantochloa* species are grouped together with low support (64%BS).

Table 2 Comparative table of habit and morphological characters between *Bambusa, Bonia, Dendrocalamus, Gigantochloa* and *Phuphanochloa*

Characters	*Bambusa*	*Bonia*	*Dendrocalamus*	*Gigantochloa*	*Phuphanochloa*	*Thyrsostachys**
Habit	usually erect	scrambling	Usually erect	usually erect	usually erect	usually erect
Branch number at mid-culm branch complement	several	Single	Several	several	several	several
Culm-sheath auricles; oral setae/ Culm-sheath blade	usually conspicuous; always present/ usually erect	usually conspicuous, occasionally inconspicuous or small; usually present, occasionally absent/ erect to deflexed	conspicuous, but often small to absent; present or absent/ erect to deflexed	usually absent or small; usually absent, occasionally present/ erect to deflexed	usually absent or small; always absent/ spreading to deflexed, never erect	usually absent or small; usually absent/ erect, occasionally deflexed
Number of glumes per spikelet	0–3	0–2	(1–)2–4(–9)	1–5	1–4	1–3(–4)
Number of fertile florets per spikelet	2–13	3–9	1–8	(1–)2–5	7–9	1–3
Rachilla internodes	distinct and disarticulating	distinct and disarticulating	obscure and not disarticulating	obscure and not disarticulating	distinct and disarticulating	obscure and not disarticulating
Stigma	typically (1–)3, plumose	typically 3, plumose	typically 1(–3), plumose	typically 1, plumose	typically 3, slightly plumose	typically 1–3, plumose
Filaments	typically free	typically free	typically free	always fused into a firm tube	typically free	typically free
Breaking up at maturity of spikelets	either break up above the glume(s) or between the florets	unknown	usually break up above the glume(s)	usually break up above the glume(s)	usually break up in one of two ways (both of which are usually present on any single individual); either above the glume(s) or above the lowest floret	usually break up above the glume(s)

* results from this study, otherwise from Sungkaew et al. 2008

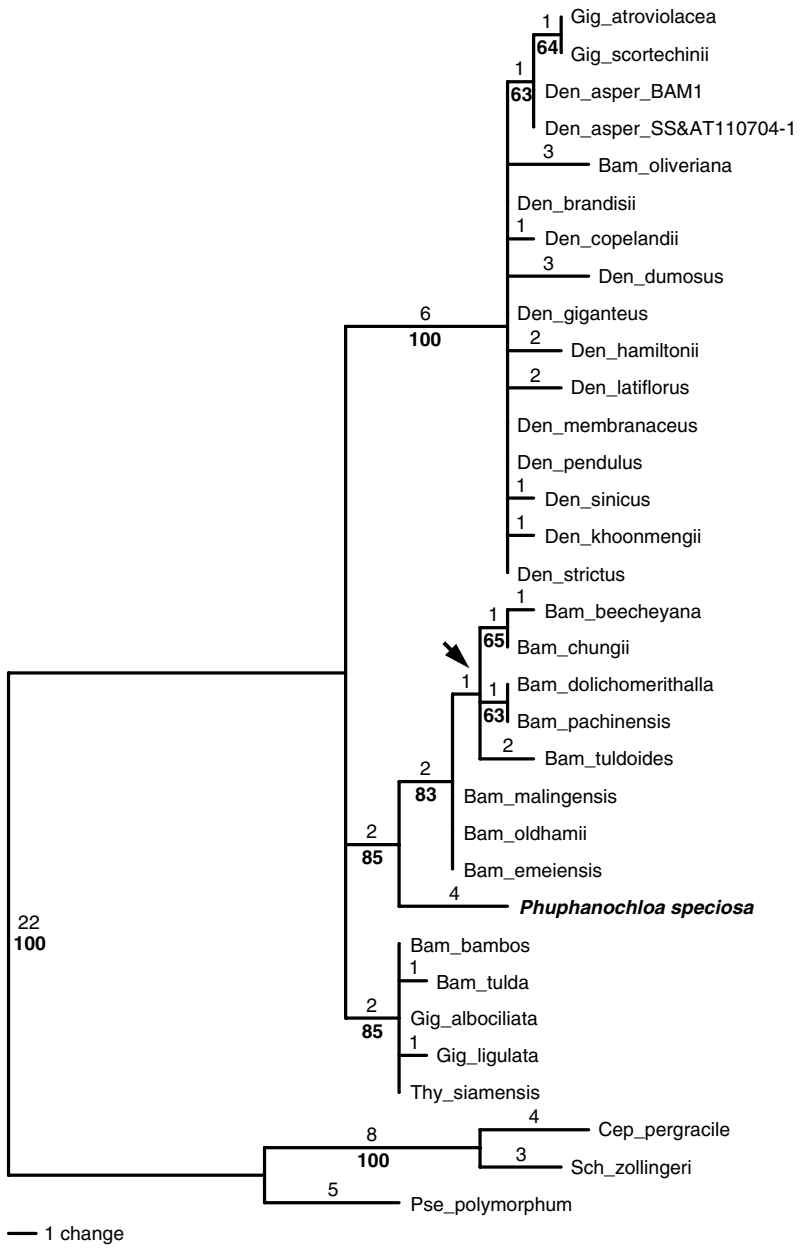

Figure 1. One of three equally most parsimonious trees shown as a phylogram obtained from comparative sequence analysis of combined *trnL-F, atpB-rbcL, rps16* and *matK* sequence data. Values above branches represent the number of steps supporting each branch. Values below branches represent the percentages of bootstrap supporting each branch. Arrow head represents node not supported by strict consensus.

Bam=Bambusa; Cep=Cephalostachyum; Den=Dendrocalamus; Gig=Gigantochloa; Pse=Pseudostachyum; Sch=Schizostachyum; Thy=Thyrsostachys.

Discussion

Morphological relationship

On the basis of morphology, *Phuphanochloa* may superficially be similar to several bamboo genera namely *Bambusa*, *Bonia*, *Dendrocalamus*, *Gigantochloa*, and *Thyrsostachys*. Vegetatively, it looks somewhat similar to either *Gigantochloa* or *Thyrsosstachys*, especially on the basis of the culm-sheath detail (see Table 2). Contrarily, it is more reproductively similar to *Bambusa* in having distinct and disarticulating rachilla of the spikelet. However, *Phuphanochloa* has the spikelets that usually break up at maturity in one of two ways (both of which are usually present on any single individual); either the spikelet totally breaks up above the glume(s) leaving only the elongated rachilla internode (0.5–2 cm long), or it breaks up above the glume(s) and above the lowest floret leaving the upper part of the elongated rachilla internode (to 0.5 cm long) along with the glume(s) and intact lowest floret. This syndrome is not the case in *Bambusa* (Sungkaew et al. 2008). In addition, while *Bambusa* has 1–3 distinctly plumose stigmas but there are usually three, and they are only slightly plumose in *Phuphanochloa*.

Molecular relationship

The results from the combined analysis of five plastid DNA regions (Figure 1) showed that the sister relationship between *Phuphanochloa* and a group comprising eight *Bambusa* species (*B. emeiensis*, *B. oldhamii*, *B. malingensis*, *B. tuldoides*, *B. pachinensis*, *B. dolichomerithalla*, *B. chungii*, and *B. beecheyana*) is highly supported (85%BS). This is congruent with the previous molecular study using a multi-gene region phylogenetic analysis (also using five plastid DNA regions, *trnL* intron, *trnL-F* intergenic spacer, *atpB-rbcL* intergenic spacer, *rps16* intron, and *matK* gene region; Sungkaew et al. 2009). These eight species of *Bambusa* group together with high bootstrap support of 83%. They represent all the four subgenera of *Bambusa* according to Xia et al. (2006). *Bambusa malingensis* represents subg. *Bambusa*; *B. oldhamii* and *B. beecheyana* represent subg. *Dendrocalamopsis*; *B. tuldoides*, *B. pachinensis*, and *B. dolichomerithalla* (treated under *B. multiplex* (Loureiro) Raeuschel ex Schultes & J. H. Schultes var. *multiplex* by Xia et al. (2006)) represent subg. Leleba; and *B. emeiensis* and *B. chungii* represent subg. *Lingnania.* This would suggest that *Phuphanochloa* can not be included in any of these four subgenera of *Bambusa* because of the high support of their sister relationship (85%BS) and the high support of a clade consisting of these eight *Bambusa* species (83%BS). Xia et al. (2006) divided *Bambusa* into four subgenera relying greatly on the culm-sheath. Base on this manner, *Phuphanochloa* would look similar to those of subg. *Lingnania* as they share a common character in having narrow culm-sheath blade. However, there is no evident from our molecular results to support this hypothesis.

There are some conflicts between morphology and molecular information. Some representatives from these four subgenera did not group together systematically. Some of them from different subgenera mis-grouped together, even though with low support, e.g. *B. beecheyana* of subg. *Dendrocalamopsis* groups with *B. chungii* of subg. *Lingnania*. Moreover, *B. bambos*, the type species of *Bambusa* which must taxonomically be regarded as a member of subg. *Bambusa*, did not group with *Bambusa malingensis*. It groups with *B. tulda*, a member of subg. Leleba, and some species of other genera, *Gigantochloa* and *Thyrsostachys* (85%BS). This would suggest that the generic delimitation of *Bambusa* is still unclear. The taxonomy of *Bambusa* is in a state of flux, it is a

large genus with over 100 poorly understood species (Ohrnberger 1999; Xia et al. 2006). Incongruence between the morphological classification and phylogenetic study on this genus has been previously revealed by Sun et al. (2005).

If ones think that the status of *Phuphanochloa* may be uncertain. There are two possible scenarios to cope with this problem. Firstly, *Phuphanochloa* may be simply regarded as a new subgenus of *Bambusa*. Secondly, some species of *Bambusa* particularly those eight species (Figure 1) should be transferred to be new members of the distinct genus *Phuphanochloa*. However, these two ways will not be systematically reasonable until the generic delimitation of *Bambusa* would be clarified. Thus, the best way to do now is to keep *Phuphanochloa* as a distinct genus being closely related to *Bambusa* sensu lato. This idea is now excepted by the BPG (Bamboo Phylogeny Group; *personal communication*).

Generic delimitations of other two genera, *Dendrocalamus* and *Gigantochloa*, are also unclear. *Dendrocalamus* is not strictly monophyletic because a species of *Bambusa* represented by *B. oliveriana*, and two species of *Gigantochloa, G. scortechinii* and *G. atroviolacea*, were embedded in the strongly supported *Dendrocalamus* group (100%BS). The misplacement of these taxa was greatly discussed in Sungkaew *et al.*, (*submitted*) and it requires further investigations.

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Evaluation of the Polymorphic of Microsatellites Markers in *Guadua angustifolia* (Poaceae: Bambusoideae)

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Abstract

Guadua angustifolia, one of the world's 20 best bamboos known for their physical and mechanical properties and wide use in the construction industry. It has been used intensively in Colombia reducing native populations to a few hectares. So far, the only strategy for the conservation of genetic and phenotypic variability of the species, although unknown, is the existence of the Germplasm Bank of Bambusoideae located in the Botanical Garden Juan María Céspedes, Tuluá - Valle del Cauca, with accessions from 16 provinces of Colombia. In this study 26 microsatellite markers were designed and evaluated in 46 accessions of *G. angustifolia* to assess the molecular genetic variability of the accessions in the bank and get a new molecular tool enable to conduct population analysis, micro- evolutionary and taxonomic studies.

Amplification of 10 loci was obtained, two showed a pattern of bands with multilocus of genetic origin; in addition, the amplification of 14 loci in Bambusa and between seven or eight loci was reported in other species of Guadua . The eight loci standardized in *G. angustifolia* displayed values of PIC (Polymorphism Index Content) between 0, 3981 and 0, 8517, and probabilities of identity between 0, 0334 and 0, 4134 being medium and highly polymorphic. Therefore, these microsatellites are very good tools to carry out population analyses, taxonomic and microevolutionary studies in *G. angustifolia* and possibly in other species of the genus Guadua and Bambusa, knowledge that will contribute in the creation and implementation of strategies of conservation and sustainable use of the same ones, specially of the Guadua in Colombia.

Introduction

Guadua angustifolia (Karl Sigismund Kunth 1822), American bamboo, is considered one of the 20 best in the world for their excellent physical and mechanical properties, their large size and its wide use in the construction industry (Villegas et al. 2003). In America is distributed from northern Mexico to northeastern Argentina (Young & Judd 1992, Londoño 1991). In Colombia, extends by three mountain ranges from north to south, at

elevations between 500 and 1 500 meters above sea level, dominating the inter-Andean valleys, where they form large associations called "Guaduales" (Londoño 1990).

Due to the continued use of this resource and the extensive colonization of human settlements, few hectares of natural *G. angustifolia* are left in our country (approximately 31 000 ha) (Castaño & Moreno 2004; Villegas et al.2003; Cruz 1994). Therefore it is important the development and implementation of conservation strategies for this species. However, the required prior biological knowledge for its development such as the dynamics of their populations, their genetic diversity, taxonomy and evolution (Frankhan et al.2002), which is lacking today (McNeely 1995; Stapleton & Ramanathan 1995; Bystriakova et al. 2003, 2004).

In 1987 the Bambusoideae Germplasm Bank at the Botanical Garden Juan María Céspedes was established, owned by the Institute for the Research and Preservation of Cultural and Natural Heritage of Valle del Cauca (INCIVA), with the aim of preserving bamboos and deepening their knowledge. This has accessions of *G. angustifolia* from 16 provinces of Colombia (Londoño 1991, Marulanda et al. 2002), thus conserve a high variability of the species, which is convenient topic of study in order to continue conserving *G. angustifolia* using this strategy.

Molecular markers are tools that have allowed to estimate the genetic variability in many species, characterize varieties in germplasm banks, select cultivars, estimated population dynamics and to carry out taxonomic, ecological and evolutionary studies in diverse organisms (Parker et al. 1998, Bachmann 1994, Chasan 1991). In order to obtain basic knowledge for the development of conservation strategies, it is useful to implement them in *G. angustifolia*.

Microsatellites are short DNA sequences of no more than six bases repeated in tandem (Goldstein & Schlötterer 1999), have codominant inheritance, are neutral and highly polymorphic, thus allowing each individual genotype and conduct allocation of parental (Parker et al. 1998, Chambers & MacAvoy 2000), characteristics that facilitate to conduct specific ecological, evolutionary and taxonomy studies, such as estimating the effective size, genetic diversity and structure of populations, allowing to characterize varieties or cultivars identification and selection, identification of breeding systems, gene flow, migration and introgression (Ouborg et al. 1999; Frankhan et al. 2002, Chambers & MacAvoy 2000, Barrera 1996). The use of these molecular markers has not yet been reported for any species of the genus Guadua, so its implementation is relevant.

In this study, the polymorphic information content of 26 microsatellite systems was evaluated in 46 accessions of *G. angustifolia* from the Germplasm Bank of Bambusoideae. Then will be useful in population analysis, and in taxonomic and micro evolutionary studies, knowledge that will help in the creation and implementation of strategies for conservation and sustainable use of Guadua.

Methodology

The study was conducted at the Laboratory of Molecular Biology of the Alexander Von Humboldt (IAvH) Institute located in the facilities of the International Center for tropical Agriculture (CIAT).

The Germ Bank and Sampling

The Germplasm Bank of Bambusoideae is located in the district of Mateguadua, Municipality of Tuluá (Valle del Cauca), approximately 800 meters away from the administrative headquarters of the Botanical Garden Juan María Céspedes owned by the INCIVA. It has an area of about 2 500 m^2. It has climatic conditions characteristic of tropical dry forest with an altitudinal location between 950 to 1 100 meters (Londoño 1990).

Young leaves were collected in good condition from 45 accessions of *G. angustifolia* from different departments of Colombia and one accession from Costa Rica, 14 accessions of different species of the genus Bambusa, and thee of Guadua (Table 1). The leaf tissue was placed in paper bags that were stored immediately in plastic jars filled with silica gel with cobalt indicator. The leaves collected were finely macerated in liquid nitrogen. The mash was kept at -80 ° C until DNA extraction.

DNA Extration and quantification

The DNA was extracted with the Micro extration DNA protocol of Dellaporta (1983) with modifications for rice and with a later mofication for *G. angustifolia* by Potosí et al. (2006).

The evaluation of the DNA was performed by electrophoresis in horizontal agarose gels at 0.8% stained with ethidium bromide, at 48 volts for 30 minutes, adding 2 ul of DNA. It was visualized on a UV transilluminator (Fotodyne Inc). Quantification was carried out in a TECAN spectrophotometer multifunctional Genius, Austria, 260 nm and by agarose gels comparison with DNA Lamda.

Primer microsatellite design

DNA from one individual was used as a source of genomic clones and was used to prepare and enrich GATA tetranucleotide markers in *G. angustifolia*. Genomic DNA was used as starting material- then Psh A1/Hae III double restriction/ligation to linker M28/M29p. M28 5’ CTCTTGCTTGAATTCGGACTA M29p 5’ pTAGTCCGAATTCAAGCAAGAGCACA), Linker-ligated DNA was denatured and hybridized to biotinylated microsatellite 5’ biotin GATA6 (50C), Dynal M270 beads and amplification with M28 primer. Eco RI digestion and ligation into de-phosphorylated Eco RI treated pUC19 followed by electroporation into *E. coli* DH10B. Colony screening was used 5’ 32P- GATA6 50C in 5XSSPE washes in 5XSSPE 50C. A set of 24 positive GATA clones were sequenced and 26 primer pairs were tested. Sequences were obtained by amplifying an aliquot of frozen bacterial culture from positive hybridizing 32-P GATA6 colonies using the M13 forward (F) and reverse (R) primers. The amplification reactions were treated with Exonuclease I and alkaline phosphatase to remove excess primer and unincorporated deoxynucleotide triphosphates. After heat deactivation, approximately 10 ng of PCR product was sequenced using M13 forward and/or reverse primers with Applied Biosystems Big Dye V3.1 and ABI3730 .

Table 1. Accessions studied from the Bambusoideae Germplasm Bank of the Botanical Garden Juan María Céspedes.

Accesion Code	Species	Morphological Variants	Provinces
XL 375	Guadua angustifolia	Cebolla	Cauca, Mercaderes
XL 345	Guadua angustifolia	Cebolla	Santander, Floridablanca
XL 542	Guadua superba		Amazonas, Leticia
JA 1006	Guadua amplexifolia		Sucre
XL 343	Guadua angustifolia	Macana	Santander, Puente Nacional
JA 1003	Guadua amplexifolia		Córdoba, Montería
Bicolor 43	Guadua angustifolia	Bicolor	Valle del Cauca, Tuluá
Bambusa vulgaris	Bambusa vulgaris	Bitata	
JA 1004	Guadua amplexifolia		Sucre, Sincelejo
Bambusa vulgaris(M2)	Bambusa vulgaris	Vulgaris	
XL 233	Guadua angustifolia	Macana	Nariño, Ricaute
XL 282	Guadua paniculata		Meta, Serranía de Matupa
XL 124	Guadua angustifolia	Nigra	Valle del Cauca, Tulua
XL 214	Guadua glauca		Putumayo, Mocoa
XL 281	Guadua angustifolia	Cebolla	Meta, Acacia
XL 291	Guadua angustifolia	Macana	Meta, Serranía de la Macarena
Bambusa bambos	Bambusa bambos		
XL 303	Guadua angustifolia	Macana	Meta, Cumaral
JA 1026	Guadua angustifolia	Macana	Huila, Aipe
Guadua weberbaueri	Guadua weberbaueri		
XL 115	Guadua angustifolia	Cebolla	Caquetá, Belén de los Andaquíes
XL 206	Guadua angustifolia	Cebolla	Putumayo, Puerto Caicedo
Bicolor42	Guadua angustifolia	Bicolor	Valle del Cauca, Tuluá
XL 109	Guadua uncinata		Caquetá, Morelia
XL 1012	Guadua angustifolia	Cebolla	Antioquia, Venecia
Guadua paniculata	Guadua paniculata		
Guaduaangus (Costa Rica)	Guadua angustifolia		Costa Rica
JA 1028	Guadua angustifolia	Cebolla	Cundinamarca, Guaduas
XL 91	Guadua angustifolia	Cebolla	Huila, San Agustín
JA 1031	Guadua angustifolia	Cebolla	Caldas, Florencia
XL 235	Guadua angustifolia	Cebolla	Nariño, Ricaute
JA 1023	Guadua angustifolia	Cebolla	Valle del Cauca, El Cairo
XL 344	Guadua angustifolia	Macana	Santander, Curiti
XL 208	Guadua uncinata		Putumayo, Puerto Caicedo
Bambusa vulgaris (M1)	Bambusa vulgaris	Vulgaris	
JA 1042	Guadua angustifolia	Cebolla	Risaralda, Santa Rosa

JA 1049	Guadua angustifolia	Cebolla	Valle del Cauca, Tuluá
JA 1041	Guadua angustifolia	Macana	Risaralda, Pereira
JA 1038	Guadua angustifolia	Macana	Valle del Cauca, Sevilla
JA 1039_2	Guadua angustifolia	Cebolla	Valle del Cauca, Sevilla
JA 1046_1	Guadua angustifolia	Macana	Valle del Cauca, Rio Frio
XL 144	Guadua glauca		Caquetá, Florencia
JA 1038_1	Guadua angustifolia	Macana	Valle del Cauca, Sevilla
JA 1047_1	Guadua angustifolia	Macana	Valle del Cauca, Buga
JA 1048	Guadua angustifolia	Macana	Valle del Cauca, Tulua
JA 1035_ 1	Guadua angustifolia	Castilla	Valle del Cauca, El Cerrito
JA 1045	Guadua angustifolia	Castilla	Quindío, Barcelona
JA 1040	Guadua angustifolia	Cebolla	Valle del Cauca, B/lagrande
JA 1056	Guadua angustifolia	Cebolla	Valle del Cauca, Cali
JA 1055	Guadua angustifolia	Cebolla	Valle del Cauca, Jamundí
JA 1051_2	Guadua angustifolia	Macana	Valle del Cauca, Jamundí
JA 1052_1	Guadua angustifolia	Macana	Valle del Cauca, Jamundí
JA 1056B	Guadua angustifolia	Macana	Valle del Cauca, Cali
JA 1058	Guadua angustifolia	Castilla	Quindío, Quimbaya
JA 1057	Guadua angustifolia	Cebolla	Quindío, La Tebaida
JA 1059_1	Guadua angustifolia	Cebolla	Valle del Cauca, Alcalá
JA 1060_1	Guadua angustifolia	Bicolor	Valle del Cauca, Tuluá
JA 1061	Guadua angustifolia	Cebolla	Valle del Cauca, Restrepo
JA 1062_2	Guadua angustifolia	Bicolor	Valle del Cauca,Vijes
JA 1063	Guadua angustifolia	Cotuda	Valle del Cauca, Restrepo
JA 1064	Guadua angustifolia	Bicolor	Valle del Cauca, Buga

JA= J. Adarve; XL= X. Londoño; ns= whitout number

Amplification of microsatellite regions

Initially, 26 microsatellites designed were tested for *G. angustifolia* by PCR in the accessions of this species. They were subsequently tested in other species of Bambusa and Guadua genus. Each reaction mixture contained 35ng/ul DNA, 10 mM Tris pH 9, 50mM KCl, 2mM MgCl2, 0.1mm of each dNTP, 0.072µM of each primer and 3U Taq polymerase (CIAT Biotechnology Unit) to a final volume of reaction 25 µl. We used a thermal cycler PTC-100 Programmable Thermal Controller, MJ Research, Inc, following the program: 94 ° C for 1 minute (94 ° C for 30 seconds, 54 ° C for 45 seconds, 72 ° C for 45 seconds) 35 times, 72 per 10 minutes, 4 ° C for five minutes, with temperature-specific banding of *G. angustifolia* optimized for each locus, which works for the other species of the genus Bambusa and Guadua (Table 2). The reaction product was assessed on agarose gels 1.5%, stained with ethidium bromide, loading 8 µl of the product together with 2 ml of buffer blue juice.

The identification of each allele per locus was performed by electrophoresis in vertical polyacrylamide gels prepared in 4% TBE 0.5X. A PCR product was added a solution of formamide (0.05% Bromophenol blue and xilencianol, in 95% formamide, 20 mM EDTA) in a 1 ml of solution per 5 ml of PCR product is denatured and a 94 ° C for 5 minutes before serving. The amount of product added to the gel varied with their concentration. The electrophoretic separation was performed at 120W, with an initial flow of 1,800 to 2,000 V with an optimum temperature of 50 ° C. Separation After about an hour apart, the gel was fixed, dyed with silver nitrate and revealed according to the method of Bassam et al. (1991). The reading of each gel was conducted on a white light transilluminator, counting the bands with higher resolution.

Data analysis

From the profiles obtained in the polyacrylamide gels, alleles of each locus were visually based on their molecular size (bp) using as reference the known values of the markers 10bp and 25 bp (Invitrogen Corp., Carlsbad, California). Later, the genotypes were described by generating a matrix of presence / absence (binary) of alleles for each microsatellite. It was counted the number of alleles identified per locus (A) and their frequencies were estimated using the respective SunOS 5.9 platform SAS version 9.1.3. At each locus, we calculated the allelic richness (A-1), the homocigosity (ho) and heterozygosity (Ho) observed, the unbiased expected heterozygosity of Nei (1978), $H_e = n(1-\sum p_i^{\ 2})/n-1$, the polymorphic information index (PIC) according to Botstein et al.(1980), $PIC = 1-(\sum_{i=1}^{n} p_i^{\ 2}) - \sum_{i=1}^{n-1}\sum_{j=i+1}^{n} 2p_i^{\ 2}p_j^{\ 2}$ where, p_i was the frequency of the i allele and p_j is the frequency of the j allele. The probability of identity (I) defined as the ability of two individuals at random from the population within a given locus have the same genotype by locus (Paetkau et al. 1995) was estimated as $I = \sum p_i^{\ 4} + \sum_{i=1}^{n-1}\sum_{j=i+1}^{n}(2p_i p_j)^2$ and the combined probability of identity (Ic) as $I_c = \prod I_k$, where k represents the locus, and indicates, for all microsatellite used, if are good descriptors of the diversity in the germplasm bank.

Table 2.Standardized microsatellites in different species of Guadua and Bambusa genus with temperature of anneling of *G. angustifolia*

Locus	T. anneling in G. angustifolia(°C)	Size (Pb) in G. angustifolia
Bam 1- 14	54	230
Bam 1- 15	54	180
Bam 11- 2	54	120
Bam 1-11	54	280
Bam 1-17	54	250
Bam 1-22	54	280
Bam 1-3	54	150
Bam 1-5	54	180
Bam 1-6	54	250
Bam 16-2	54	200
Bam 17- 2	54	250
Bam 1-8	54	250
Bam 2-1	50	250
Bam 2-11	54	150
Bam 2-13	54	250
Bam 2-2	54	500
Bam 2-3	48	180
Bam 2-5	48	250
Bam 2-6	50	180
Bam 2-7	54	500
Bam 2-8	45	200
Bam 4-2	54	250
Bam 9-2	54	180

Note: The sequences of the primers (5'-3 ') and type of repetition is not included in this table because they have not yet been published and are the property of the entities funding the project.

Results and Discussion

Amplification of the microsatellites regions

Of the 26 microsatellites evaluated were able to standardize in *G.angustifolia* 10 loci in *G. superba, G. amplexifolia* and *G. weberbaueri* 7 loci, in *G. paniculata, G. glauca* and *G. uncinata* 8 loci, in *B. vulgaris* 18 loci and in *B. Bambos* 12 loci (Table 3).
The amplification in agarose gels ranged between 150 and 500 bp and in the acrylamide gels were distinguished alleles between 101 and 500 bp (Figures 1 and 2).

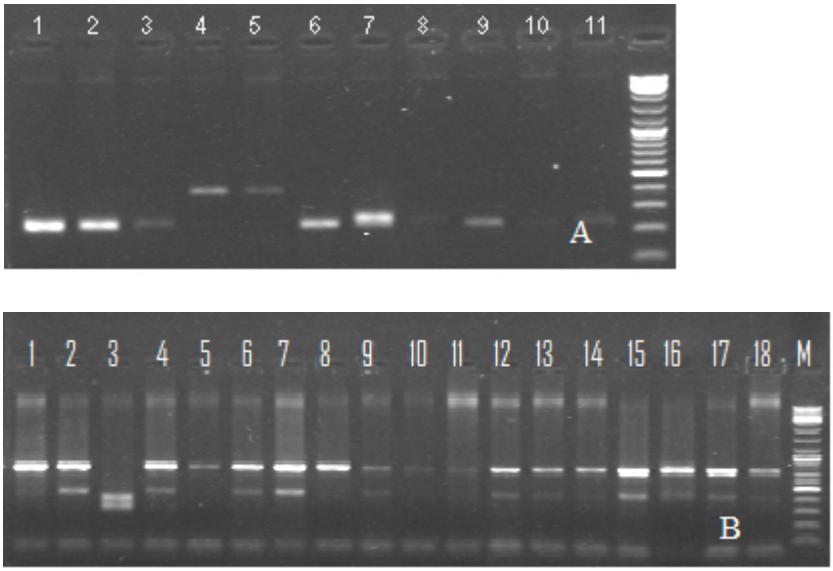
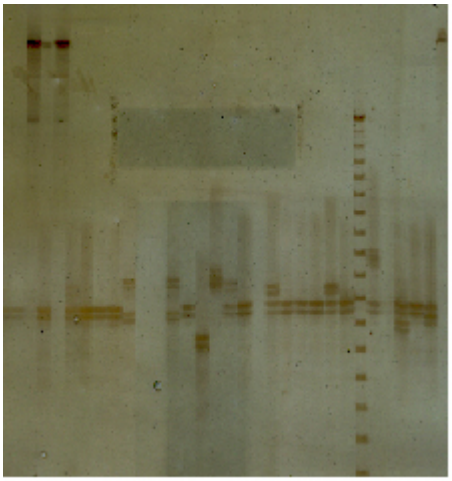


Figure 1. Microsatellites Amplification. A. **Amplification of locus Bam 2-13 in *G. angustifolia* (1-3, 6-11) and *B. vulgaris* (4, 5).** B. **Bam 1-11 in *G. angustifolia* (1-18) and *B. vulgaris* (3).**

Table 3. Optimally standardized microsatellites in each species of Bambusa and Guadua genus.

Especie	G. angustifolia	G. superba	G. amplexifolia	G. paniculata	G. glauca	G. uncinata	G. weberbaueri	B. bambos	B. vulgaris
Bam 2-1	X			X	X	X			
Bam 2-13	X	X	X	X	X	X	X	X	X
Bam 2-5	X	X	X		X	X	X		
Bam 2-2	X	X	X	X	X	X	X	X	X
Bam 2-3	X	X	X	X	X	X	X	X	X
Bam 2-6	X			X					X
Bam 1-11	X	X	X	X	X	X	X	X	X
Bam 2-7	X	X	X	X	X	X	X		
Bam 2-11	X	X	X	X	X	X	X	X	X
Bam 2-8	X								
Bam 1-14									X
Bam 1-15								X	X
Bam 11-2									X
Bam 1-17								X	X
Bam 1-22								X	X
Bam 1-3									X
Bam 1-5									X
Bam 1-6								X	X
Bam 16-2									X
Bam 17-2								X	X
Bam 1-8								X	X
Total	10	7	7	8	8	8	7	12	18

The amplification of microsatellite regions in species of the same genus has been reported in plants such as cassava (Roa et. Al. 2000), in forest trees (Dayananda et al. 1997), and apparently is very common in the grasses. Indeed, within the subfamily Bambusoideae, Nayak & Rout (2005) also succeeded in amplifying 18 microsatellite regions in different species of the genus Bambusa. Marulanda et al. (2007) tested Single Sequences Repeats (SSR) in rice and sugarcane in different species of the Guadua genus, obtaining successful amplification of 37 of these sequences, which indicates the great genetic proximity between the genus in this family, as reported Ishii & McCouch (2000), Kresovich et al. (1995) and Zhao & Kochert (1992), who have identified sequences of rice capable of amplifying in different species of maize and bamboo.



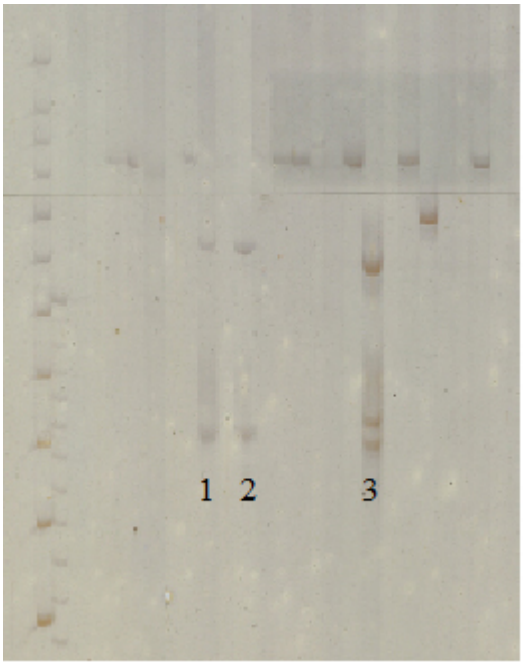


Figure 2. Viewing acrylamide gels at 4% for the identification of alleles of the loci A. Bam 2-13 and B. Bam 2-11 (Bambusa: 1, 2, 3)

This high conservation of microsatellite loci within the family Poaceae promotes the study of genetic variability in species where these markers have not been developed yet, since it would be possible to use these SSR sequences that have been evaluated, such as those obtained in this study , instead of making the whole process of design libraries, saving time and money. In turn, this would permit obtaining the knowledge of the genetic diversity in those species for which this area is unknown, as in the case of most bamboos. As a result, it is recommended to evaluate this new set of microsatellites in other species of the subfamily Bambusoideae.

Regarding the loci Bam 2-8 and Bam 2-11, although amplified in all species of Guadua and Bambusa they presented a profile of bands in acrylamide gels similar to those with a multilocus gene origin (Avise 1994). However, only the locus Bam 2-11 were achieved analyzable, consistent, and reproducible, bands in all the accessions studied (Figure 3). Nevertheless, it is recommended a further analysis of its primers design.

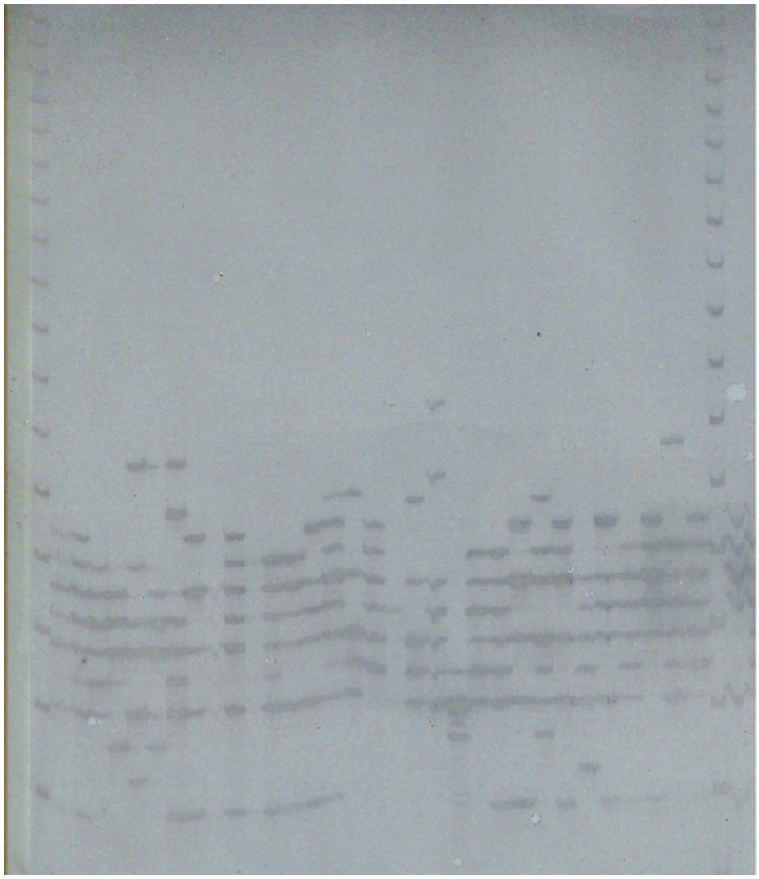


Figure 3. Perfil de bandas obtenidas con el locus Bam 2-11 en geles de acrilamida al 4%.

Evaluation of microsatellites

With the eight loci amplified in 46 accessions of *G. angustifolia*, 69 alleles were found in total, with an average of 8625 ± 3662 alleles per locus, ranging between 5 and 14 alleles and allelic richness averaged 7625 ± 3662 (Table 4). Three null alleles were obtained in the loci Bam 2-6, Bam 2-2 and Bam 2-7, one in each locus, respectively. With the Bam 2-11 locus, profiles were obtained in acrylamide from 5 to 9 bands per individual, with 20 alleles in the 46 accessions of *G. angustifolia*. On average, there were more heterozygotes than homozygotes in the eight loci. In the locus Bam 1-11, heterozygous individuals are not distinguished, while in the locus Bam 2-1, the majorities were it (Table 4).

The polymorphic information content (PIC) has been widely used as a descriptor of the degree of information that provides a site of the genome. PIC values above 0.5 indicate highly polymorphic loci, such as the loci 2-1 Bam, Bam 2-5, Bam 2-7, Bam 2-6 and Bam 1-11; informational medium values between those with 0.25 and 0.5, as were the loci Bam 2-13, Bam 2-2 and Bam 2-3 and informative little lower than the value 0.25. According to this descriptor, no loci were monomorphic for the 46 accessions of *G. angustifolia* and the most informative locus was Bam 2-6 with a PIC value of 0.8517 (Figure 4). However, this index came from studies in human genetics and the purpose of assessing the likelihood of being able to deduct from the genotype of an offspring, of which their parents had received a particular feature. Because of this, when wild populations are being studied in the absence or individuals without knowing their parents, this index is not the most desirable, also implies the absence of recombination.

Table 4. Descriptive estimators of genetic diversity obtained for 8 microsatellite systems evaluated in the accessions of *G. angustifolia*.

Locus	T anneling	High- Frecuency alleles		PIC value	Probability	A	A-1	ho	Ho	he	He
		Allele (bp)	Frecuency		Identity (I)						
Bam 2-1	50	232	0.2283±0.0619	0.8511	0.1082	14	13	0.0435	0.9565	0.1349	0.8843
Bam 2-13	54	228	0.7609±0.0629	0.3981	0.4134	11	10	0.5870	0.4130	0.5896	0.4196
Bam 2-5	48	254	0.2174±0.0608	0.6750	0.1269	13	12	0.4130	0.5870	0.2966	0.7191
Bam 2-2	54	500	0.6848±0.0685	0.4672	0.2871	5	4	0.6957	0.3043	0.5017	0.5094
Bam 2-3	48	166	0.7609±0.0629	0.3860	0.3730	6	5	0.6304	0.3696	0.5951	0.4139
Bam 2-6	50	152	0.1196±0.0478	0.8517	0.0334	9	8	0.8696	0.1304	0.1385	0.8807
Bam 1-11	54	437	0.6304±0.0712	0.5043	0.2480	6	5	10,000	0.0000	0.4518	0.5604
Bam 2-7	54	429	0.3913±0.0720	0.6294	0.1566	5	4	0.6522	0.3478	0.3103	0.7051
Total						69	61				
Average						8.625±3.662	7.625±3.662	0.611±0.290	0.389±0.290	0.377±0.185	0.6356±0.1894

Number of alleles per locus (A), allelic richness (A-1); observed homocigosity (ho), observed heterozygosity (Ho); expected homocigosity (I) Nei unbiased heterozygosity (He), polymorphic information content (PIC); probability of identity (I).

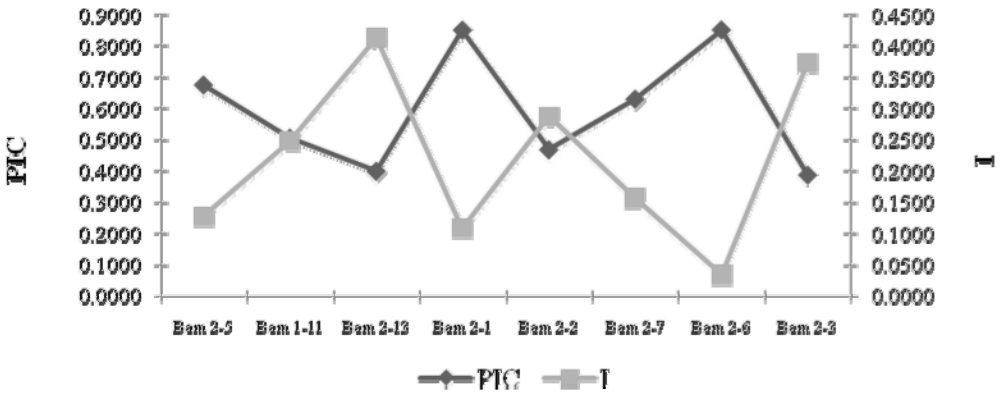


Figure 4. Comparison of the polymorphic information content (PIC) and probability of identity (I) obtained with eight loci in 46 accessions of *G. angustifolia*

The probability of identity (I) may be a better estimate of the degree of information of the genome of a site obtained by the SSR in populations, because it indicates how high is the probability of finding two individuals at random in the same locus in particular, and therefore that is so discriminating that site. Furthermore, it is not based on any postulate, but rather more a probability. Among lower the values of I are the most informative sites studied using microsatellites. According to this index, the locus Bam 2-6 is the most informative (0.0334), followed by Bam 2-1 (0.1082), and the least informative loci is Bam 2-13 (0.4134) (Figure 10). In turn, the combined probability of identity, evaluate how good is the set of all microsatellites for the diversity analysis, in this case, Ic was 7.882x10-07, indicating that the eight loci analyzed for 46 accessions *G. angustifolia* are sufficiently informative to study the genetic diversity in this bank.

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Occurrence of filamentous fungi on Brazilian giant bamboo

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Abstract

Bamboo has many economical and environmental advantages compared with other materials commonly employed in construction. However, bamboo is handicapped by the low natural durability of the most of species. According to optimal environmental conditions, several insects or fungi decay bamboo.

The aim of this research was to identify taxonomically some filamentous fungi that decay bamboo in contact with the soil. Fungi were collected from samples of bamboo strips expose to outdoor conditions. Isolated fungi were taxonomically characterized based on morphological and genetic (Amplified Ribosomal DNA Restriction Analysis-ARDRA) approaches.

Ten isolates of filamentous fungi were obtained. Data derived from ARDRA analyses showed the presence of seven different taxonomic groups (ribotypes). Based on microscopic and macroscopic analysis, fungi were identified as belonging to cellulolytic genera: *Arthrinium*, *Fusarium*, *Acremonium*-like and *Trichoderma*, and an unidentified isolate. As there was no fungal mycelial growth of green in samples of bamboo, *Trichoderma* sp. may have been originated from the proper soil. In addition, the fungus that was evaluated separately showed morphological characteristics similar to those of basidiomycete (Basydiomycota).

Introduction

In global terms, 40% of energy consumption and carbon emission in the world are caused by construction (Ferraz 2008). This situation is exacerbated by the use of native timber for building. According to Kageyama (1987), the deforestation of tropical rainforest may cause the extinction of entire species. The market preference by certain tropical woods because of its high quality, provoke its intensive use and became a serious problem, especially at Sao Paulo State, Brazil.

The solution to this problem involves the use of materials less harmful to the environment than that conventional ones. The possibility of applying bamboo, therefore, appears as an alternative to the tropical wood.

However, bamboo applications are hampered by the low natural durability of the most of specie. Decay caused by physical, chemical and biological agents associate bamboo as a low quality material, creating the false idea that bamboo should be employed only in the scarcity of most appropriate materials.

Fungi were considered plants for a long time. Unlike plants, fungi are heterotroph and do not have clorophyll or other photosynthetic pigment. Their cell walls are composed by chitin, cellulose does not, unless some aquatic fungi.

Fungi can decompose dead matter (saprotrophic) or obtain its nutrients from living organisms (parasitic), preferring simple carbohydrates, but may also use more complex sources, as starch and cellulose (Burton & Engelkirk 2005). Basidiomycetes fungi are the most responsible by decay materials composed by lignin and cellulose. This group is represented by mushroons, puffballs and bracket fungi, most of them known for its economic importance, provoking plant diseases, or acting as decomposers of organic matter and for its culinary potential. However, representatives of others fungi groups, such as ascomycetes are able to colonize and degrade lignocelullosic material (Sette et al. 2008).

According to Highley (1999), "fungus damage to wood may be concerned to three general causes: lack of suitable protective measures when wood storing, improper seasoning, storing, or handling of the raw material produced from the log and failure to take ordinary simple precautions in using the final product".

From the 1980's, many studies on the degradation of wood by fungi were performed. Auer et al. (1988) associated the monoculture of eucalyptus and the high incidence of fungi. Wood has great potential as building material since it is well applied to buildings and since they were well designed, constructed properly and adequately maintained. However, any of these aspects is often overlooked at the construction, allowing the attack of the decay agents, such insects and fungi (Nunes et al. 2000).

The objective of this research was to identify taxonomically some fungi that decay bamboo in contact to the soil. In a next step, intends to inoculate these fungi on bamboo, seeking to evaluate the effectiveness of some treatments applied to bamboo strips.

Materials and Methods

Figure 1 shows the flowchart of the steps undertaken during the development of this research.

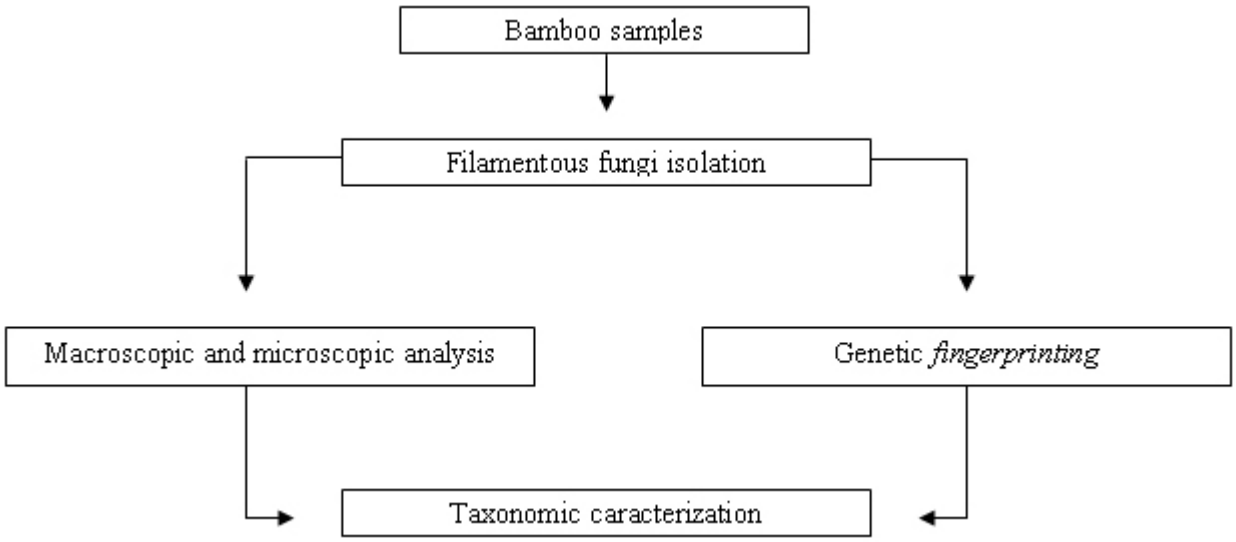

Figure 1 - Flowchart for the implementation of isolation and identification of fungi associated with bamboo.

Strips of 15 cm x 3 cm x 3 cm were obtained from a 5 years old culm of giant bamboo (*Dendrocalamus giganteus* Munro) Strips were exposed to an oxisol type, simulating the decay by wet soil fungi, allowing the colonization of several species (Figure 2).

Figure 2 – Aspect of bamboo strip after 15 days of exposition.

After 15 days of exposure, strips were numbered and delivered to Division of Microbial Resources (CPQBA/UNICAMP) for filamentous fungi isolating and identifying.

A visual inspection of the bamboo strips indicated the development of several fungi (Figure 3), wich were readily separated by the morphological characteristics of the colonies. Bamboo strips were washed with sterile distilled water to remove the soil and to isolate only the fungi associated with bamboo. Filamentous fungi were plated by swab technique on culture media MA2 (Malt Extract Agar 2%) and SDA (Sabouraud Dextrose Agar) added 300 mg/L riphampicin, antibiotic to prevent bacteria proliferation. The plates were incubated at laboratory temperature (28 ± 1 °C) for 15 days. Isolation of colonies was conducted daily and pure cultures were obtained after serial transfers on MA2 medium (Figure 4).

Figure 3 – Fungi spores (dark spots) and mycelia (white areas) infesting bamboo.

Figure 4 – Culture of bamboo-derived fungus grown in Petri dish.

The colonies were observed by stereoscope to the fungi identification. Microscope slides were prepared by scrubbing technique, stained with lactophenol cotton blue and visualized in optical microscope. These observations, using the morphological criteria determined by the literature, allowed the preliminary identification of some genera. The identification of species requires molecular techniques (sequencing and phylogenetic analyses) and additional macro and microscopic analyses.

Isolates were subjected to ARDRA analyses (Amplified Ribosomal DNA Restriction Analysis) to identify possible different taxonomic groups. Filamentous fungi were cultured on MA2 medium and after culture growth, genomic DNA extraction was performed according to Raeder & Broda (1985). The 28S rRNA D1/D2 region of the filamentous fungi were amplified from genomic DNA by Polymerase Chain Reaction (PCR) using the following set of primers, NL-1m (5' GCA TAT CAA TAA GCG GAG GAA AAG 3') and NL-4m (5' GGT CCG TGT TTC AAG ACG 3'). PCRs were performed according to Sette et al. (2006). PCR products were digested using the restriction enzymes *Msp*I, *Hha*I, *Hae*III and AluI (GE Healthcare). Restriction reactions were carried out in 2h at 37 °C and the electrophoresis were performed on a 2.5% agarose gel, with a 100-bp DNA ladder, for 2.5h at 230 V.

In addition to the filamentous fungi that have developed in bamboo, it was obtained a fungus fruit body, probably a basidiomycete, from one sample of decayed bamboo.

Results and Discussion

From two bamboo samples, ten isolates of filamentous fungi were identified, based on microscopic and macroscopic analysis, as belonging to the genera: *Arthrinium* (F1, F2, F4, F8, F9 e F10), *Fusarium* (F3), *Acremonium*-like (F5) and *Trichoderma* (F6), and an unidentified isolate (F7) (Table 1). In addition, the fungus that was evaluated separately from a decayed bamboo (F11) showed morphological characteristics similar to those of basidiomycete (Basydiomycota), a well known lignocelullolytic degraded group of fungi.

Table 1 - Data from the morphological characterization and genetic fingerprinting.

Isolates	*Hae*III	*Msp*I	*Hha*I	*Alu*I	Ribotypes	Morphologic id.
F1	A	A	A	A	1	*Arthrinium* sp.
F2	A	A	A	A	1	*Arthrinium* sp.
F4	A	B	A	A	1A	*Arthrinium* sp.
F8	A	A	A	A	1	*Arthrinium* sp.
F9	A	B	A	A	1A	*Arthrinium* sp.
F10	A	A	A	A	1	*Arthrinium* sp.
F3	B	C	B	B	2	*Fusarium* sp.
F5	A	B	C	C	3	*Acremonium*-like
F6	C	D	D	C	4	*Trichoderma* sp
F7	D	E	E	D	5	NI*
F11	A	F	F	C	6	NI*

NI * Non identified.

According to Morakotkam et al. (2007), *Arthrinium* (Xylariales) are a dominant genus in bamboos. Representatives of this genus and its telemorph (*Apiospora*) have been reported as fungi associated with bamboo from New Zealand and Japan (Morakotkam et al. 2007). The genus *Fusarium* (Hypocreales) were also reported as fungal associated with bamboo plants (Hino & Katumoto 1961; Morakotkam et al. 2007). *Arthrinium* and *Fusarium* are soil-inhabiting fungi that could be found in decomposing plant material. Both are cellulolytic, but this activity for *Arthrinium* is rarely reported. *Fusarium* and its anamorph *Giberella* have been isolated from many plants and cause some plant diseases (Rubini et al. 2005).

There are no data in the consulted literature concerning *Acremonium* (anamorphic fungi) and *Trichoderma* (Hypocreales) derived from bamboo samples. As there was no fungal mycelial growth of green in samples of bamboo in the present study, *Trichoderma* sp. (F6) may have been obtained from the proper soil where the bamboo was removed. It is worth to mention that representatives of *Trichoderma* and *Acremonium* are very common in soil and are also able to produce cellulolytic enzymes, which are responsible for cellulose degradation (Nakari-Setälä & Petillä 1995; Stemberg 2004; Ikeda et al. 2007).

Some of isolated fungi showed morphological features very similar and to verify the genetic diversity (polymorphism) of them ARDRA analyses were carried out (Figure 5 and Figure 6). The band pattern (ribotype) generated by enzymatic digestion allowed the differentiation of taxonomic groups previously obtained by conventional taxonomy. Seven different ribotypes were obtained: ribotype 1, 1A, 2, 3, 4, 5 and 6 (Table 1).

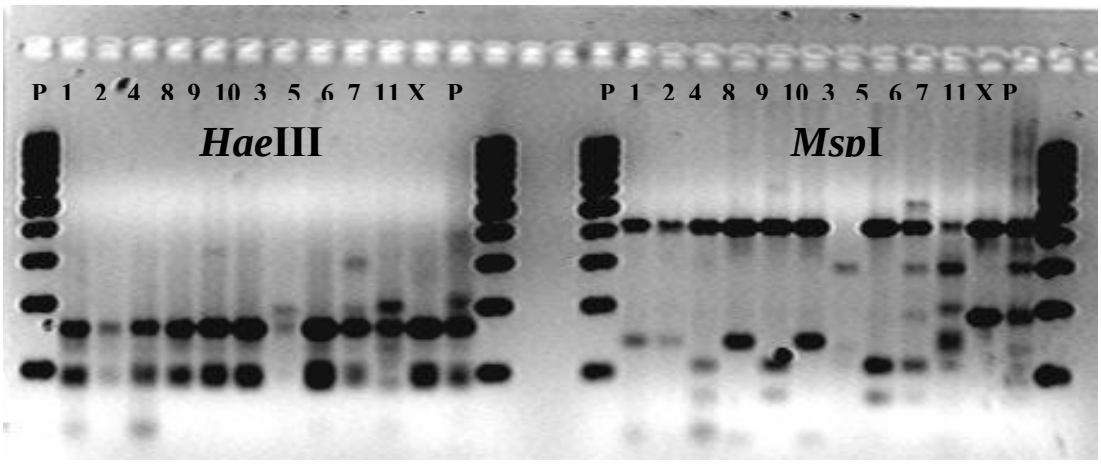

Figure 5 – Restriction profile from the eleven isolateds after digestion with the *Hae*III and *Msp*I enzymes. The numbering at the top of the figure represents the fungi order of application on the agarose gel. P = Standard molecular weight (1kb). X = Sample to be disregarded because it is not part of this project.

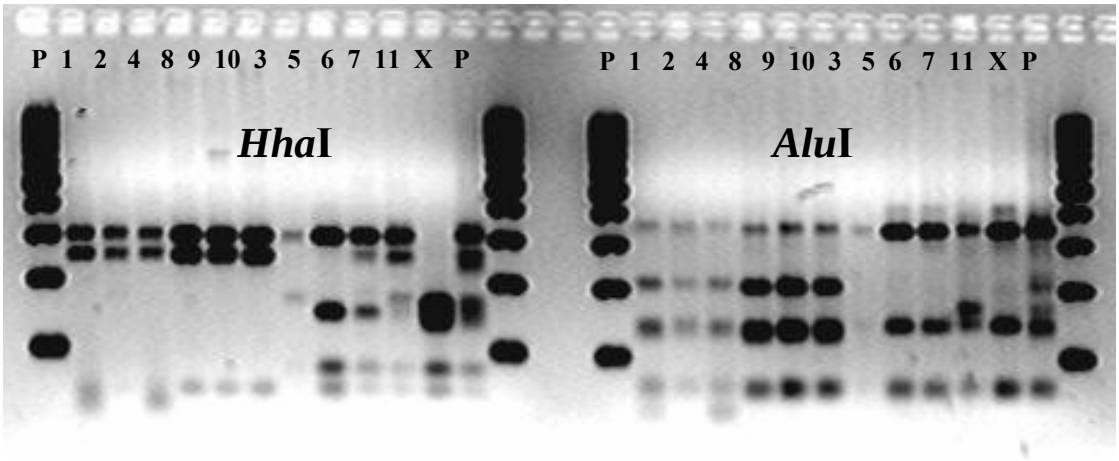

Figure 6 – Restriction profile from the eleven isolateds after digestion with the *Hha*I and *Alu*I enzymes. The numbering at the top of the figure represents the fungi order of application on the agarose gel. P = Standard molecular weight (1kb). X = Sample to be disregarded because it is not part of this project.

Ribotypes 1 and 1A showed little difference in the restriction profile when *Msp*I enzyme was used. As both isolates showed morphological (macroscopical and microscopical) characteristics similar to the genus *Arthrinium*, the polymorphism may not be representative or may indicate strains of different species.

On the other isolates, the results of ARDRA corroborated the morphological analysis, since the fungi showed different restriction profiles and were classified morphologically as belonging to different genera. The isolated fungi unidentified by conventional taxonomy (F7 and F11) showed morphological characteristics and restriction profile different from the others, suggesting that it should belong to different filamentous fungi genera.

Aiming at a more accurate identification of different ribotypes obtained in this work, as well as the identification of ribotypes F7 and F11 (not identified by conventional taxonomy), further studies of sequencing and comparative analysis should be performed.

Conclusions

Although a definitive taxonomic assignment of the fungi isolated and characterized in this study was not always possible, these data present an emerging view of filamentous fungi from Brazilian bamboo samples, since, to our knowledge, there were no previous reports on fungi isolated from bamboo in Brazil. Based on the literature, the genera *Arthrinium* and *Fusarium* have been reported as fungi associated with bamboo in other countries. However, it is important to highlight that it is the first report concerning *Acremonium* from bamboo samples.

The occurrence of cellulolytic fungi in bamboo was expected, since these fungi are able to use the bamboo cellulose as carbon source. The filamentous fungi isolated in the present study will be deposited in the Brazilian Collection of Environmental and Industrial Microorganisms (CBMAI) for further research on effectiveness of some treatments applied to bamboo strips against these cellulolytic filamentous fungi.

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Consideration of the flowering periodicity of *Melocanna baccifera* through past records and recent flowering with a 48-year interval

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Abstract

The gregarious flowering of *Melocanna baccifera* has been recorded in its native area mainly since 2003 and this period of dynamic flowering is now coming to an end. For over 100 years, the flowering periodicity of the species has been estimated by many researchers as being in the vicinity of 30 – 45 years. However, local information from the author's detailed interviews with farmers in the Mizoram area of northeast India indicates that a more accurate estimation is 48-year. Based on this estimation, the author and his colleagues conducted important ecological research on the flowering and fruiting process in this area, while flowering information for 2008 was obtained from Taiwan and that for 2009 from Japan. These two data sets present accurate records of the last fruiting year, and flowering occurred as expected in the 48th year after seeding. This outcome suggests that understanding the true flowering periodicity of bamboo requires the monitoring of seedling with accurate fruiting data in addition to vegetative information.

Introduction

For more than 100 years, bamboo researchers have been interested in estimating the flowering periodicity of bamboo (cf. Seifriz 1923; Raizada & Chatterjii 1956; McClure 1966; Janzen 1976). Although bamboo flowering is gregarious and synchronized in many cases, its prediction is exceptionally hard work because of the very long flowering periodicity involved. This also means that it is difficult for a single researcher to carry out observation of bamboo flowering and confirm its periodicity.

Bamboo flowering is mainly classified into the two types of gregarious and sporadic flowering. Many cases of sporadic flowering are seen, but, its exact definition is not clear. Some such flowering occurs in small-scale vegetation and is even seen in parts of the culm. Although the relationship between the flowering periodicity and simultaneousness remains unclear, it is currently considered that gregarious flowering with periodicity usually occurs simultaneously. In the past many triggers for flowering have been discussed, including drought, burning, trimming, disease (Hori 1911), transplant and injury (Seifriz 1923). However, at present, the flowering for these reasons is regarded as a different physiological occurrence from the gregarious and simultaneous phenomenon brought about by the biological clock.

Gregarious flowering of bamboo results in the death of the parent population, and this occurrence has long been recognized as continuing for several years as whole in tropical areas. In Japan, the flowering of *Phyllostachys bambusoides* was reported in around 1970, and continued for about ten years (Kasahara 1971). Similarly, the recent flowering of *Sasa veitchii* var. *hirsuta* recorded near Kyoto city continued over a period of four years (Abe & Shibata 2007).

Melocanna baccifera is a species that has extensive past flowering records. The form of its characteristic fruit and the culm neck are worth noticing, and the first taxonomical records of this species also refer to these points naturally (Roxburgh 1814). Its flowering periodicity has been estimated many times, but, as the distinction between sporadic flowering and gregarious or extensive flowering was insufficient, these estimations can be considered capricious. The reason for this problem is a lack of surveys on flowering vegetation from seedling stage. *M. baccifera* flowered gregariously in 2005 – 2008 in its native region, with the flowering area reaching up to several tens of thousands of square kilometers. Ecological research in this native area by the author and his colleagues revealed that sporadic flowering occurs one year before and after gregarious flowering, and that the area covered by gregarious flowering moves from the northeast to the southwest over a period of several years. This has also been noted in Bangladesh by Alam (2008).

In relation to the recent flowering, some flowering records derived from fruits taken from native areas during the last flowering are being collected. These examples include cases reported from Japan and Taiwan, where seedlings are maintained in a pure condition without being mixed with other seedlings. These plants clearly flowered in the 48th year after seeding. Referring to these examples, the author use this paper to consider the relevant points in order to gain an accurate understanding of *M. baccifera*, and in turn, its flowering periodicity, and re-inspects the past flowering records of this species.

Flowering records of *M. baccifera* seedlings with a 48-year interval

In Japan the flowering of *M. baccifera* was observed in May, 2009. The plantation in question is derived from a seeding brought in 1961 by Koichiro Ueda, who was performing a bamboo resource survey, from what is now Bangladesh (former East Pakistan) (Ueda 1968) to the former Shirahama Experimental Station of the Field Science Education and Research Center at Kyoto University. In those days Ueda was the only Japanese person to have visited East Pakistan, so it is clear that the flowering periodicity of the species is 48 years, at least, for the genealogy he brought into Japan.

In Taiwan, flowering was recorded in 2008. Lu (2009) reported that the flowering plantations in question were derived from two seedlings introduced from a group of 58 from USA through USDA, which collected fruits in Puerto Rico from a fruiting plantation in 1960 after the flowering of 1959. This flowering record also supports the estimation that the species flowers every 48 years.

Flowering records of *M. baccifera* in the past reports

There are many bamboo flowering records in the world, but it is thought that the reports recorded by observers themselves are rare, especially for tropical bamboo species. In the case of *M. baccifera*, the first record by

Roxburgh (1814) and even that of Staff (1904) noting the detail of the fruit shape and inflorescence were not observed directly in the native flowering area. Most past records are simply general descriptions formulated by referring to lots of information from native areas.

Although the accuracy of these data resources is uncertain, in Mizoram, India, records provided by the state government indicate gregarious flowering in 1815, 1863, 1911 and 1958 – 1959. In this information supplied on the website of International Network of Bamboo and Rattan (http://www.bambootech.org/), the oldest flowering record is from 1815. This information is not enough to rely on because the records it is based on are unknown, and the recorded year is similar to that of the first notification of this species. However, there is still the possibility of pinpointing this flowering occurrence from the record of Brandis referred to by Blatter (1929), which reported flowering at Chittagong, Bangladesh, in 1811 without consideration of whether it was gregarious flowering or not (Table 1). Below, the author introduces past flowering records according to information from the Mizoram state government based on the supposition of a 48-year flowering interval.

The next flowering records after those of 1815 are based on Munro (1868), who recorded flowering in 1864 – 1865 in Arracan. Riviere & Riviere (1878) also recorded flowering for similar years in present-day Bangladesh and reported a scarcity of bamboo timber resulting from the death of bamboo forest following the flowering. Staff (1904) noted that the flowering area covered about 6,000 square miles. All flowering records from the 19th century after Munro referred to his records (Gamble 1896; Brandis 1899). For subsequent flowering, we see an occurrence in 1901 – 1902 in the Chittagong area of what is now Bangladesh from reporting on fruit and inflorescence by Staff (1904). Although this flowering does not fit the 48-year interval, it is estimated that the area it covered was relatively large.

The next gregarious flowering, thought to have occurred in 1911, can be understood from the reporting of Troup (1921) in Chittagong and the Arakan mountains as referred to by Blatter (1929, 1930a, 1930b) (Table 1), followed by the reports of Parry (1931) in Assam, India and Hossain (1962) in the former East Pakistan as referred to by Janzen (1976) (Table 2). Camus (1913) did not mention this flowering despite publishing in the same year. Concerning Mizoram, India there are two mentions of the flowering in 1911 by Rokhuma (1988) and in 1911 – 1912 by Thanchuanga (2004). On the other hand Janzen (1976) did not refer to the three intimate records of Blatter (1929, 1930a, 1930b). As a result it seems that there was gregarious flowering around 1911 from Bangladesh to Myanmar through northeast India.

There are many records of the last gregarious flowering from the latter half of the 1950s to the beginning of the 1960s. I has already been mentioned that Ueda also came across this flowering in Bangladesh in 1961 as the first Japanese person there (Ueda 1968). Janzen (1976) referred to two records: the flowering in 1960 at Mizoram, and that in 1958 – 1959 at Chittagong (Table 2). In Mizoram, Rokhuma (1988) recorded flowering in 1958 – 1959, and Thanchuanga (2004) in 1959 – 1960. In addition to these, there is another flowering report for 1957 – 1960 by Rain Forest Research Institute of Jorhat in Assam (2003). Alam (2008) noted that gregarious flowering in the Chittagong area of Bangladesh occurred in 1960 – 1961 after a period of sporadic flowering from 1952 to 1958 or 1959 and that this occurrence covered an estimated area of 1,000 square miles.

Although many flowering reports exist, they are inadequate for detailed consideration of flowering periodicity because they lack important information such as whether the flowering of all vegetation was seen or not.

Specifically, many flowering records for *M. baccifera* do not offer enough information to allow estimation of the true flowering periodicity. In addition to this, we need to understand the flowering phenology by which the species flowers at the end of the year and fruiting is seen in the following year. This means that the recorded year in past records is that of fruiting rather than that of fruiting. In the temperate zone, however, the timing of flowering tends to be delayed, and the flowering year becomes the same as the fruiting year.

There are also many flowering records for *M. baccifera* outside the 48-year interval for flowering. This kind of flowering was recorded in 1801, 1849, 1889, 1892 and 1900 – 1902 by Staff (1904). As shown in Table 1 Blatter (1929) also noted flowering in 1889, 1892, 1900 – 1902 and 1904 – 1905. In addition to these records Nath (1968) reported flowering in 1967 at Manipur, India, and Alam (2008) reported an instance in 1901 – 1905 in Chittagong, Bangladesh. However, it is not possible to ascertain whether the flowering in these records is gregarious or otherwise.

Flowering reports of *M. baccifera* outside its native area

M. baccifera has been recognized as a useful resource of bamboo timber and food, which has prompted planting around the world outside its native area. Instances of planting are especially high in regions that neighbor the native area, such as India and Nepal. One flowering report from Blatter (1929) comes from the records of the botanic garden in Kolkata. This kind of reporting is found for many places. McClure (1966) reported the flowering and fruiting of plantation in Jamaica and Puerto Rico in 1957 and 1958 (a flowering record that matches the 48-year interval) as well as flowering in Honolulu in 1948 and 1949. Furthermore, flowering in 1990 in northern Queensland, Australia (Poudyal 2006) and in 2003 at a Sri Lanka plantation introduced in 1910 (possibly introduced with fruit) (Ramanayale & Weerawardene 2003) are recorded.

Past discussion on the flowering periodicity of *M. baccifera*

Since the end of the 19th century, many estimations concerning the flowering periodicity of *M. baccifera* have been suggested. However, the quantity of records available has been insufficient except for those after the last flowering around 1960. The first reference to flowering periodicity is thought to have been made by Kurz in 1876 (Gamble 1896). This estimation was based on flowering records for Arakan (Staff 1904) and was 30 years. Brandis (1899) also referred to the observation of Gamble. Staff referred to Kurz's estimation but also noted that the information was insufficient for full discussion. Blatter (1929) introduced two estimations of 30 years from Kurz (1876) and 45 years from Troup (1921). Blatter (1930a) also pointed out that regular flowering periodicity is difficult to find when the interval of all flowering records over a broad area are dealt with on the same level, and induced the need to distinguish the "extensive flowering" and "gregarious flowering". He also noted that the periodicity estimated only from "gregarious flowering" is around 50 years. On the other hand McClure (1966) made reference only to past estimations and the introduction of a gardener's estimation in Jamaica of an approximately 60-year periodicity. Godesberg (1969) proposed an estimation of 45 years.

Janzen (1976) referred to the flowering records of the species from two areas in India and one area in present-day Bangladesh (Table 2). His discussion offered no definite estimate of the flowering interval in these three areas and as a result it was impossible to estimate flowering periodicity as a species. He indicated some

estimated periodicity as 7 – 10 years, 26 – 30 years, 27 years, 31 – 33 years, 42 – 49 years, 47 – 49 years and 46 – 51 years by the simple calculation. In recent years there are some estimations such as 40 – 45 years by Seethalakshmi et. al (1996), and 48 – 50 years as well as 40 – 47 years by Banik (1998) based on records from Mizoram, India and from northeastern Bangladesh, respectively. In addition, Rao et. al (1998) noted three periodicities of 30 – 35 years, 45 – 48 years and 60 – 65 years. On the other hand Alam (2008) estimated the flowering periodicity in Chittagong Hill Tracts, Bangladesh as 50±5 years.

As outlined above, the flowering periodicity of *M. baccifera* was previously estimated as between 30 and 45 years. In more recent years, other periodicity estimations of around 50 and 60 years have been presented. However, no exact estimation matching the 48-year periodicity referred to here is found.

Discussion – Requirements for understanding the true flowering periodicity of bamboo

The flowering periodicity of bamboo differs by species, and seems to have a shorter tendency for those mentioned tropical area. On the other hand the periodicity in temperate bamboo species longer and in Japan is commonly said to be either 60 or 120 years. In this country, there have been ongoing trials to identify the true bamboo flowering periodicity of bamboo since the 19th century, and two flowering records have been obtained for *Phyllostachys pubescens* with a 67-year interval after seeding (Watanabe et. al 1982; Shibata 2002).

The flowering periodicity of *M. baccifera* has recently prompted detailed discussion, e.g., Alam (2008). However, as past flowering records for the species do not seem to be based on first-person observation at flowering sites, it is difficult to conclude that the reporters understood the true ecological process of flowering in detail. According to the author and his colleagues' ecological research at Sairang in India's Mizoram area, sporadic flowerings on a small scale has been observed one year before and after gregarious flowering. If we look at this three-year flowering phenomenon on the same level, while the overall flowering area moves from the northeast to the southwest, the overall flowering period can be understood as 8 – 10 years.

The flowering of bamboo is observed on various scales. In the case of *M. baccifera*, this scale is very large. In its vegetation area, non-flowering bamboo groves (called Mauhawk in Mizoram) and shifted-flowering bamboo groves may be mixed in with gregarious flowering bamboo vegetation. These groves should not be confused with the three-year flowering period that including gregarious flowering in the second year as mentioned above. It is clear that this kind of confusion will hinder the process of understanding bamboo's actual flowering periodicity. It is important to pinpoint the real year of gregarious flowering year by omitting the small-scale flowering that takes place before and after it and extracting the true flowering periodicity and flowering year.

The area of gregarious flowering for *M. baccifera* is unique. The phenomenon transits over a period of four yearscovering an area of more than 10,000 square kilometers annually in the whole of the native area. This is a dramatic vegetation change that can be seen from space. It is clear and relevant that the factor behind this phenomenon is slash-and-burning agriculture implemented by farmers.

Conclusion

The results obtained from research in Mizoram, India show that the flowering of this species clearly occurs every 48 years on a large scale. However, the transition of the flowering area over a period of several years – referred to as "the flowering wave" (Alam 2008) – skews information that would enable identification of the true flowering periodicity. To obtain the true vakue, it is necessary to carry out detailed ecological research at the flowering sites.

The estimation of a 48-year flowering periodicity for *M. baccifera* was supported by ecological research in Mizoram, India and by flowering records from Japan and Taiwan on 2008 and 2009. To confirm the true flowering periodicity of bamboo, the growth of bamboo plantations needs to be accurately monitored from the seedling stage to the flowering stage.

This research was supported by Grant-in-aid for scientific research (A) from Japan's MEXT (No. 17255007; representative: Shibata).

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http://www.bambootech.org/ National Mission on Bamboo Applications, India 2009/02/20

Table 1. Flowering records of *Melocanna baccifera* in Blatter(1929)

Flowering year	Reporter	Flowering area	Flowering type and remarks
1811	Brandis	Chittagong	?
1863 – 1866	Gamble	Chittagong, Arakan.	Gregarious flowering
		Bot.G.Calcutta	?
1889	Gamble	Garo and Khasia Hills	Gregarious flowering
1892	Troup	Assam	Gregarious flowering
1900 & 1902	Troup	Garo and Khasia Hills	Gregarious flowering
1901 & 1902	Troup	Chittagong, Arakan	Flowering in limited area
1904 & 1905	Troup	Chittagong, Arakan	Flowering in limited area
1908 – 1912	Troup	Chittagong	Extension of flowering area
1909 – 1910	H. de L.	Calcutta Bot. G. (cultivated)	□
1910 – 1913	Troup	Arakan	Extension of flowering area in 1912-1913 to the eastearn area of Yoma
1910 – 1911	Troup	Silhet (Assam)	Gregarious floweirng
1911 – 1912	Troup	Garo Hills, Cachar, Sylhet, Lushai Hills (Assam)	Gregarious flowering
1912 – 1913	Troup	Bamonpokri plantation(Kurseong)	?
1915 – 1916	Troup	Arakan	Gregarious flowering

Table 2. Flowering records of *Melocanna baccifera* in Janzen(1976)

(Figures in parentheses represent the year after the last recorded flowering)

Flowering area	Flowering year and related reports on flowering periodicity
Mizo Hills, Assam	1863 – 66, 1892 – 93(26 – 30), 1900 – 02(7 – 10), 1933(31 – 33), 1960(27) from Chatterjii(1960)
Lushai Hills, Assam	1864, 1911 – 12(47 – 48) from Parry.(1931)
Chittagong, East Pakistan	1863 – 66, 1908 – 12(42 – 49), 1958 – 59(46 – 51) from Hossain(1962)

Gregarious flowering of *Melocanna baccifera* around north east India
Extraction of the flowering event by using satellite image data

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Abstract

For the identification and mapping of the gregarious flowering area of *Melocanna baccifera*, the most common bamboo species ranged from Myanmar to Bangladesh, an object-based land cover classification was conducted for a QuickBird image covering 1.5km^2. The segmentation of the image well corresponded with the actual land cover, and the bamboo flowering area was successfully extracted. The method is expected to be applicable to the low resolution satellite images covering the larger spatial scales, and to enable the visualization of the geographical sequential flowering pattern of the bamboo from east to west in its distribution range.

Keywords: bamboo flowering, *Melocanna baccifera*, remote sensing, QuickBird, object-based classification, Mizoram,

Introduction

Melocannna.baccifera is distributed in North east India, Myanmar, and Bangladesh (Alam 1995). From past study, it flowered in 1765, 1815, 1863, 1911, and 1959 in Mizoram State, showing 48 years interval. As predicted from the interval, *M. baccifera* flowered in 2006 to 2007 around Aizawl, the capital of Mizoram state. Flowering started from November 2006, and bamboo clumps died and defoliation started from January 2007. In February seeds were grown up on the bamboo and seeds fallen in May 2007. Then seed emerged in rainy season started from June 2007.

In Mizoram, the shifting cultivation is most common cropping system until now. The quick regeneration from the rhizome after the slush-and-burn cropping preferred *M. baccifera* and the bamboo has increased with expanding shifting-cultivation. Mizoram state has an area of 21,081km^2 and half of it is covered by bamboo forest of which *M. baccifera* stands account for 90% area (Report on Bamboo Resources Inventory). The death of *M. baccifera* after gregarious flowering, therefore, had catastrophic impact on the agriculture, local vegetation and human society. In past flowering events, rats consumed bamboo seeds and increased explosively, then, they shifted their food source to agricultural products, mainly rice. Therefore serious famine has been repeated in 48 years cycle. In 2008, the serious decrease of rice production was also reported.

The bamboo ranged from Myanmar to Bangladesh and actually flowering started from eastern part of their distribution range and flowering area moved to west. The last flowering event started probably from 2005 in the eastern part such as Myanmar and flowering in Bangladesh confirmed in 2009. Even though it is clear that this flowering event occurred in vast area, probably several tens of thousands km^2, exact flowering range in each year has not yet been clarified and flowering wave from east to west also has not yet been visualized. Accurate identification of geographical range of flowering event during successive gregarious flowering of *M. baccifera* is quite important to understanding the ecology of *M. baccifera* and making counter measure for the catastrophic damage to the society and local people.

We challenge the problem using remote-sensing technique. Our ultimate purpose is to clarify the flowering sequence of the bamboo in geographical scale. In this paper, we report the methodology to identify the flowering area in satellite images.

Research site

This study focused on Mamit in Mizoram, India (Fig.1) where we have continuously monitored the flowering and regeneration process of the bamboo. Main form of agriculture in research site is shifting-cultivation called as 'Jhum' in local and most of fallow stands consists of *M. baccifera*. Around Mamit, flowering started in 2008.

Satellite image analysis

In order to extract flowering area of *M.baccifera*, land cover classification map was made from satellite image taken by QuickBird satellite (Digital Globe). The image covered 1.5km^2 and was taken on January 25, 2009 (Fig.2) when inflorescence was made already and most bamboo leaves turned brown and easily distinguished by the other vegetation or non-flowered bamboo stand. Resolution of QuickBird is 2.5m (multispectral) or 0.6m (panchromatic) and it enables the precise mapping of flowering area.

For image analysis, ENVI 4.5 and IDL 6.0 (ITT Visual Information Solutions) were used. Object-based classification method was carried out for mapping ground cover. In the object-based classification, DN (digital number) of pixels and shade pattern were analyzed. In addition to these data, size of object and pattern of texture are considered in classification. An extension tool of ENVI 4.5, Feature extraction was used for the classification.

Result and discussion

Fig. 3 is classification map obtained by the object-based classification of the area shown by Fig. 2. In the study site, fallow lands of various ages make a patch mosaic pattern. Such a small scale mosaic pattern was successfully visualized by the segmentation map. The segmentation map was then subjected to supervised classification based on ground truth data. In Fig. 4, the extracted flowering area of *M. baccifera* obtained by the classification was shown.

Thus the use of high resolution satellite image can successfully identify the flowering area of the bamboo successfully. The object-based classification method was quite powerful for our purpose. However to identify the flowering area of each year in a successive flowering event in large spatial scale ranging from Myanmar to Bangladesh, low resolution images taken with high frequency and covered large area must be used. The current results using QuickBird image will be utilized for the development and validation of the analyses using low resolution images.

Acknowledgement

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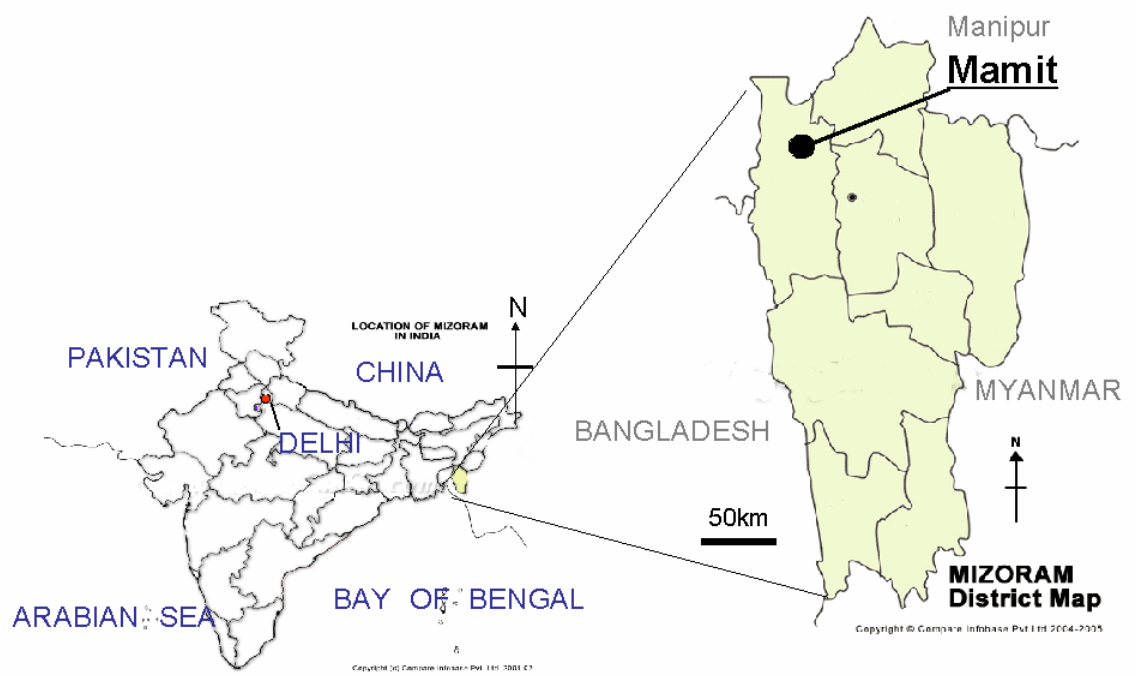

Fig. 1. Maps showing the research site in Mizoram, India.

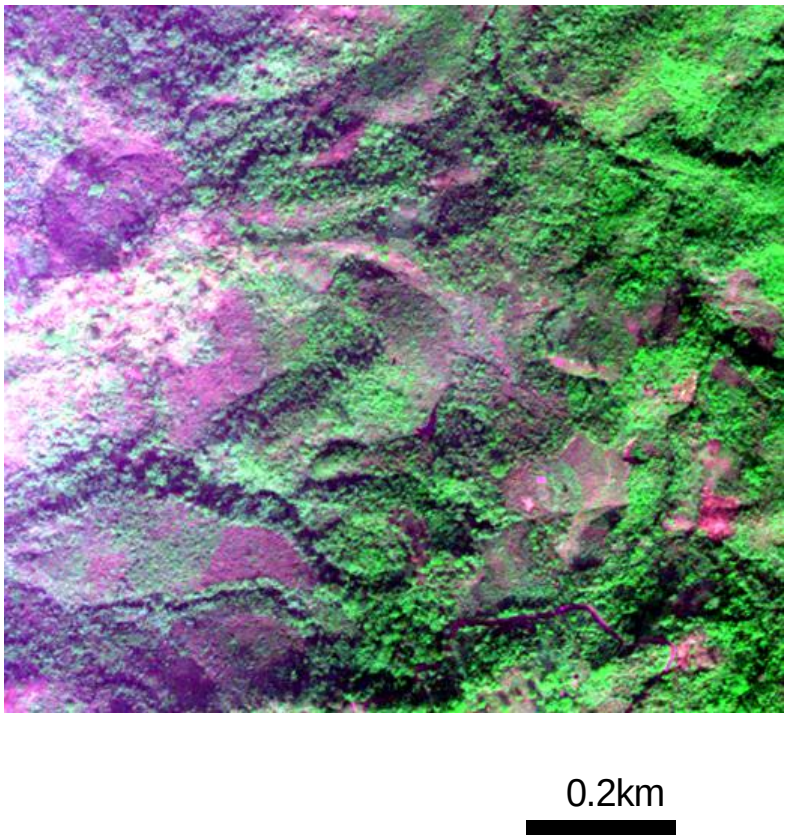

Fig. 2. QuickBird image of Mamit study site.

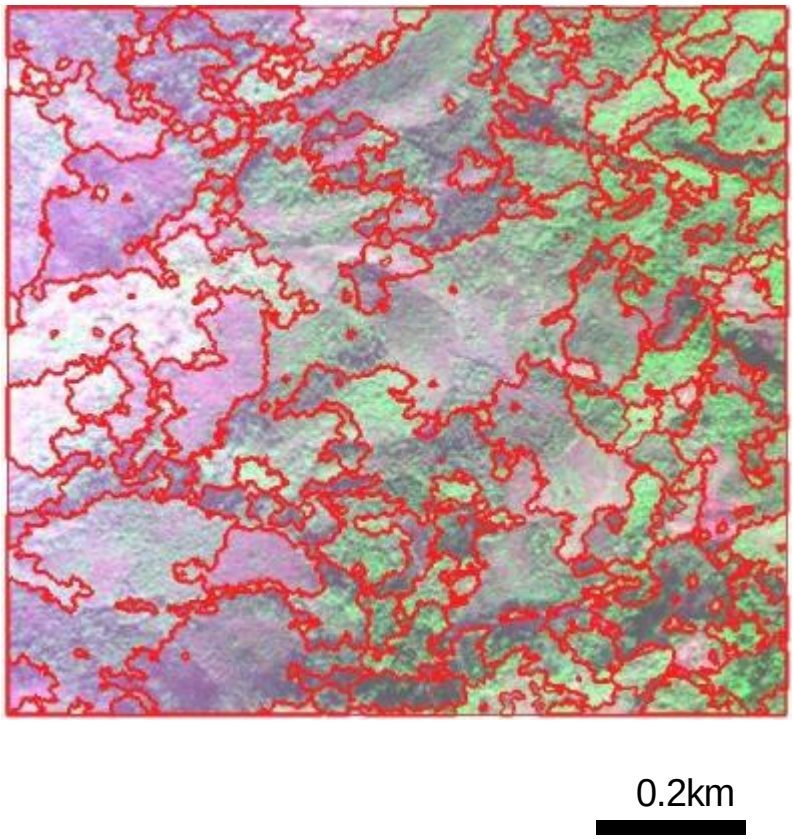

Fig. 3. Image segmentation in study area. Lines are borders of segmented objects.

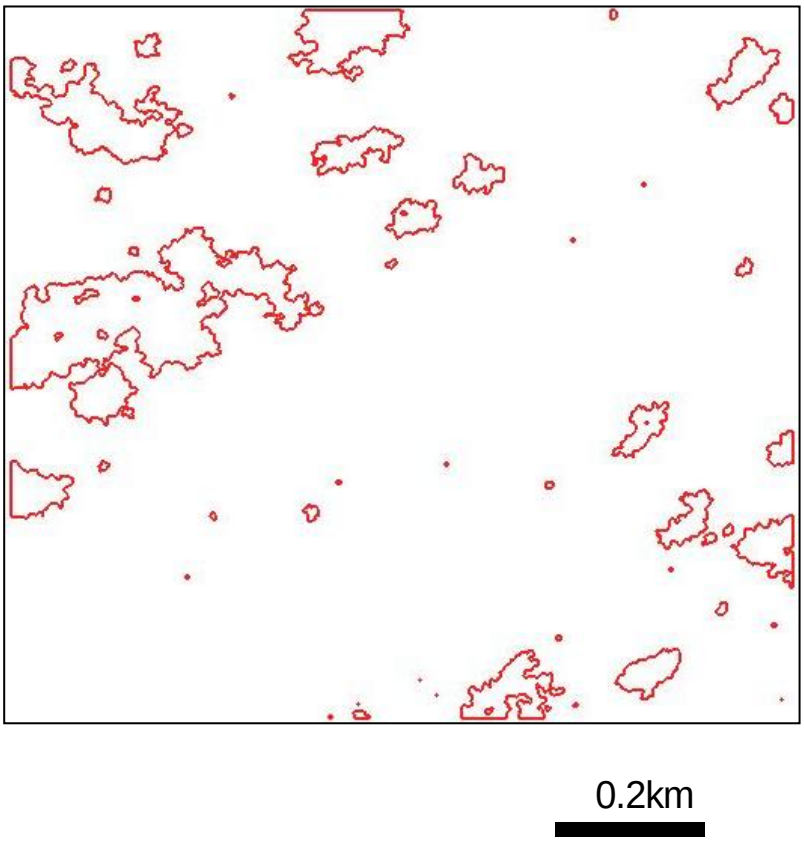

Fig.4 Extracrted bamboo flowering area

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Preface

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Founding President, European Bamboo Society.
General Manager, « Bambuparque » ~ a bamboo nursery in Portugal (60 ha. of bamboo/ 1 million of potted plants)

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B.S. Landscape Horticulture, Nursery Management
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Past-President and Honorary Lifetime Member, American Bamboo Society
Founding member and C.E.O., World Bamboo Organization

Research on bamboo has made enormous progress these last 20 years, stimulated by the increasing demand of poles for industry, construction, handicraft... and also by the new methods of investigation. But we all agree that there is still so much to discover that we can consider ourselves to be just at the beginning.

We are not going to point out to you the value of this meeting, your presence shows you don't need to be convinced. We will speak briefly about the World Bamboo Organization's mission which is: "To promote and support the use of bamboo as a sustainable and alternative natural resource through the development of partnerships and alliances, and the creation of mechanisms for global communication, information exchange and technology transfer."

The papers that will be presented here on the biology, cytology, physiology, embryology and so on, are of substantial scientific interest. Science has contributed to the tremendous progress we know. Presently however, we should not forget the disastrous consequences of some scientific discoveries. Of course it's not the discoveries that are to blame, but the way they have been used.

If we do not know how to propagate, grow and cultivate bamboo, the threat diminishing bamboo resources will prevail.

Let us continue going forward, there is still a long way to go, but let us take care to keep in mind the fragile balance of our planet. François Rabelais, a French writer warned us 500 years ago when he wrote: "Science without conscience is nothing but ruin of the soul". Let us never forget.

Micropropagation Protocol for *Melocanna baccifera* using Nodal Explants from Mature Clump

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Abstract

A complete protocol for micropropagation of *Melocanna baccifera* using nodal segments from mature clumps is described. Single nodal segments collected from the 18 years old clumps were pretreated with a mixture of fungicide bavistin and bactericide streptomycin, followed by surface disinfection with 0.1% $HgCl_2$ solution for 10-12 min., and inoculated on liquid Murashige and Skoog (MS) medium supplemented with cytokinin. Highest bud break with multiple shoots was obtained on liquid MS medium supplemented with 20µM 6-benzylaminopurine (BAP). *In vitro* differentiated shoots were further multiplied on liquid MS medium supplemented with 15µM BAP and 3µM 6-furfurylaminopurine (Kn) at a rate of 2.99 folds, every 4 weeks. Nearly sixty five percent of *in vitro* shoots were rooted on half-strength MS medium supplemented with 25µM indole-3-butyric acid (IBA). Later on *in vitro* raised plantlets were hardened and acclimatized.

Keywords: *Melocanna baccifera*; bamboo; micropropagation; tissue culture.

Introduction

Melocanna baccifera (Roxb.) Kurz commonly known as 'muli' is an important bamboo from South East Asia, distributed chiefly in the Northeast India, Bangladesh and Myanmar region. The culms are thin walled with long internodes and are ideal for splitting, and widely used in house building, to make woven wares (baskets, mats, handicrafts, wall plates, screens, hats) and domestic utensils, and are an important source of superior paperpulp (Alam 1995). The young shoots are edible and during the rainy season constitute one of the important foods of tribal peoples in association with which it grows. The remarkable large fruits of *M. baccifera* are fleshy and edible; they are used as famine food and relished by wild and domestic animals. The leaves may be used in brewing liquor. Tabasheer, a medicine, as a cooling tonic and as an aphrodisiac, is the residue of the watery sap and found in the internodes of the culms (Singh 1986). Its net like extensive rhizome system protected the forest soil from erosion (Banik 1989).

This bamboo is accredited as one of the priority bamboo species for international action (Williams and Rao 1994). This bamboo is flowering since 2004 throughout in its natural range. Maximum forest cover is now denuded due to its gregarious flowering habit. Myanmar reports that the share of the bamboo species *Melocanna*

baccifera declined from 51.3 percent in 1990 to 36.2 percent in 2000 due to overexploitation (Lobovikov *et al*. 2007).

Considering the erratic flowering behaviour of bamboo and seed viability for a very short period, it is difficult to use seeds for raising large plantations continuously. Although propagation is possible by variety of vegetative methods, each method has its own limitations. Supply of planting material remains critical in establishing bamboo plantations and grove, from which culms may be taken to support bamboo based industries. Use of bamboos as industrial raw material besides their traditional uses, is however increasing day-by-day creating a wide gap between demands and supply which is escalating at alarming pace. In such conditions, *in vitro* methods remain an alternative solution. These techniques can be applied either for a practical purpose viz. mass propagation by micropropagation and/or for some fundamental studies like understanding flowering phenomenon, genetic studies etc.

Probably there is no report on *in vitro* regeneration in the genus *Melocanna*. The aim of the present study was to set up a protocol for the establishment, regeneration, multiplication and rooting *in vitro*, of *Melocanna baccifera* using nodal explants from mature clump.

Materials and methods

Explant source: Single nodal segments were collected during March to May from 18 years old clumps growing at the experimental plot of Forest Research Institute, Dehradun, India. After removal of the leaf sheath, individual nodes, each with the bud, were washed with dilute solution of 5-10 drops Tween-20 (HiMedia, India) per 100 ml of distilled water for 10 min. followed by running tap water for 15 min. Pre-disinfection treatments was given to reduce the contamination, where nodal segments were treated with a mixture of aqueous solution of fungicide bavistin (BASF, India) and bactericide streptomycin (HiMedia, India) at a concentration of 0.1% each for 20 min. For surface disinfection, nodal segments were treated with aqueous solution of 0.1% $HgCl_2$ (HiMedia, India) for 10-12 min. To remove the traces of disinfectant, nodal segments were finally washed with sterilized distilled water in laminar air flow for 3-4 times. The surface disinfected axillary buds were inoculated on liquid MS (Murashige and Skoog 1962) medium supplemented with cytokinin.

Effect of growth regulators on bud break: Different concentrations of 6-benzylaminopurine (BAP; 0-40µM) or 6-furfurylaminopurine (Kn; 0-40µM) alone were used in liquid MS medium for bud break. The pH of the medium was adjusted to 5.8 by using 1 N NaOH prior to autoclaving. The liquid medium (10ml) was dispensed into 25 x 150mm test tubes (Borosil, India). The culture tubes with media were autoclaved at 105kPa and 121^0C for 20 min.

Shoot multiplication: Proliferated *in-vitro* shoots were separated into clumps (four shoots) and used for further shoot multiplication. Various concentrations of BAP (0-25µM) or Kn (0-25µM) alone or in combinations were used in liquid MS medium. Subculturing was carried out every 4 weeks on fresh shoot multiplication medium. The number of shoots cultured and the number of shoots derived at the end of subculture gave the multiplication rate.

Effect of auxin on root induction: *In-vitro* raised shoot clumps (three or four shoots) derived from shoot multiplication medium were used for root induction. Half strength liquid MS medium with various concentrations of indole-3-butyric acid (IBA; 5-30µM) or α-napthalene acetic acid (NAA; 5-30µM) alone were used.

Culture conditions: All cultures were incubated at 27 ± 2ºC temperature and illumination of 16hrs photoperiod with light intensity of 2400 lux, obtained by white cool fluorescent tubes of 40 watts (Philips, India).

Hardening and acclimatization: Rooted plantlets were taken out from the flasks, washed to remove adhered medium and then transferred to autoclaved 250 ml screw cap glass bottle containing 1/3 volume of soilrite. These plantlets were nurtured with half strength MS medium (without organics) twice a week for two weeks and were kept in tissue culture incubation room. After two weeks these bottles were shifted to mist chamber having relative humidity of 70-80% with a temperature of 30 ± 2^0C. The caps of bottles were removed and plantlets were allowed to remain in the bottle for one week before they were transferred to polybags containing a mixture of sand, farmyard manure and soil in a ratio of 1:1:1. In the mist chamber, the plants were kept for four weeks and were irrigated with half strength MS medium. Later, these polybags were shifted to high-density double deck agronet open shade house for acclimatization.

Statistical analysis: A completely randomized design was followed for all the experiments. Each experiment was repeated thrice and data represents the mean of three experiments. Each treatment consisted of minimum twelve replicates. Data was subjected to one way Analysis of Variance (ANOVA) using Microsoft Excel ver. 2007 © Microsoft Technologies, USA. Degree of variation was shown by Standard Error (SE), Critical Difference (CD) at 5%. The CD values computed, were used for comparing differences in means of various treatments.

Results

Effect of growth regulators on bud break: Axillary bud break was observed in nodal segments within 15-20 days, when cultured on MS medium supplemented with cytokinin. The morphogenic response of explant towards axillary bud proliferation was markedly influenced by the concentration of growth regulator in the medium. Nodal segments cultured on liquid MS medium without plant growth regulator, yielded only 10.33% bud break response. Amongst cytokinin tried, BAP proved its superiority in inducing multiple buds (Fig. 1). Maximum bud break response (82.80%) was obtained on liquid MS medium supplemented with 20µM BAP (Fig. 2-A). However, among kinetin treatments, maximum responding explants (55.40%) were recorded at 25µM concentration.

Shoot multiplication: Response of *in vitro* shoot multiplication varied with cytokinin type and its concentration used in the medium. 15µM BAP concentration gave an average of 10.40 shoots with a multiplication rate of 2.60 folds in a period of four weeks, while 7.09 shoots developed from a propagule (four shoots) with a multiplication rate of 1.77 folds on MS medium supplemented with 20µM Kn . However, a synergistic effect was observed when lower concentration of Kn was added to the medium with BAP (Table-1). Thus, optimal *in*

vitro shoot multiplication was found to be 2.99 folds on MS supplemented with 15µM BAP and 3µM Kn (Fig. 2-B).

Effect of auxin on root induction: Shoots of 2-3cm length were used for various *in vitro* rooting experiments. *In vitro* rooting was obtained when *in vitro* grown shoots were transferred on half strength MS medium supplemented with auxins. However, spontaneous rooting was observed in few cultures if they remained on multiplication medium for more than 2 months duration. A thin one root per propagule was obtained and during hardening the plantlets did not survived. Amongst auxins tried for *in vitro* rooting, IBA was found to be better for *in vitro* rooting response as compared to NAA (Table-2). On medium supplemented with 25µM IBA, 64.66% rooting was observed (Fig. 2-C). Any increase or decrease in IBA levels in MS medium reduced the rooting percentage.

Hardening and acclimatization: Healthy plantlets with good roots and shoot system developed within 5-6 weeks when *in vitro* raised shoots were transferred on rooting medium. During hardening and acclimatization the shoots elongated, leaves turned greener and expanded. Over 65% of tissue culture plants were hardened and acclimatized (Fig. 2-D).

Discussion

For tissue culture of bamboo the use of starting material (seeds or adult plants) and the choice of the propagation method are crucial (Gielis 1999). The disadvantages of using seed are insufficient or no knowledge of genetic background, restricted availability of seeds for most species and rapid loss of germination capacity. In addition there is a huge variability in responsiveness in tissue culture (Saxena and Dhawan 1994). In the present investigation, nodal segments containing pre-existing axillary bud from mature clumps were used to initiate the *in vitro* cultures. The suitability of nodal segments is further reported in the micropropagation of bamboos (Nadgir *et al.* 1984; Prutpongse and Gavinlertvatana 1992; Saxena and Bhojwani 1993; Hirimburegama and Gamage 1995; Ramanayake and Yakandawala 1997; Arya and Sharma 1998; Bag *et al.* 2000; Das and Pal 2005; Sanjaya *et al.* 2005; Arya *et al.* 2006; Jimenez *et al.* 2006; Arya *et al.* 2008).

Presence of cytokinin in the medium leads to the promotion of bud differentiation and development. Hirimburegama and Gamage (1995) found cytokinin to be essential for bud break. In present study, axillary bud proliferation was more in number on BAP supplemented medium as compared to medium supplemented with Kn. Highest bud break of 82.80% was obtained on MS medium supplemented with 20µM BAP. The efficiency of BAP for shoot culture initiation is also reported in *Bambusa ventricosa* (Huang and Huang 1995); *B. bambos* (Arya and Sharma 1998)*; D. strictus* (Mishra *et al.* 2001); *D. asper* (Arya *et al.* 2002); *D. hamiltonii* (Sood *et al.* 2002); *D. giganteus* (Arya *et al.* 2006); *Guadua angustifolia* (Jimenez *et al.* 2006); *Drepanostachyum falcatum* (Arya *et al.* 2008).

In the present study a synergistic effect was evident when combination of BAP and Kn was tried for *in vitro* shoot multiplication. MS medium supplemented with 15µM BAP + 3µM Kn gave the optimal multiplication rate of 2.99 fold, which was significantly higher as compared to the multiplication obtained on MS medium supplemented with BAP or Kn alone. Similar positive effects of BAP and Kn interactions for *in vitro* shoot

multiplication were reported in *Dendrocalamus longispathus* (Saxena and Bhojwani 1993); *D. giganteus* (Ramanayake and Yakandawala 1997); *D. strictus* (Ravikumar *et al.* 1998); *Bambusa balcooa* (Das and Pal 2005; Arya *et al.* 2008).

Occasionally spontaneous rooting in the absence of exogenous auxin was observed, which was not significant and the plantlets thus obtained were not able to survive during hardening. Spontaneous rooting have already been reported by Shirgurkar *et al.* (1996) who obtained 50% spontaneous rooting on multiplication medium in *Dendrocalamus strictus*. Jimenez *et al.* (2006) and Ramanayake *et al.* (2008) have described spontaneous root development in shoots raised from adult culms of *Guadua angustifolia* and *Bambusa atra*, respectively. Our observation on root induction in shoots of *Melocanna baccifera* reveals that IBA alone was more effective. Efficacy of IBA on root induction is well reported in *Dendrocalamus strictus* (Nadgir *et al.,* 1984), *B. vulgaris* (Hirimburegama and Gamage 1995); *D. membranaceous* and *B. nutans* (Yasodha *et al.* 1997); *D. giganteus* (Ramanayake and Yakandwala 1997); *D. strictus* (Ravikumar *et al.* 1998); *Thamnocalamus spathiflorus* (Bag *et al.* 2000); *D. asper* (Arya *et al.* 2002); *B. balcooa* (Das and Pal 2005); *Pseudoxytenanthera stocksii* (Sanjaya *et al.* 2005); *Drepanostachyum falcatum* (Arya *et al.* 2008).

Conclusion

This is a first report for micropropagation of *Melocanna baccifera* using nodal segments from mature clumps. A multiplication rate of 2.99 folds was obtained with a good rooting percentage. The protocol can be used as a non conventional method for rapid propagation of this bamboo.

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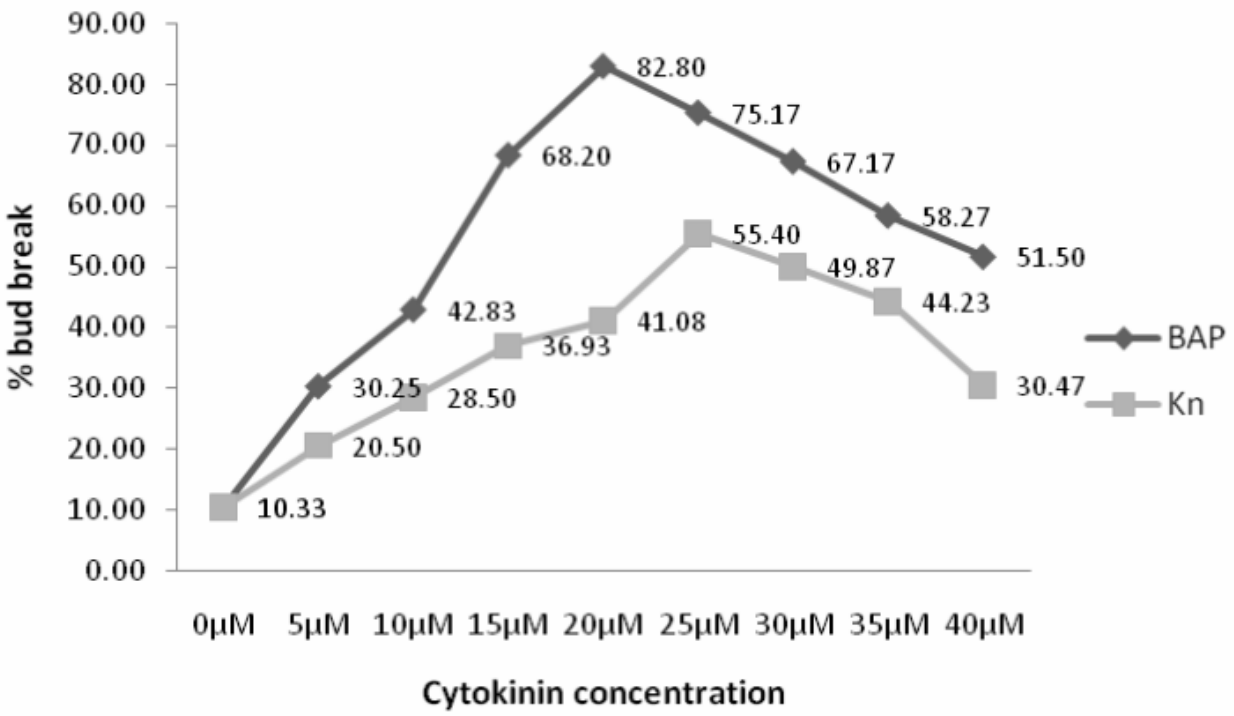

Figure 1: Effect of cytokinin concentrations on bud break from nodal segments of *Melocanna baccifera*, after 15 days in culture.

Figure 2: Micropropagation of *Melocanna baccifera* using nodal segments from mature clumps. (A) nodal segment showing bud break after 15 days of culture on MS medium + 20µM BAP; (B) *in vitro* multiplication on MS medium +15µM BAP .+ 3µM Kn after 3 weeks of culture; (C) *in vitro* rooting on half strength MS medium with 25µM IBA; (D) Hardened tissue culture raised plantlets in polybags.

Table 1: Effect of cytokinin in MS medium on shoot multiplication of *Melocanna baccifera*, after 4 weeks in culture. Propagules of four shoots were cultured.

Treatment	Mean shoot number	Mean shoot length (cm)	Multiplication rate
Control	03.47 ± 0.27	1.43 ± 0.11	0.87 ± 0.07
BAP			
5µM	06.51 ± 0.19	1.82 ± 0.15	1.63 ± 0.05
10µM	09.05 ± 0.25	2.35 ± 0.17	2.26 ± 0.06
15µM	10.40 ± 0.30	2.45 ± 0.12	2.60 ± 0.08
20µM	09.92 ± 0.17	2.06 ± 0.22	2.48 ± 0.04
25µM	08.82 ± 0.20	1.96 ± 0.13	2.20 ± 0.05
30µM	08.24 ± 0.19	1.88 ± 0.14	2.06 ± 0.05
Kn			
5µM	04.86 ± 0.19	1.71 ± 0.09	1.22 ± 0.05
10µM	05.42 ± 0.15	1.78 ± 0.07	1.35 ± 0.04
15µM	06.10 ± 0.20	2.17 ± 0.13	1.52 ± 0.05
20µM	07.09 ± 0.15	2.02 ± 0.08	1.77 ± 0.04
25µM	06.61 ± 0.29	1.85 ± 0.07	1.65 ± 0.07
30µM	05.91 ± 0.26	1.67 ± 0.09	1.48 ± 0.06
BAP + Kn			
10µM +1µM	09.27 ± 0.12	2.20 ± 0.23	2.32 ± 0.03
10µM +3µM	09.50 ± 0.20	2.18 ± 0.16	2.38 ± 0.05
10µM +5µM	10.03 ± 0.26	2.32 ± 0.17	2.51 ± 0.07
15µM +1µM	10.75 ± 0.27	2.46 ± 0.17	2.69 ± 0.07
15µM +3µM	11.94 ± 0.35	2.50 ± 0.20	2.99 ± 0.09
15µM +5µM	11.23 ± 0.24	2.22 ± 0.22	2.81 ± 0.06
20µM +1µM	10.19 ± 0.23	1.97 ± 0.11	2.55 ± 0.06
20µM +3µM	09.95 ± 0.19	1.87 ± 0.20	2.49 ± 0.05
20µM +5µM	09.35 ± 0.68	1.89 ± 0.22	2.34 ± 0.17
CD at 5%	**0.22**	**0.12**	**0.06**

Control: liquid MS basal medium

Table 2: Effect of auxin (IBA) in MS medium on rooting of *in vitro* shoots of *Melocanna baccifera*, after 4 weeks in culture. Propagules of four shoots were cultured.

Treatment	Response %	Mean root number	Mean root length (cm)
IBA			
5µM	20.70 ± 3.31	1.57 ± 0.19	2.07 ± 0.28
10µM	35.10 ± 4.20	2.08 ± 0.18	2.39 ± 0.22
15µM	52.77 ± 3.82	2.39 ± 0.19	2.70 ± 0.23
20µM	59.14 ± 2.91	3.69 ± 0.28	3.32 ± 0.34
25µM	64.66 ± 3.24	5.08 ± 0.21	4.07 ± 0.25
30µM	58.83 ± 2.64	4.64 ± 0.35	3.52 ± 0.20
NAA			
5µM	37.36 ± 3.53	2.25 ± 0.16	1.81 ± 0.07
10µM	53.84 ± 4.44	3.94 ± 0.19	2.37 ± 0.09
15µM	48.48 ± 2.69	3.48 ± 0.17	2.12 ± 0.12
20µM	38.42 ± 3.85	3.05 ± 0.25	2.08 ± 0.10
25µM	34.03 ± 3.43	2.70 ± 0.17	1.94 ± 0.15
30µM	27.62 ± 2.14	2.48 ± 0.15	1.70 ± 0.07
CD at 5%	**4.78**	**0.33**	**0.35**

Bamboo Propagation: Practical Experiences of Some Private Nursery Operators in Laguna, Philippines

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Abstract

Keeping in mind that the demand for bamboo propagules is increasing very fast, the author took a close look at the nursery practices of five bamboo propagators operating in the province of Laguna, the province where the foremost research organizations of the country in agriculture and forestry are located. His major findings: (1) most propagators are unaware of research findings on the use of improved methods; consequently they continue to use traditional methods that gives high survival rates but limited quantities, (2) propagators use a light weight mixture consisting of garden soil, rice hull and coconut coir as propagation medium, (3) a few propagators use growth hormones to induce root formation, and (4) they sometimes conduct research that once in a while produces surprising results. The author urges research institutions to assist bamboo nursery operators by giving them training and information materials that are easy to understand and follow.

Introduction

There is some kind of revolution going on in the Philippines right now and it involves bamboo. More and more people, NGOs, local government units (LGU), private land owners, resort managers, environmentalists and many others are increasingly getting interested in planting bamboo for various reasons (e.g. pole production, landscape beautification, erosion control, carbon sequestration, food production, bambusetum development and tourism enhancement). Consequently, the demand for planting materials has increased tremendously, prompting many enterprising individuals to go into the business of bamboo propagation.

At present, the local demand for bamboo propagules is greatest for ornamental species but that for timber or construction bamboo is expected to catch up soon because many LGUs, private landowners and companies engaged in bamboo processing are expected to put up their own plantations in the very near future.

Although much work by scientists has been accomplished in almost every country where bamboo is being planted, their research results often do not trickle down to bamboo propagators, and even if they do, many local propagators have found that some methods that work satisfactorily under experimental conditions actually do not turn out to be as effective in practice.

Because they have years of practical nursery experience, bamboo nursery operators are valuable sources of information. As the saying goes "experience is the greatest teacher". For sure, there is much that we can learn about bamboo propagation from experienced nursery operators. For one thing, they are the most reliable judges of whether technologies developed by experimentation do really work in practice. And bear in mind, some of them also do carry out some improvisations that sometimes bring about positive results.

The province of Laguna is located at the southern portion of Metro Manila. The province is famous for its gardens that supply the landscaping plants needed by Metro Manila and nearby provinces. The country's foremost educational and research institutions in agriculture and forestry are located in Los Baños, including the University of the Philippines at Los Baños, the Ecosystems Research and Development Bureau, the Philippine Council for Agriculture, Forestry and Resources Research and Development (PCARRD) and the Forest Products Research and Development Institute.

This paper presents a summary of what the author has learned from the experiences of co-nursery operators in Laguna, Philippines and his own 12 years of experience in propagating different species of bamboo.

Nurseries Included in the Survey

Name and address	Nursery size	Bamboos raised	APC**
Sardo's garden* Lalakay, Los Baños, Laguna	1,500 sq. m	ornamental	1,500
Tony's Garden*	1,500 sq. m	ornamental	1,500
Lito's Garden* Maahas, Los Baños, Laguna	2,000 sq. m	ornamental	2,000
Laguna Botanic Nursery* Timugan, Los Baños, Laguna	1,000 sq m	ornamental	1,500
CDC Bamboo Nursery Sto. Tomas, Calauan, Laguna	3,000 sq m	ornamental timber	2,000 6,000

*Also raises non-bamboo garden plants

**APC – annual production capacity

Note that of those included in the survey, only CDC Bamboo Nursery (or CDC for short) which is owned and operated by the author and two partners, is engaged in the production of both ornamental and timber bamboos. CDC has been in existence for less than a year.

The quantities produced by the nurseries are dependent largely on demand, especially for timber bamboos. Large quantities are not raised unless there are firm orders from customers.

Species Being Propagated

With the exception of CDC, nurseries in Laguna are involved only in the production of propagules of a few species, all ornamental. We can't blame them from specializing because ornamental bamboos are not only in high demand. They also command prices many times higher than other species. The ornamental species being propagated in large numbers include: (1) *Thyrsostachys siamensis*, (2) *Bambusa dolichomerithalla*, (3) *Bambusa multiplex* forma *variegata*, (4) *Schizostachyum brachyladum*, (5) *Bambusa vulgaris wamin* and (6) *Phyllostachys aurea*. There is much interest in producing propagules of black bamboos (*Bambusa lako* and *Gigantochloa atroviolacea*) but mother plants of these species are still quite scarce and very expensive.

Insofar as timber or construction bamboos are concerned, the emphasis has been in the raising of planting stocks of three species: *Bambusa blumeana* (Kawayan tinik), *Dendrocalamus asper* (giant bamboo) and *Bambusa merriliana* (bayog). However, small quantities of the following species are also being propagated: *B. philippinensis* and *Schizostachyum lumampao.*

Propagation Methods

By Seeds

Bamboo seeds are seldom available so like other propagators in the country and other parts of the world, bamboo propagators in Laguna rarely use seeds to produce new plants. Recently, however, one operator bought seeds of two species of black bamboo, Java black bamboo (*Gigantochloa atroviolacea*) and Timor black bamboo (*Bambusa lako*), from eBay. He placed an order for 100 seeds for each species and sowed them immediately when they arrived. More than 50% of the Java black bamboo germinated within two weeks after sowing. No germination was obtained from Timor black bamboo; the reason could be that the seeds have lost their viability after many months of storage at the sellers' outfit.

In the Philippines, there is one species that produces flowers almost every year---*Schizostachyum brachycladum*. There has been no report, however, that seeds have been produced from clumps of the said species. Amazingly, no clump of the species has been reported to die out after flowering.

Clump Division and Offset Planting

Almost every bamboo nursery operators in Laguna uses these two traditional methods of propagation (Banik, 1995; PCARRD, 2006) to produce new planting stocks. Clump division is the most widely employed method for species that have small diameters and do attain heights greater than 2 to 3 meters such as *Bambusa multiplex*, *B. muliplex* forma *variegata* and *B. multiplex* var *riviereorum*. Clump division is carried out by using machetes or saws. The divisions are commonly planted in large plastic bags filled with a medium consisting of a mixture of decomposing rice hull, garden soil and coconut coir.

Although rice hull is nutrient poor and does not decompose easily, it is very popular among plant propagators in the Philippines because of its light weight, which makes handling and transport of potted plants easy and less costly. Another advantage is that they increase the porosity of the medium allowing air circulation to proceed

easily. Because rice hull is nutrient poor, most plant propagators apply fertilizers to make their plants more vigorous and nice looking. For bamboo, the most common fertilizer is urea.

Clump division is definitely not a satisfactory technique for large scale production over short periods because it takes time for clumps to grow to a size that will make them ready for another round of division. Laguna bamboo propagators like the technique, however, because it is simple, easy to implement, cheap, and most of all, it gives 100% survival most of the time.

The use of offsets is also a favorite method for propagators of ornamental bamboo in Laguna because it offers the same advantages as the clump division method. Propagators use it for species that are bigger than those propagated by clump division and which command very high prices in the market. Thai monastery bamboo (*Thysostachys siamensis*) which sells like hot cakes in the country is propagated by offsets. Each offset consists of a rhizome and a portion of the culm cut just above the 4th or 5th node from the base. The offsets are planted in plastic bags filled with the medium described above and kept under partial shade until they produce new leaves. Watering is done every day and urea fertilizer is applied once a month or once every two months.

Other ornamental plants propagated by offsets in Laguna are *Bambusa dolichomerithalla*, *Schizostachyum brachyladum*, pink bamboo (probably a *Bambusa*), Australian bamboo (also probably a *Bambusa*) and *Phyllostachys aurea*, a running species.

By Culm Cuttings

Among those included in the survey, only CDC propagates bamboo by culm cuttings. The main reason for this could be that the other nursery operators have no technical background on bamboo, do not know what publications are available and have not been in contact with government extension workers. Because of their poor technical background, they find it quite difficult to understand many of the existing references. the fact that most of the publications available There has been very little attempt on the part of research agencies to carry out public education and information activities that would spread the technologies developed by research to reach their intended beneficiaries.

Propagation by culm cuttings is definitely an improvement over the traditional methods, i.e. clump division and offset. The principal advantage of using culm cuttings over clump division and the offset method is that more propagules can be obtained from a single culm within a matter of months.

The procedure employed by CDC in propagating culm cuttings evolved from carefully studying techniques described in various references (Anonymous (a), 1997; Anonymous (b), 1997; Banik, 1995; Lantican, 2008; PCARRD, 2006; Virtucio and Roxas, 2003). It consists of the following steps:

1. Selection of the culm to be cut
2. Cutting of the selected culm near the base
3. Trimming of the branches to 2 or 3 internode lengths
4. Cutting of the culm (with a saw) into segments consisting of 1, 2 or 3 internodes with the cut positioned 2 to 3 cm below the basal node
5. Planting of the cuttings in black polyethylene bags or in propagation plots

6. Watering of the cuttings daily at least 3 times a day.
7. Transferring the rooted cuttings

Based on the experience of the CDC, the best culms to use for culm cuttings are those that are mature and with well developed branches and lateral buds. According to Virtucio and Roxas (2003), a culm is perceived to be mature when all its culm sheaths have already fallen off. This rule of thumb would of course not work in the case of species with persistent culm sheaths such as *Thrysostachys siamensis*.

Between cuttings with branches and those only with buds, CDC's observation is that cuttings with branches give a higher percentage of rooting than those with nothing but buds. Cuttings that only have buds may root but rooting is very much longer compared to those with branches.

In terms of the number of internodes in a cutting, CDC prefers the use of single node cuttings. The cuttings are planted vertically or in a slanting position and then their cavities are filled with water. Filling the cavities with water prevents the fast drying of the cuttings, increasing their chances to produce roots.

When cuttings are made up of two or more internodes, the cuttings are buried in the soil in a horizontal position. Before they are buried, a hole is usually made in each internode and water is poured into the cavity.

The planting medium used by the propagators varies from one individual to another but the most widely used is a mixture of garden soil, rice hull and coconut coir. Several propagators who use garden soil only as a medium claim that they get similar results as those who use mixtures but they said using rice hull and coconut coir would greatly reduce the weight of their rooted cuttings.

CDC prefers the use of polyethylene bags over propagation plots because once rooted, those planted in the bags can be sold and transported right away but those planted in propagation beds have to be dug, planted in a container and conditioned for a week or two before they can be sold.

Keeping the cuttings moist everyday before rooting takes place is of key importance in growing cuttings. CDC uses a misting system constructed using PVC pipes and nozzles.

As many propagators have observed, there is a great variability in the rooting ability among different species of bamboo when propagated by culm cuttings. There are those that root easily (within a couple of weeks in the case of *Bambusa vulgaris*, *B. philippinensis* and several varieties of *B. multiplex*) and there are those that are very difficult to root such as *Dendrocalamus latiflorus* and *Thyrsostachys siamensis*. Portions of the culm that give high percentages of rooting also vary substantially from one species to another (see Table 2).

Incidentally, to educate some people who repeatedly call rooted bamboo cuttings (culm and branch) as "seedlings", which is absolutely inappropriate because seedlings are produced from seeds, the author has proposed that the word "cutlings" be used instead.

By Branch Cuttings

Branch cuttings have the same advantage as culm cuttings over the traditional methods of propagation (PCARRD, 2006). Many propagules can be obtained from a single culm.

In Laguna, only CDC uses this method for propagating some species of bamboo. The CDC findings:

1. Some species respond very well to the method but some do not.
2. The method works very well with branches that have "swollen" bases.
3. Branches that have adventitious roots below the branch bases (e.g. *Bambusa blumeana* and *Schizostachyum brachycladum*) are rather easy to propagate.
4. Many species of bamboo form adventitious roots below some of their branches when the culm is cut some distance from the ground.
5. Branch cuttings root faster when the branches have 2 to 3 internodes.
6. The application of a growth hormone (IBA + NAA) induces roots to form earlier in some species, even when the branch has no swollen base. In fact, species like *Bambusa multiplex* forma *variegata* would root easily even if the branch does not include its base if treated with a growth hormone and planted in an enclosed plastic bag.

Marcotting

Marcotting is the term used by some bamboo growers to refer to a method of bamboo propagation in which branch bases are covered with a propagating medium (usually coconut coir) and held in place using transparent plastic sheets tied around the culm with strings or fine wire, PCARRD (2006), Virtucio and Roxas (2003).

The method was tried in the author's farm on *Dendrocalamus latiflorus* by the instructors of a training course but it did not work well. The author tried it on several other species but it also did not work well. Although the author hasn't tried it, he believes wounding the culm just below the branch base and applying a growth hormone may lead to better rooting.

Summary and Conclusions

Table 2 summarizes the findings obtained by the author in the survey that he conducted. The table shows the ranges in the percentage of rooting for different bamboos and vegetative propagation methods.

There is a great need to establish more bamboo nurseries in the Philippines, not only to fill the requirements of those involved in landscaping but more so to produce propagules in large quantities for plantation establishment, watershed protection, carbon sequestration, erosion control, riverbank stabilization and the reduction of the incidence of landslides. There is clearly a need to upgrade the knowledge of small-scale propagule producers through training and information materials. Concerned agencies of the government are definitely not doing enough to make sure that their research findings find their way to their intended beneficiaries.

One of the research areas worth looking into concerns the observation made by CDC that the rooting ability of cuttings of some species seems to be affected by the season of the year. For example, *Bambusa philippinensis*

cuttings root more easily during summer than in the rainy months. Another area worth looking into is the development of a culm maturity index that is based on easily observed characters so that propagators can be guided accordingly in choosing the culms that they will use for propagation.

In closing, the author is convinced that researchers can learn a lot from private bamboo propagators' experiences. Learning what their practices are could lead them to research problems that are worth investigating.

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Table 1. Findings of the CDC on the propagation of different species of bamboo by cuttings.

Species	Age	# of nodes	Part	Direction
Bambusa bambos	1 - 2	2 - 3	B - M	U, S
B. blumeana	1	1 - 2	B - M	U, S, H
B. dolichomerithalla	1	1	Branchy	U, S
B. merrilliana	1	1 - 2	Branchy	S, H
B. multiplex	1	1	Branchy	U, S
B. multiplex f. variegatum	1	1	Branchy	U
B. oldhamii	1 - 2	1 - 2	Branchy	U, S
B. philippinensis	1 - 2	1 - 2	Branchy	U, S
B. vulgaris	0.5 - 1	1 - 3	Branchy	S, H
B. vulgaris vittata	1 - 2	1 - 3	Branchy	U, S, H
B. vulgaris wamin	1 - 2	1 - 3	Branchy	U, S
Dendrocalamus asper	1 - 2	1 - 3	B - M	H
Gigantochloa levis	1	1 - 3	B - M	H
Schizostachyum brachycladum	1 - 2	1	Branchy	U, S
Schizostachyum lima	1 - 2	2 - 3	Branchy	H

Legend:
B - M: base to middle
U - upright
S - slanting
H - horizontal

Table 2

Ranges in percentage rooting for different species and vegetative methods (based on the experiences of bamboo nursery operators in Laguna, Philippines)

	Scientific Name	Stem cuttings	Branch cuttings	Clump division	Offset	Marcot
1	*Bambusa atra*			>90	>90	
2	*B. bambos*	50-70	50-70			
3	*B. blumeana*	50-70	50-70			
4	*B. dolichomerithalla*	50-70		>90	>90	<5
5	*B. merrilliana*	40-50	50-60			
6	*B. multiplex*	25-40		70-80	70-80	
7	*B. multiplex f. variegata*	60-70	60-70	>90	>90	
8	*B. multiplex var. riviereorum*	<5		>85	>85	<5
9	*B. oldhamii*	50-70				
10	*B. philippinensis*	70-85				
11	*B. sp. (pink bamboo)*	80-100				
12	*B. sp. (Australian bamboo)*	50-70				
13	*B. vulgaris*	70-85	70-85			
14	*B. vulgaris var. vittata*	70-85	70-85			
15	*B. vulgaris var. wamin*	50-70	50-70			
16	*Dendrocalamus asper*	50-70	50-70			
17	*D. latiflorus*	<10				<10
18	*D. strictus*	50-70	50-70			
19	*Gigantochloa atter*	50-70				
20	*Gigantochloa levis*	40-60	50-70			
21	*Guadua angustifolia*		50-60			
22	*Meloccana baccifera*	<10			>90	
23	*Phyllostachys aurea*				>80	
24	*Sasa fortunei*	<10	<10	70-80	70-90	
25	*Schizostachyum brachycladum*	50-60			>90	<5
26	*S. lima*	50-60		>70	>80	
27	*S. lumampao*	50-60			75-90	
28	*Thyrsostachys siamensis*	<5			>90	

Cyanogenic Glucosides in Juvenile Edible Shoots of some Indian bamboos

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Abstract

The cyanogenic glucosides, secondary metabolites of plants, are glucosides of the α-hydroxynitrile which plants use to protect themselves against predators. There are approximately 25 cyanogenic glucosides with the major cyanogenic glucosides *viz.* amygdalin, dhurrin, linamarin, lotaustralin, prunasin and taxiphyllin being found in the edible parts of plants. Bamboo, a tall grass with about 1250 species in 75 genera, is one of the most primitive grasses surviving today. Apart from the diverse use that the various parts of the plant are put to, the tender juvenile shoot is consumed. While shoots of some species can be eaten raw and without any pretreatments, there are a large number of species whose shoots possess an acrid taste due to the presence of cyanogenic glucosides and have to be pre-boiled in water for varying periods of time to make them fit for consumption. The cyanogenic glucosides present in bamboo shoots are taxiphyllin, a *p*- hydroxylated mandelonitrile tiglochinin, which is rapidly hydrolysed to glucose and hydroxybenzaldehyde cyanohydrins. Hydroxybenzaldehyde cyanohydrin then decomposes to hydroxybenzaldehyde and hydrogen cyanide. Cyanogenic glucosides in fresh shoots of four species of edible bamboos (*Bambusa balcooa, B. bambos, B. tulda* and *Dendrocalamus giganteus*) at three different stages of growth were studied. The cyanogenic glucoside content showed variation in quantity in all species and also as the shoot advanced in age. There was also difference in the quantity of the glucoside in the tip, middle and basal portion of the same shoot. The findings of this study may be valuable for use in food composition databases and for prevention of diseases caused by cyanide toxicology due to consumption of bamboo shoots.

Keywords: Bamboo shoot, Cyanogenic glucosides, Picrate method, Taxiphyllin.

Introduction

Known more for their uses in the industry, bamboos have an additional usage in utilization of its young shoots as food. Juvenile shoots are not only delicious but have high nutritive value. Most bamboo species produce edible shoots, fibre and timber but less than 100 species are commonly grown or utilized for their edible shoots (Midmore 1998; Collins and Keilar 2005). The species employed for commercial production of edible bamboo shoots belong to a few genera like *Bambusa, Dendrocalamus* and *Phyllostachys* (Kleinhenz et al. 2000) which are consumed in different forms as fresh, fermented, pickled, dried or canned in East and South East Asia,

including the major countries of Japan, China, Korea and Indonesia. In India, the consumption of tender shoots is confined mainly to the North-Eastern states of the country where it is a part of the traditional cuisine, both in fresh and fermented form. Bamboo shoots are nutritionally very rich in proteins, carbohydrates, dietary fibre, and amino acids and low in fats and cholesterol; the juvenile younger shoots being much richer in nutrients than the fermented and canned form of shoots (Nirmala et al. 2008). The freshly emerging juvenile shoots are further more nutritionally superior than the older emerged shoots (Nirmala et al. 2007). While shoots of some species can be eaten raw and without any pretreatments, there are a large number of species whose shoots possess an acrid taste due to the presence of cyanogenic glucosides and have to be pre-boiled in water for varying periods of time to make them fit for consumption.

In the present study, the total cyanogenic glucoside content in fresh shoots of some selected bamboo species, *viz. Bambusa balcooa, B. bambos, B. tulda* and *Dendrocalamus giganteus*, at three stages of growth were analyzed. These bamboos were selected on the basis of their nutritive value and also because of the fact that they are popularly consumed and have commercial value.

Materials and methods

Samples.

Juvenile shoots of four edible bamboos (*Bambusa balcooa, B. bambos, B. tulda* and *Dendrocalamus giganteus)* at three different stages of growth, *viz.* soon after emergence above ground, two weeks old and three weeks old, were obtained from the bamboos growing in the P.N. Mehra Botanical Garden of Panjab University, Chandigarh, India and from those growing in the wild. The culm sheaths were removed and the shoots were cut longitudinally in half (Figure 1). The half shoot section was cut transversely at the tip, middle and basal portion and a small shoot section from each was sliced and ground in a pestle and mortar and used for estimation. Because of rapid breakdown of the bamboo cyanogenic glucoside to HCN, the ground material was processed immediately.

Picrate Method.

25 mg of the shoot ground in pestle and mortar, was weighed out accurately and put in a flat-bottomed plastic vial immediately after grinding (Egan et al. 1998, Bradbury et al. 1999). 0.5 ml of 0.1 M phosphate buffer at pH 6 was added to each and a picrate paper attached to plastic strip was put and the vial immediately closed with a screw capped lid.

After about 16-24 hours at 30^0C, the picrate paper was then carefully removed and immersed in 5 ml of distilled water for about 30 min. The absorbance was measured at 510 nm and the total cyanide content (ppm or mg/kg) was determined by the equation

Total cyanogen content (mg/kg) = 396×absorbance×100/z

Where z = weight (mg) of ground shoot (Bradbury et al. 1999)

Results and discussion

Variations could be seen in the amount of cyanogenic glucoside from species to species as well as the shoot ages. In one week old emerging bamboo shoots, a trend could be seen in all the species as one goes from the apical, the middle portion and towards the basal portion of the same shoot. The cyanogenic glucoside content is highest in one week old shoots in the tip portion and gradually decreases towards the base. As indicated in Table 1, the highest amount is present in *Dendrocalamus giganteus* (1164 mg/kg) while lowest in *Bambusa bambos* (223 mg/kg).

As the shoot ages, the cyanide content in the shoot is seen to increase more towards the middle portion of the shoot while it decreases in both the basal and tip portion of the shoot (Table 2). It reaches a maximum in the middle portion of the shoot of *Dendrocalamus giganteus* (1012 mg/kg). This same trend of increase in the middle portion can further be seen in the 3 weeks old shoot of all selected species (Table 3), with highest in the middle portion of the shoot of *D. giganteus* (1132 mg/kg).

The cyanide content is minimum in the emerging shoots of *B. bambos* (tip=859; middle=371; base=223 mg/kg) as also indicated by Haque and Bradbury (2002) (Table 1). Taxiphyllin content is highest in the shoots of *D. giganteus* at all 3 selected stages of growth. The values are quite high with minimum of 139 mg/kg in basal portion of *B. bambos* and maximum in the tip portion of *D. giganteus* (1164 mg/100 kg). Generally, plants which contain more than 20 mg/ 100 g of fresh plant material are considered potentially dangerous (Kingsbury 1964). European Food Society Authority (EFSA 2004) have stated that a level of up to 10 mg/kg HCN is not associated with acute toxicity. Thus, the cyanide content in the bamboo shoots in the raw state without any pretreatments or processing could prove potentially toxic for the consumer. However, the total HCN content in the shoots decreases substantially following harvesting and the bamboo shoots sold commercially as food can be processed adequately by boiling before consumption (FSANZ 2004). Ferreira et al. (1995) reported that the acridity caused by HCN can be removed progressively upto 70 % from bamboo shoots by boiling them in water for 20 minutes at 98^0C while boiling them at higher temperatures and longer intervals removes progressively up to 96% of the acridity. Thus, the glucoside content in the bamboo shoots would be reduced to lesser than the permissible limits as determined by health standards and organizations by proper processing of the shoots before consumption.

The cyanogenic glucosides are glucosides of the α-hydroxynitriles and belong to the secondary metabolites of plants. They are amino acid derived plant constituents. The biosynthetic precursors of the cyanogenic glucosides are different L-amino acids, which are hydroxylated, then the N-hydroxylamino acids are converted to aldoximes and these are converted into nitriles and hydroxylated to α-hydroxynitriles and then glycosylated to cyanogenic glucosides (Vetter 2000; FSANZ 2004). All known cyanogenic glucosides are β-linked, mostly with D-glucose. Many edible plants contain cyanogenic glucosides, whose concentrations can vary widely as a result of genetic and environmental factors, location, season, and soil types (Ermans et al. 1980; JEFCA 1993). Table 4 summarises some of the main food sources of cyanogenic glucosides and their estimated potential yield of hydrogen cyanide released on hydrolysis. There are approximately 25 known cyanogenic glucosides, and a number of these can be found in the edible part of some important food plants. These include amygdalin (almonds), dhrrin (sorghum), lotaustralin (cassava), linamarin (cassava, lima beans), prunasin (stone fruit) and

taxiphyllin (bamboo shoots) (JEFCA 1993; Padmaja 1995). The cyanogenic glucosides in bamboo shoots is in the form of taxiphyllin, a *p*- hydroxylated mandelonitrile tiglochinin, which is rapidly hydrolysed to glucose and hydroxybenzaldehyde cyanohydrins (FSANZ 2004). Hydroxybenzaldehyde cyanohydrin then decomposes to hydroxybenzaldehyde and hydrogen cyanide. This is a means by which plants protect themselves against predators (Jones 1998; Moller and Seigler 1999). However, taxiphyllin is unusual in being comparatively thermolabile (Davies 1991). Of the 4 species studied, *B. bambos* has the least amount of cyanogenic glucosides and the young shoots are delicious.

The present study is a preliminary study and may help to throw more light on the way of consumption of bamboo shoots and help in developing protective steps towards the potential toxic effects caused by the cyanogenic glucosides present in them. The findings of this study may further be valuable for use in food composition databases and for prevention of diseases caused by cyanide toxicology due to consumption of bamboo shoots.

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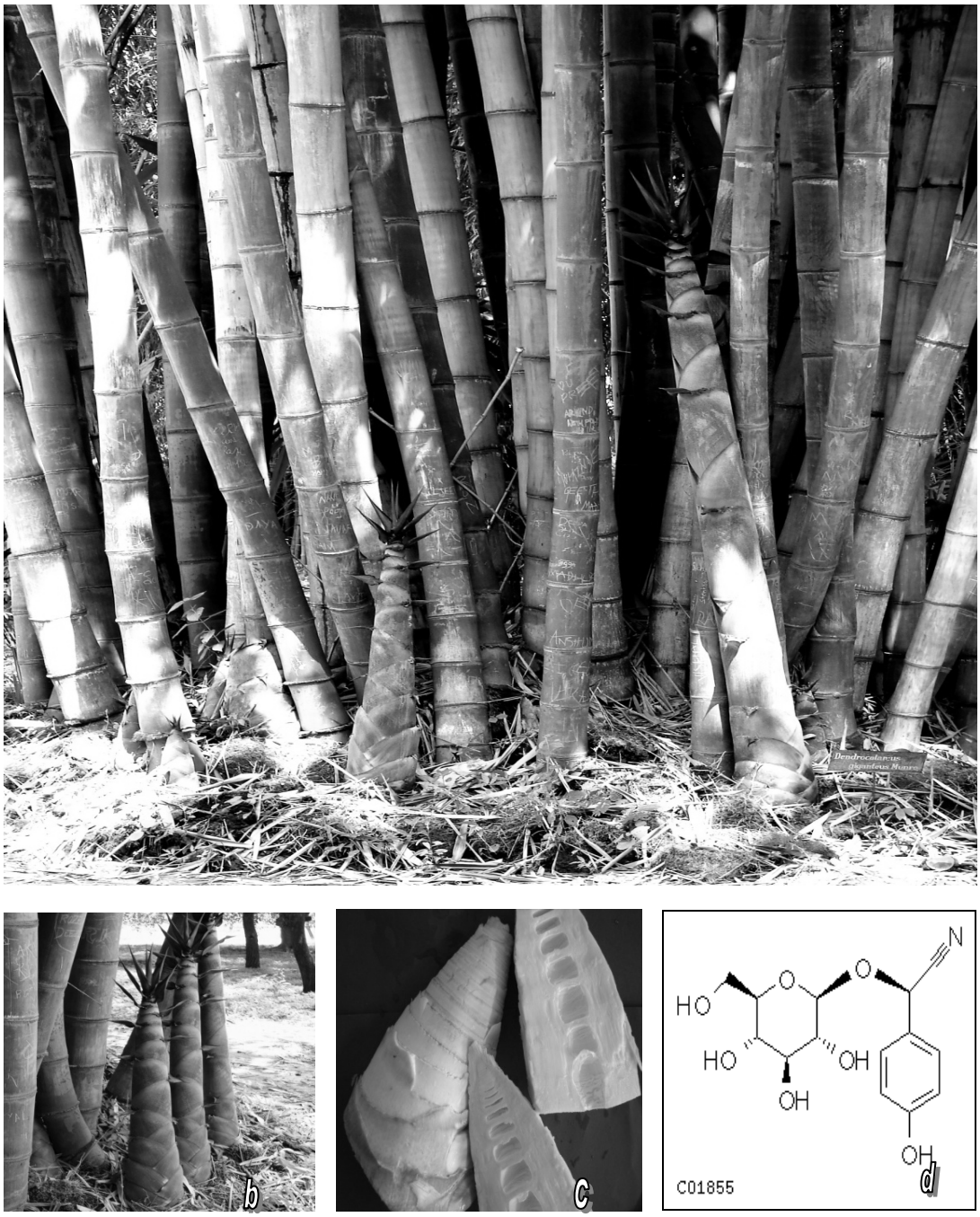

Fig.1. a. Plant morphology of *Dendrocalamus giganteus*; b. Emerging shoots; c. Sliced shoots; d. Taxiphyllin.

Table 1. Total cyanide content in mg/kg of one week old fresh bamboo shoots.

Portion of Shoot / Species	Tip (mg/kg)	Middle (mg/kg)	Base (mg/kg)
Bambusa balcooa	1006	811	304
B. bambos	859	371	223
B. tulda	746	455	331
Dendrocalamus giganteus	1164	974	857

Table 2. Total cyanide content in mg/kg of two weeks old fresh bamboo shoots.

Portion of Shoot / Species	Tip (mg/kg)	Middle (mg/kg)	Base (mg/kg)
B. balcooa	659	890	293
B. bambos	504	678	171
B. tulda	564	629	302
D. giganteus	943	1012	380

Table 3. Total cyanide content in mg/kg of three weeks old fresh bamboo shoots.

Portion of Shoot / Species	Tip (mg/kg)	Middle (mg/kg)	Base (mg/kg)
B. balcooa	445	944	188
B. bambos	422	997	139
B. tulda	391	1061	280
D. giganteus	911	1132	281

Table 4. Some of the main food sources of cyanogenic glucosides and their estimated potential yield
of hydrogen cyanide released on hydrolysis

Food source	Cyanogenic glucoside	Hydrogen cyanide yield (mg/100 g fresh weight)
Almond bitter seed	Amygdalin	290
Apricot kernel	Amygdalin	60
Bamboo stem (unripe)	Taxiphyllin	300
Bamboo sprout tops (unripe)	Taxiphyllin	800
Cassava tuber bark (less toxic clones)	Linamarin and Lotaustralin	69
Cassava inner bark (very toxic clones)	Linamarin and Lotaustralin	7
Cassava tuber bark (very toxic clones)	Linamarin and Lotaustralin	84
Cassava inner tuber (very toxic clones)	Linamarin and Lotaustralin	33
Flax seedling tops	Linamarin, Linustatin, and Neolinustatin	91
Black Lima bean, Puerto Rico (mature seed)	Linamarin	400
Peach kernel	Prunasin	160
Sorghum shoot tips	Dhurrin	240
Wild cherry leaves	Amygdalin	90-360

(adapted from: Frehner et al.. 1990, Plant Physiology, 94, 28-34)

In-vitro Organogenesis and Simultaneous Formation of Shoots and Roots from Callus in *Dendrocalamus asper*

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Abstract

Dendrocalamus asper, popularly known as sweet bamboo, is an edible bamboo having high international trade potential. Direct axillary shoot and simultaneous formation of shoot and root from callus regenerated from mature nodal explants was, obtained on MS medium supplemented with different concentrations of BAP and, 2, 4 -D in combination with BAP and with different auxins IAA, IBA and NAA. Highest frequency of axillary shoots regenerated in medium containing 7.0 mgl^{-1} BAP. Effect of 2,4- D in combination with BAP, IAA,IBA and NAA on organogenesis was studied. When the medium was supplemented with 1mgl^{-1} each of 2,4-D+BAP, 2.4-D+IAA+NAA and 2,4- D+IAA+NAA+IBA, explants developed callus which subsequently produced shoots and roots simultaneously in the same medium after 6 weeks. These further developed into plantlets and were transferred successfully to living soil. To the best of our knowledge, this is the first report of simultaneous development of shoot and root from callus in *D. asper* and is a novel technique for propagation of bamboos wherein culture initiation and root induction is the main constraint.

Keywords: Shoot-regeneration, callus, organogenesis, *Dendrocalamus asper*, micropagation, bamboo.

Abbreviations: BAP-6-benzylaminopurine, 2,4-D- 2,4-dichlorophenoxyacetic acid,IAA-indole-3-acetic acid, IBA-indole-3-butyric acid, MS-Murashige and Skoog medium, NAA -1-naphthalene acetic acid

Introduction

Dendrocalamus asper is a densely tufted sympodial bamboo and plays a major role in both shoot and timber production. In addition to being used as raw material for pulp in the paper industry, it is one of the most favored edible bamboo as its shoots are tender and sweet. Though native to South East Asia, it has been introduced in many countries due to its high economic value, especially the shoots. Due to its high shoot quality, it has tremendous demand in the international market and the species is being over exploited leading to dwindling of the natural resources. *In-vitro* propagation techniques can provide alternative means for rapid propagation of this economically important bamboo species.

For bamboo propagation, different techniques are available such as seeds, clump division, rhizomes and culm cutting (Banik 1994, 1995). But these methods suffer from serious drawbacks for large or mass scale

propagation. Micropropagation offers a rapid means of producing plant stock and overcome the draw backs of conventional propagation (Gielis 1999). *In-vitro* culture has been successful for various bamboo species using different explants *viz* seeds, seedling, embryo, stem, and leaves (Rao et al. 1990; Zamora 1994). Regeneration of *D. asper in vitro* has been achieved through induction of multiple shoots and somatic embryogenesis by using different explants seeds, and *i*n vitro shoots (Arya and Arya 1997, 2002; Arya et al. 1999, 2008a, 2008b). Organogenesis has been reported in *Bambusa multiplex, Bambusa nutans Dendrocalamus giganteus, Phyllostachys nigra* (Huang et al. 1989; Ramanayake and Wanniarachchi 2003; Kalia et al. 2004; and Ogita 2005).However, till date, there has been no report of shoots and roots being formed directly from the callus. The present paper describes for the first time regeneration of shoot and root from the callus of *D. asper* by using nodal explants.

Materials and methods

Initiation of aseptic culture

Single nodal segments (3-4 cm in length) with unsprouted bud were collected from secondary and tertiary branches of bamboo plants grown in Botanical Garden Panjab University, Chandigarh, India.. The outer prophyllus covering the axillary bud were removed and the explants swabbed with 70% alcohol, washed with fresh soapy water of surgical hand wash - chlorohexidine gluconate solution, for 10 min. Explants were treated with solution containing bavistin (0.5% w/v), streptocyclin (0.1% w/v) and rifampicin (0.1% w/v) for 10 min, followed by treatment with streptocyclin and rifampicin(0.5% w/v) and ciprofloxacin (0.25% w/v) for 2 min. The explants were then surface sterilized with 70% alcohol for 1 min followed by immersion in 0.1% mercuric chloride for 5 min. After sterilization, explants were rinsed 5 times with autoclaved distilled water. Explants were inoculated vertically to jars containing half strength Murashige and Skoog (1962) basal medium (MS) supplemented with sucrose (3% w/v), and agar (0.8% w/v) for bud sprouting and screening for any contamination.

Shoot multiplication

Sprouted buds with 3 shoots (Figure 1A) were transferred to MS medium supplemented with 3% sucrose 3.5 and 7 mgl^{-1} BAP for shoot proliferation. The elongated single shoots of about 3-4 cm in length were severed and small segments (5-6 mm) were transferred to MS medium supplemented with 1-4 mgl^{-1} 2, 4-D, BAP, NAA, IBA and IAA in different combinations to induce callus and organogenesis (Figure 1 E,F). pH was adjusted to 5.8, agar added (0. 8% w/v) and the medium autoclaved at 121°C and 1.5 kg/cm^3 for (20 min). Cultures were kept in growth chamber at (35°C ± 2°C, 16 hr light: 70 ± 5 µmol m^{-2} s^{-1} and 8 h. dark).

Rooting

A cluster of 4-8 shoots were separated and transferred to root induction medium. The shoot cluster were placed on liquid MS medium supplemented with 1-3 mgl^{-1} NAA and in combination with 1mgl^{-1}IAA. Percentage of rooted propagules, numbers, and length or roots was noted after 4 weeks in culture. Plantlet derived from callus and rooted shoot, were transferred to a mixture of soil, fine sand and peat moss (1:1:1). Humidity and light

conditions were controlled. After an acclimatization period, a cluster of 3-4 the plants were re-potted into polythene bags.

Statistical analysis

All the experiments were laid out in completely randomized design with five replications of a set of five, 25 explants were used. Induction percentage is expressed as the average percentage of explants that developed into callus, shoots or roots divided by the total number of explants used. Counts of shoots per explants and multiplication rate was presented as the mean ± standard error. The data was subjected to statistical analysis to analyse Analysis of variance (ANOVA) through General Linear Model (GLM). In order to differentiate the mean values, mean range test (LSD) was applied from SPSS version 10.5.

Results and Discussion

Micropropagation by development of axillary buds.

The axillary buds sprouted within 10-14 days and grew to 3-4 cm in length within 3 weeks. Number of axillary buds increased after transferring the sprouted nodal explants to solid MS medium supplemented with different concentrations of BAP. The shoot proliferation response varied depending on the concentration of BAP (Table 1 and Figure 1B,C). A maximum of 91.66 shoots were obtained within 12 weeks on medium containing 7.0 mgl^{-1} BAP. Number of shoots and multiplication rate is higher than that advocated by Arya and Arya (1997, 2002) wherein they obtained 65 shoots using 3mgl^{-1} BAP. Subsequently, a stock of actively proliferating shoots were maintained in medium containing 7 mgl^{-1} BAP using clumps of 3-5 shoots.

Rooting of shoots

The effect of different concentrations of NAA singly or in combination with IAA on number, length and root formation *in vitro* was studied (Table-2). Roots emerged from shoots within 2 – 3 weeks on MS medium supplemented with NAA or in combination with IAA. When NAA is used singly, roots are induced only in 60% of shoots. The medium with NAA 3 mgl^{-1} + IAA 1 mgl^{-1} was most effective as roots developed in 80% shoots (Table 2, Figure 1D). Also, root number and root length was maximum in this combination (Table 2).

According to Shirgaurka et al. (1996), bamboo species vary widely in their ability to develop roots, during vegetative propagation by classical or *in vitro* methods. Axillary shoots of *D. asper* and *Bambusa bambos* rooted well in the presence of NAA and IBA in the rooting medium (Arya and Arya 1997; Arya and Sharma 1998; Arya et al. 2002). *B. tulda* and *D. giganteus* required coumarin in addition to auxin in the medium to induce roots (Saxena 1990; Ramanayake and Yakandawala 1997). Ramanyake et al. (2006) working on *B. vulgaris*, achieved a high degree of shoot proliferation with BAP in the medium . The shoots were subsequently transferred to the rooting medium supplemented with 3- 10 mgl^{-1} IBA Roots were formed but the frequency was very low compared to rooting in shoots pretreated with TDZ for 2-3 subcultures. These findings show the variability of requirements for roots induction in some bamboo species. The auxin IAA were used in

combination with IBA and coumarin for rooting of *in vitro* grown shoots (Saxena and Bhojwani 1991). Sanjay et al. (2004) found that treatment of culm cuttings with IAA increased the roots numbers.

Micropropagation via organogenesis.

Table 3 indicates the effect of 2, 4-D in combination with BAP or with different auxins (IAA, IBA, NAA) on organogenesis . When 1-5 mgl^{-1} of 2,4-D was used singly, callus was formed but there was no further growth. Of all the growth regulator combinations used, a combination of $1mgl^{-1}$ 2,4-D+BAP, 2,4-D+IAA+NAA and 2,4-D+IAA+NAA +IBA each resulted in plantlets, where in all the others, only non regenerable callus was formed. In a medium supplemented with both 1 mgl^{-1} of 2, 4-D and BAP, 75% of explants developed callus at the cut ends within 4 – 6 weeks. Callus did not proliferate further in the same medium and 5 – 10 shoots with more then 8 – 10 roots were regenerated (Figure 1F,G,H). When 2,4-D +IAA+NAA ($1mgl^{-1}$) was used in the medium, though there was prolific production of callus, only 25% developed into shoots and roots. These further developed into plantlets and were transferred successfully to soil (Figure 1 I). A high rate of transplantation and plant survival of 95% was obtained. The results indicate that 2,4-D controls the development pathway as in all three instances where plantlets are formed, it is present in the medium. Plantlets raised from axillary shoots and organogenesis were transplanted successfully to soil with 80-90% survival rate (Figure 1J,K).

In earlier work done in bamboos, only shoots have been formed from callus. In *D. hamilltonii*, Sood et al. (1994) reported development of friable and compact-nodular callus in a combination of 2,4-D and BAP. The later formed shoot buds as well as embryoids. It is known that the identity of induced tissues in *in vitro* system is driven by the ratio of auxins and cytokinins. The different quantitative requirements for auxin and cytokinin in order to induce various tissues in culture is probably part due to different endogenous concentrations of these hormones within explants. Transfer of tissue explants to medium with higher levels of auxin induce development of root regenerative tissues, whereas transfer of explants to medium with higher levels of cytokinin induce new shoot regenerative tissues and inductive media containing both auxin and cytokinin induce proliferation of callus (Gordon et al. 2008). Many studies have confirmed that auxins like 2,4-D activate auxin response factors and auxin signal pathways and regulate genes related to growth and development (Tao et al. 2002; Yazawa et al. 2004, Che et al. 2006; Piscke et al. 2006). In *D.asper*, organogenesis via callus takes place when 2,4-D is used in combination with BAP, IAA, NAA and IBA. There is simultaneous development of shoots and roots from callus in low concentrations of growth hormones. Che et al. (2008) have reported that callus follow three basic developmental programs – somatic embryo development, shoot organ differentiation and mixed development pathway with both somatic embryogenesis and shoot organogenesis. Probably, a fourth developmental program exists wherein both shoots and roots develop simultaneously from the callus as has been seen in our present work in *D. asper*. This strengthens the suggestion that there exists a diversity of developmental programs in cultured explants. Gordon et al. (2008) have characterized early patterning during *de novo* development of *Arabidopsis* shoot meristem using fluorescent reporters of known gene and protein activities required for shoot meristem development and maintenance. Some progenitor cells have been identified that initiate development of new shoot meristems. Such progenitor cells could also be present for development of new shoot meristems. In the present work, both shoots and roots are formed from the callus in a medium supplemented with 2,4-D in combination with BAP, IAA, NAA and IBA. The combination of $1mgl^{-1}$ 2,4-D and BAP is most suitable for inducing both shoots and roots and further plantlet development. This is a novel

technique and would be of immense help in large scale propagation of *D.asper* and if applicable, to other bamboo species also, wherein culture initiation and root induction is the main constraint.

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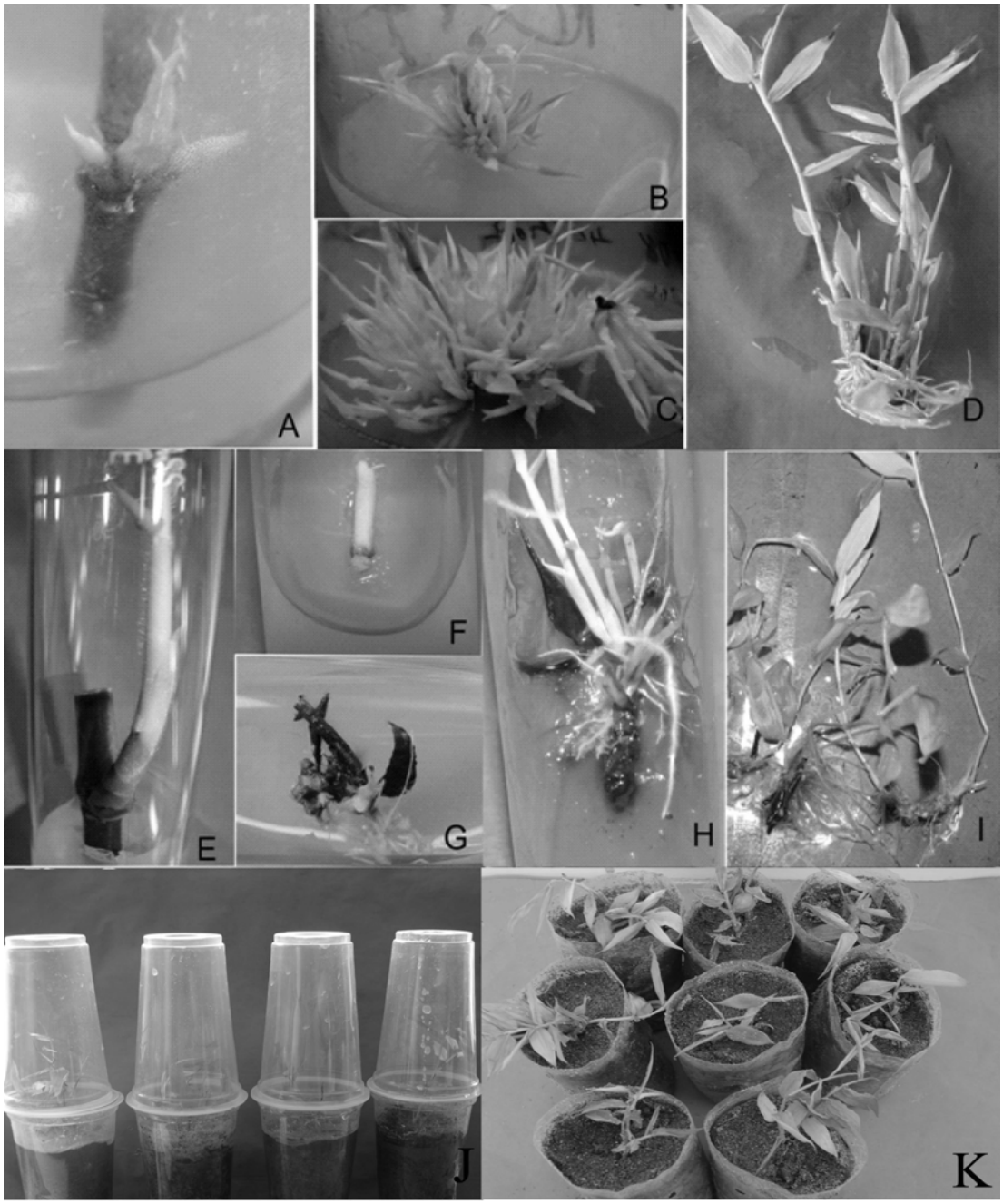

Fig. 1. A,E Bud sprouting in MS 1/2 medium containing 3% sucrose. B,C Direct regeneration of axillary shoots from nodal explants in a cluster of 3 shoots. D Rooted plant obtained through axillary shoots. F Callus induction at the cut end of nodal explants. G Shoot and root regeneration directly from the callus. H Indirect shoots developing to plantlet form. I 8-12 weeks old recovery plantlet. J Plantlet hardening. K Plants after 3-4 months

Table 1 – Effect of BAP concentration in MS medium on shoots growth after 12 weeks.

BAP Conc. mg/l	Shoot Numbers	Multiplication rate
0	Nil	Nil
3	65.00 ± 5.00[a]	21.66 ± 0.28[b]
5	75.66 ± 4.04[a]	25.22±0.34[b]
7	91.66± 7.63[a]	30.55 ±0.39[b]

Value suffixed in the rows with same letters are not significantly different with each other at < 0.05 probability level.

Table 2 – Effect of auxin on root formation of *in vitro* shoots.

NAA(mg/l)	IAA (mg/l)	Rooting (%)	No. of Roots	Root Length(cm)
0	0	0	0	0
1	0	0	0	0
2	0	20	2-3	1- 4
3	0	60	2-4	3 – 5
1	1	20	1-3	2 – 3
2	1	50	3-5	2 -4
3	1	80	8-9	4-7

Table 3 – Effect of auxins and cytokinin on regeneration.

MS +PGR (Plant growth regulators)					Phase I %	Phase II %	Results
2,4-D mg/l	BAP mg/l	IAA mg/l	NAA mg/l	IBA mg/l			
1	1	0	0	0	75% callus	75% shoots + roots	Plantlets
2	1	0	0	0	80% callus	23% roots	Roots
3	1	0	0	0	80% callus	60% callus	Callus
4	1	0	0	0	100% callus	40% callus	Callus
1	0	1	1	0	100% callus	25% shoots + Roots	Plantlets
2	0	2	2	0	100% callus	20% roots	Roots + callus
3	0	3	3	0	100% callus	100% dead brown callus	dead brown callus
4	0	4	4	0	100% callus	100% dead brown callus	dead brown callus
1	0	1	1	1	100% callus	40% shoots + roots	Plantlets
2	0	2	2	2	100% callus	100% callus	20% roots
3	0	3	3	3	100% callus	100% callus	callus
4	0	4	4	4	100% callus	100% callus	callus
5	0	5	5	5	100% callus	100% callus	callus

Micropropagation and Evaluation of Growth Performance of the Selected Industrially Important Bamboo Species in Southern India

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Abstract

This paper deals with micropropagation and field evaluation of six industrially important bamboo species viz; *Bambusa balcooa, B. bambos, Dendrocalamus asper, D strictus, D. stocksii* and *Guadua angustifolia*. Maximum multiple shoot induction was observed from the nodal shoot segments in MS liquid medium as compared to agar gelled medium with additives (ascorbic acid 50 mg/l + citric acid 25 mg/l + cysteine 25 mg/l) + NAA (0.1 -0.25 mg/l) + BAP 1.0 – 2.5 mg/l. Number of shoots per explant varied (3-8 shoots/explant) with the species. Further multiplication of shoots was the best in fresh MS liquid medium with additives + NAA (0.1-0.25 mg/l) + BAP (1.0 – 2.5 mg/l). In case of *D. asper* and *D. stricuts,* MS liquid medium with additives + NAA (0.25mg/l) + TDZ (0.25mg/l) proved the best for shoot multiplication. Optimum requirement of cytokinin varied with the species. Shoot multiplication rate varied from 2.5 – 5.0 fold in 4 weeks period. In most of the species, MS/4 basal salts medium with IBA/NAA (1.0 – 2.0 mg/l) proved the best for rooting. Hardening was found essential for 4-5 weeks.

Multilocational field trials of micropropagated plants of five species viz; *B. balcooa, B. bambos, D. asper, D. strictus* and *D. stocksii* were established in Karnataka and Andhra Pradesh during July-August, 2005. Field trials of *D. asper* and *G. angustifolia* were established in Karnataka, Andhra Pradesh and Kerala during 2005-2006. Initial survival rate of five bamboo species varied from 81-100%. Maximum survival rate was in *D. strictus* and minimum in *D. asper.* At the age of 40 months, overall growth in terms of culm height and diameter were maximum in *B. balcooa* and minimum in *D. asper.* In another trial, the initial survival rate varied from 89 to 100 per cent for *D. asper* and 81 to 100 per cent for *G. angustifolia.* At the age of 40 months, survival rate was minimum in both the species under semi arid condition as compared to high rainfall tropical humid condition. Maximum culm height and diameter were found in *G. angustifolia* in high rainfall area in Karnataka. Details of micropropagation protocols and results of the field performance are discussed in this paper.

Keywords: Micropropagation, industrially important bamboo species, multilocational trials, growth performance, Southern India.

Introduction

India is rich in genetic resource of bamboo. There are 125 indigenous and 10 exotic species in the country, which constitute 12.5% of forest area. National Mission on Bamboo Application (NMBA), National Bamboo Mission (NBM) and Department of Biotechnology (DBT) Govt. of India are promoting cultivation and improvement of 15 industrially important bamboo species in the country (Swarup and Gambhir, 2008). India is second after China in bamboo resource and having 125 species in 23 genera spread over an 8.96 million hectare area in 21 states and union territories, which is 12.8% of total forest area (Anonymous, 2003). Genetic diversity between and within bamboo species provide scope for the selection of the species and best genotypes for commercial cultivation. Apart from indigenous bamboo species, exotic species like; *D. asper*, *G. angustifolia, Phyllostachys bambusoides* and *P. pubescens* are fast growing and industrially important species have high potential for commercial cultivation in India. Demand of bamboo is estimated to 26.6 million tones and supply is only 13.47 million tones per year (Anonymous, 2003). New uses of bamboo, particularly as a substitute of wood, housing sector and value added product will increase further demand of bamboo (Pandey, 2008). Currently, India is importing timber approximately rupees 10,000 crore annually, which can be partly prevented by use of bamboo as a substitute of commercial timber. The Institute of Wood Science and Technology, Bangalore has pursued research work on bamboo on propagation, improvement and cultivation for the past one decade. With the support of NMBA, NBM and DBT Government of India, several projects are ongoing on development/refinement of protocols for macro and micropropagation, production of quality planting material, establishment of germplasm bank, field evaluation and development of agroforestry models of industrially important bamboo species.

Most of the industrially important bamboo species have long flowering cycle (30 to 120 year) which is a limiting factor for planting programme, in addition, sporadic flowering is uncertain, and short viability of seeds further restrict the availability of seeds as and when required for planting programmes. Vegetative propagation through offset cutting, rhizome splitting, culm and branch cuttings are successful in bamboo species (Banik, 1994; Seethalakshmi *et al*, 2008). Most of the classical techniques of vegetative propagation are low cost infrastructures based but are useful for small scale production of clonal planting material (Nautiyal *et al.,* 2008). For mass scale propagation (>50,000 plants/year) classical techniques are largely insufficient and inefficient and tissue culture is the only reliable method (Geilis *et al.,* 2002).

Most of the studies on micropropagation of bamboo species are based on seedling explants either through axillary shoot proliferation or somatic embryogenesis (Rao *et al.,* 1985; Saxena, 1990; Chambers *et al.,* 1991; Sood *et al.,* 1992; Woods *et al.,* 1995; Chang *et al.,* 1995; Arya *et al.,* 1999). Success rate of micropropagation of bamboo species from mature clumps have been reported with limited success rate (Hassan and Debeg 1987; Huang *et al.,* 1989; Prutpongse and Gavinlertvatana 1992; Chatuvedi *et al.,* 1993; Ravikumar *et al*., 1998; Lin and Chang, 1998; Bag *et al.,* 2000; Sanjay *et al.,* 2005; Victor *et al.,* 2006).

The present paper deals with micropropagation and evaluation of growth performance of *Bambusa balcooa, B. bambos, Dendrocalamus asper, D strictus* and *D. stocksii* in Karnataka and Andhra Pradesh and two exotics viz; *D. asper* and *G. angustifolia* in semi arid and high rainfall area in Karnataka and Kerala.

Materials and Methods

Nodal shoot segments of 2.0 -2.5 cm in length were used as a explant. Explants were surface sterilized with 70% ethanol for 30-45 seconds, followed by 0.075-0.1% Mercuric chloride for 4-5 minutes depending on the explants. Explants were washed 6-7 times with sterile distilled water. Culture tubes of 25X150 mm were used for the shoot initiation. Each culture tube consisted single explant.

Shoot initiation

In case of Dendrocalamus asper, D. stocksii and G. angustifolia, explants were used from field grown mature culms, where as, in case of B. bambos and D. strictus explants were collected from seedlings. MS medium (Murashige and Skoog, 1962) liquid and agar gelled with additives ascorbic acid (50 mg/l), citric acid (25 mg/l) and cysteine (25 mg/l) were tested with auxins (IBA and NAA 0.1-0.25 mg/l) and cytokinins (BAP 1.0-5.0 mg/l and TDZ 0.1-1.0 mg/l) to standardize the best combination and concentration of auxin and cytokinin. Cultures were incubated at 28 + 2oC temperature and 2500 lux intensity of light for 12 hours photo period.

Shoot multiplication

In vitro differentiated shoots were subcultured on fresh MS liquid medium with additives, NAA (0.1-0.25 mg/l), Kn (1.0-5.0 mg/l), BAP (1.0-5.0 mg/l) and TDZ (0.1-0.5 mg/l) either alone or in combination for shoot multiplication. Subculturing for further shoot multiplication was carried out within 2 weeks on fresh MS liquid medium. For comparison MS liquid and agar gelled media were tested for shoot multiplication. Shoot multiplication cultures were incubated at 28 + 2oC temperature and 2500 lux intensity of light for 12 hour photo period.

Rooting

Shoot clumps (2-3 shoots/clump) were used for in vitro rooting. MS/2 and MS/4 basal salt media with various auxins viz., IAA, IBA, NAA and NOA (0.5-2.5 mg/l) were tested for high frequency rooting. Initial 2-3 days cultures were kept in dark conditions, followed by under light condition at 28 + 2oC temperature and 2500 lux intensity of light for 12 h photo period for early rooting.

Hardening

In vitro regenerated plantlets of B. bambos, B. nutans, D. strictus D. stocksii and G. angustifolia were transplanted in containers (polybags of 600 cc) consisted of sand, soil and compost in the ratio of 4:2:4. In vitro raised plants were kept in polyglobules for 3 weeks. Inside polyglobule humidity was about 90% and temperature was 30+3oc. Plants were kept in shade for 2 weeks before keeping in open nursery.

Field evaluation

Micropropagated plants of B. balcooa were outsourced from Growmore Biotech, Hosur, where as the rest of the species were raised at IWST, Bangalore. Field trials of industrially important five species viz., Bambusa

balcooa, B. bambos, Dendrocalamus asper, D. strictus and D. stocksii were established at three locations (Nallal, near Bangalore, Yelawala near Mysore and Dullapally near Hyderabad) during July-September, 2005. In another trial, micropropagated plants of D. asper and G. angustifolia were used for the field trials at Aluva and Palakkad (Kerala); Thithimathi (Coorg, Karnataka) (falling under high rainfall tropical humid zone); Nallal, near Bangalore, Yelawala near Mysore and Dullapally near Hyderabad (falling under semiarid conditions) during 2005-2006. The experiments were laid in Randomized Block Design at an spacing of 5x5 m. Pits of 1 cum were made by employing mechanical jaw cum bulldozers (JCB). Periodical watering, weeding and soil working were carried out as and when required. Growth parameters such as, survival rate, culm height, culm number and culm diameter was recorded at periodical intervals. Data pertaining to survival per cent was subjected to arc-sine transformation and two way analysis of variance (ANOVA) (Jayaraman, 2001) was carried out for all the growth parameters and critical difference ($p<0.01$) value was estimated to know the significant difference.

Results and Discussion

Shoot initiation

Optimum requirement of PGR's varied with the species. MS liquid medium with additives + NAA 0.1 mg/l + BAP 2.5 mg/l favored multiple shoot induction in B. bambos and D. strictus. Where as, medium consisted NAA 0.25 mg/l + BAP 2.5 mg/l favoured rapid multiple shoot induction in D. stocksii (Figure 1) and NAA 0.25 mg/l + BAP 5.0 mg/l in G. angustifolia. In case of D. asper, medium with NAA 0.25 mg/l + TDZ 0.25 mg/l proved the best for multiple shoot induction and growth.

Shoot multiplication

Shoot clumps (3-4 shoots/clump) were essential for further shoot multiplication. MS liquid medium proved better than agar gelled medium for shoot multiplication and growth. Shoot multiplication rate improved after 4-5 passage of subculturing on shoot multiplication medium. Optimum requirement of PGR's also varied with species. MS liquid medium with additives + NAA 0.1 mg/l + BAP 1.0 mg/l favoured shoot multiplication and growth in B. bambos. Where as, medium consisted NAA 0.25 mg/l + BAP 2.5 mg/l proved suitable for shoot multiplication and growth in D. stocksii. G. angustifolia shoots multiplied the best in MS liquid medium with NAA 0.25 mg/l + BAP 5.0 mg/l. Medium with NAA 0.25 mg/l with TDZ (0.25 mg/l) favoured shoot multiplication in D. asper and D. strictus (Figure 2). Subculturing was found essential within 2 weeks medium to maintain growth and vigour. Shoot multiplication rate varied from 2.5-5 fold depending on the species. Minimum shoot multiplication was in G. angustifolia and maximum in D. asper.

Rooting

Shoot clump of 2-3 shoots were found to be ideal for rooting. Requirement of type of auxins and its concentration varied with the species. MS/4 basal salts agar gelled medium with NAA 1.0 mg/l favoured high rate (>95%) in B. bambos (Figure 3), D. stocksii and G. angustifolia (Figure 5). In case of D. asper, IBA 2.0

mg/l proved the best (100%) (Figure 4). Where as in D. strictus combined use of IBA (2.0 mg/l) + Kn / BAP (0.5 mg/l) favoured 60% rooting.

Hardening

Plantlets with 5-7 cm of shoot length with 2-3 roots proved ideal for hardening. Keeping plants in polyglobules in mist chamber for 3-4 weeks, favoured high rate of survival (>90%) in all the species. New growth of shoots and roots initiated in the 3rd week of hardening. Plantlets of 3-4 tillers with shoot length of 25-30 cm attained within 4-5 months period after hardening (Figure 6-8).

Fig 1 to 8. Micropropagation of the selected bamboo species; 1) Multiple shoot induction in *D. stocksii,* 2) Shoot multiplication of *D. strictus* in liquid medium, 3) Rooted shoots of *D. asper,* 4) Rooted shoots of *B. bambos,* 5) Rooted shoots of *G. angustifolia,* 6) Hardening of micropropagated plants of *D. asper*, 7) Hardened plants of *D. asper* and 8) Hardened plants of *D. stocksii.*

Field performance

In the first trial, the initial survival of micropropagated plants of five bamboo species in three different locations varied from 81 to 100 per cent (Figure 9). Maximum survival rate was in *D. strictus* (Bangalore) and minimum in *D. asper* (Mysore and Hyderabad). The results after 40 months showed statistically significant difference ($p<0.01$) for all the growth parameters (survival rate, culm height, culm number and culm diameter) between species and location. However, the interaction between location and species was not significant for all the growth parameters (Table 1).

Highest survival rate was found in *D. strictus* in all the three locations (100% in Bangalore, 96% Mysore and 90% in Hyderabad) and minimum in *B. balcooa* at Bangalore (85%). In case of Hyderabad, least survival rate was recorded in *D. stocksii* (54%). The results did not reveal any significant difference between the sites. *B. balcooa* culm height was significantly superior from other species in all the three location (4.34 m in Bangalore, 3.92 m in Mysore and 3.38 m in Hyderabad) (Figure 11) and was minimum in *D. asper* (1.83 m in Bangalore, 1.75 m in Mysore and 1.42 m in Hyderabad). However, culm number showed inverse pattern with maximum culm numbers in *D. asper* (15.00 in Bangalore, 11.75 in Mysore and 10.87 in Hyderabad), which was significantly superior from other bamboo species and minimum culm number was in case of *B. balcooa* (6.77 in Bangalore, 4.63 in Mysore and 4.10 in Hyderabad) in all the three locations. Culm diameter also showed similar trend as culm height (Table 1)

In another field experiment, the initial survival rate of two non indigenous species varied 89 to 100 per cent for *D. asper* and 81 to 100 per cent for *G. angustifolia* (Figure 10). The performance after 40 months of planting showed significant difference ($p<0.01$) for all the growth parameters at species level, locations wise and also the interaction between latter two levels (Table 2). The results on survival rate of *D. asper* was maximum in Kodagu location (100%) followed by Alwaye (83.5%). The per cent survival in latter two tropical humid locations was significantly different from other four semi arid areas. Least survival was observed in Hyderabad (54%). The growth parameter such as height, culm number and culm diameter was highest in Kodagu (6.83 m, 45 and 32.1 mm respectively) (Figure 12) and was least in Hyderabad (1.42 m, 7.9 and 8.5 m respectively). The values of all the growth parameters for Kodagu were significantly better from semiarid conditions such as Bangalore (Figure 13 and 14), Mysore (Karnataka), and Hyderabad (Andhra Pradesh).

The results on another exotic Columbian bamboo (*G. angustifolia*) showed similar field performance as like in *D. asper*. Where, Kodagu location showed significant higher values for survival rate (100%), culm height (13.89 m), culm number (27.3) and culm diameter (56.1 mm) compare to other locations. Minimum values for survival rate (10%) was recorded in Mysore and for rest of the growth parameters such as culm height (0.43 m), culm number (3.3) and culm diameter (7.9 mm) were low in Hyderabad trial, respectively.

The result after 40 months on overall field performance of five different bamboo species in first experiment indicated that the performance of *B. balcooa* under rain fed semiarid condition was superior. Though, the survival rate and culm number was found to be minimum, with respect to culm height and culm diameter, the result showed best performance. And also, the results showed similar kind of performance among the species in all the three locations. Another significant observation was that, the performance of local species such as *B. bamboos, D. strictus* and *D. stocksii* showed equal field performance to *B. balcooa*. But from the point of

industrial requirement criteria's such as, culm straightness, culm diameter, easy harvesting and culm wall thickness, *B. balcooa* is desirable and considered to be promising species under rain fed semiarid conditions.

Similarly, the important finding of the second experiment is that the performance of two exotic bamboo species was found to be better in Kodagu and Alwaye. The best performance in these two locations could be due to favourable locality factors and which falls under tropical humid conditions compare to other four locations, which fall under semiarid type of zones. Hence, the result showed significant interaction between location and species. The performance from the present findings clearly indicated that the two exotic bamboo species adopted well and performed better under tropical humid with high rainfall and soil factors than semiarid conditions.

Figure 9. Initial survival rate of micropropagated plants of the selected five bamboo species in three locations in southern India under semiarid condition.

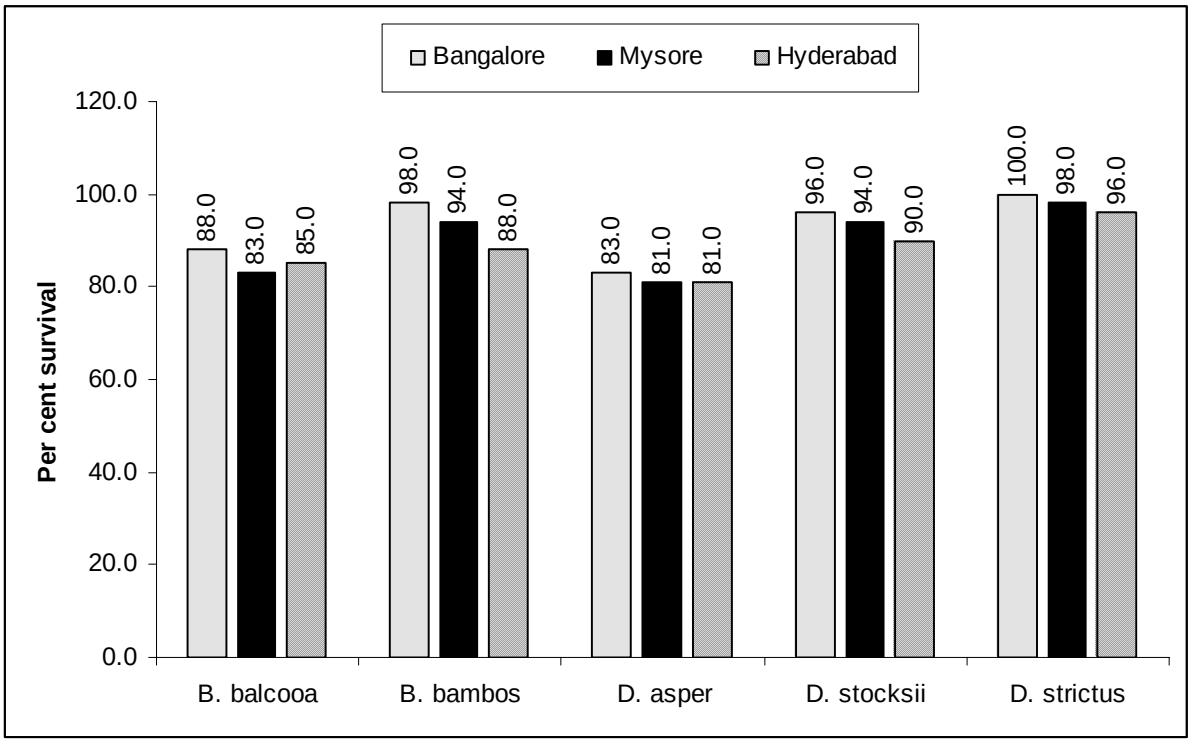

Table 1. Growth performance of micropropagated plants of the selected five bamboo species in three locations in southern India under semiarid condition after 40 months of planting.

Source	Species	Survival %	Height (m)	Culm No.	DBH (mm)
Bangalore	***B. balcooa***	85.00 (69.0)	4.34^{a}	6.77^{c}	22.2^{a}
	B. bambos	98.00 (85.1)	3.70^{b}	9.25^{bc}	14.1^{b}
	D. asper	98.00 (85.1)	1.83^{c}	15.00^{a}	8.1^{c}
	D. stocksii	96.00 (83.1)	3.56^{b}	9.38^{bc}	12.6^{bc}
	D. strictus	100.00 (90.0)	3.98^{ab}	9.75^{b}	16.0^{b}
	F - test	**NS**	**<0.01**	**<0.01**	**<0.01**
Mysore	***B. balcooa***	58.00 $(50.3)^{b}$	3.92^{a}	4.63^{c}	18.1^{a}
	B. bambos	81.00 $(68.6)^{ab}$	3.17^{b}	7.00^{b}	12.4^{b}
	D. asper	59.00 $(51.9)^{b}$	1.75^{c}	11.75^{a}	10.2^{b}
	D. stocksii	76.00 $(65.2)^{ab}$	3.20^{b}	7.13^{b}	13.1^{b}
	D. strictus	96.00 $(83.1)^{a}$	3.39^{b}	8.38^{b}	14.6^{ab}
	F - test	**<0.01**	**<0.01**	**<0.01**	**<0.01**
Hyderabad	***B. balcooa***	78.00 (62.1)	3.38^{a}	4.10^{c}	16.3^{a}
	B. bambos	72.00 (58.2)	2.85^{b}	7.20^{b}	10.8^{b}
	D. asper	74.00 (59.6)	1.42^{c}	10.87^{a}	7.6^{b}
	D. stocksii	54.00 (47.4)	2.69^{b}	6.82^{b}	10.2^{b}
	D. strictus	90.00 (74.5)	2.97^{ab}	8.16^{b}	12.4^{ab}
	F - test	**NS**	**<0.01**	**<0.01**	**<0.01**
Location X Species		**NS**	**NS**	**NS**	**NS**
SE		**10.32**	**0.15**	**0.98**	**1.81**

* Values in parentheses are arc-sine transformed. Values with the same superscripts in a column do not vary significantly and means compared column-wise; NS = not significant and SE = standard error.

Figure 10. Initial survival rate of micropropagated plants of the selected two exotic bamboo species in six locations in southern India.

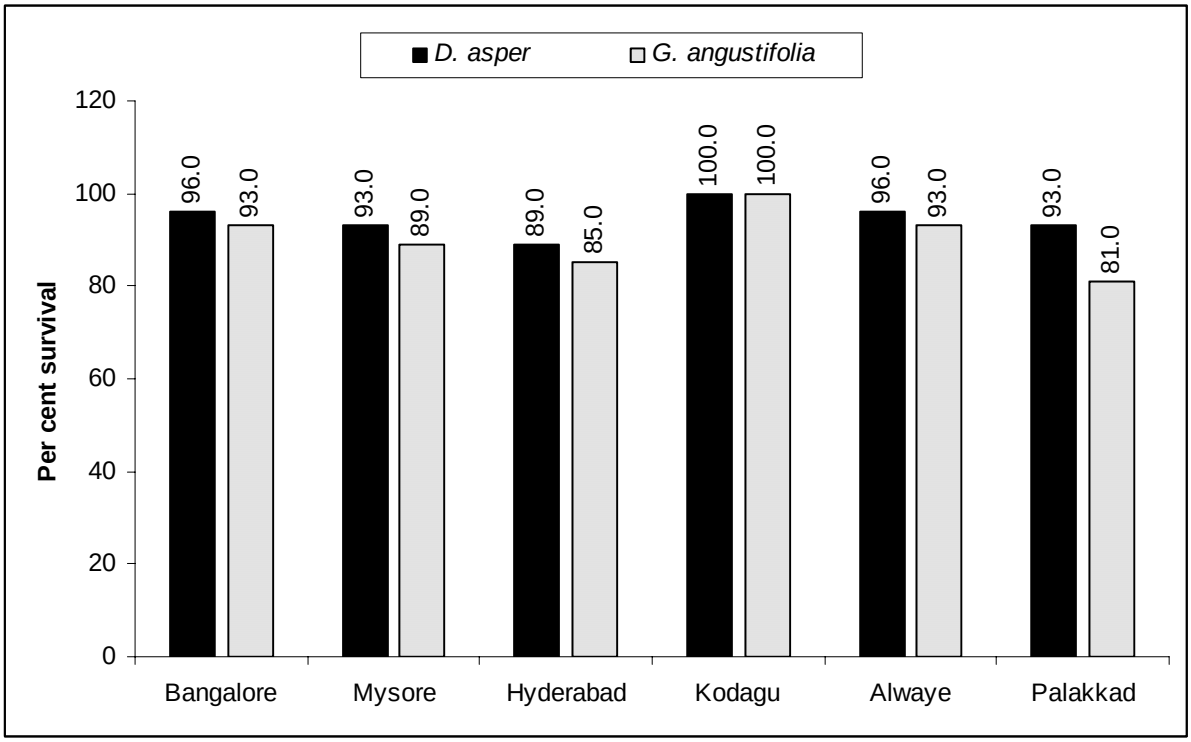

Table 2. Growth performance of micropropagated plants of the selected two exotic bamboo species in six locations in southern India after 40 months of planting.

Source	Species	Survival %	Height (m)	Culm No.	DBH (mm)
D. asper	**Bangalore**	91.00 (72.7)^{bc}	2.12^{d}	16.3^{d}	9.0^{d}
	Mysore	60.00 (50.6)^{de}	2.23^{d}	15.3^{d}	11.6^{c}
	Hyderabad	54.00 (47.1)^{e}	1.42^{e}	7.9^{e}	8.5^{d}
	Kodagu	100.00 (90.0)^{a}	6.83^{a}	45.0^{a}	32.1^{a}
	Alwaye	96.00 (83.5)^{ab}	5.75^{b}	18.9^{c}	27.5^{b}
	Palakkad	80.00 (63.7)^{cd}	3.20^{c}	31.8^{b}	12.6^{c}
	F - test	**<0.01**	**<0.01**	**<0.01**	**<0.01**
G. angustifolia	**Bangalore**	55.00 (48.1)^{c}	2.79^{c}	11.4^{b}	14.8^{c}
	Mysore	10.00 (18.8)^{d}	1.25^{e}	8.0^{b}	9.0^{d}
	Hyderabad	41.00 (39.6)^{c}	0.43^{f}	3.3^{d}	7.9^{d}
	Kodagu	100.00 (90.0)^{a}	13.89^{a}	27.3^{a}	56.1^{a}
	Alwaye	90.00 (75.2)^{b}	7.70^{b}	11.3^{b}	40.4^{b}
	Palakkad	15.00 (22.3)^{d}	2.10^{d}	11.7^{b}	15.9^{c}
	F - test	**<0.01**	**<0.01**	**<0.01**	**<0.01**
Location X Species		**<0.01**	**<0.01**	**<0.01**	**<0.01**
SE		**10.32**	**0.15**	**0.98**	**1.81**

* Values in parentheses are arc-sine transformed. Values with the same superscripts in a column do not vary significantly and means compared column-wise; NS = not significant and SE = standard error.

Fig 11 to 14. Field trials of micropropagated plants of selected bamboo species; 11) Over view of micropropagated plants of five bamboo species trial at the age of 40 months at Bangalore, Karnataka, 12) Over view of *G. angustifolia* (left) and *D. asper* (right) trial at the age of 40 months in Kodagu, Karnataka, 13) Over view of *G. angustifolia* at the age of 40 months in Bangalore, Karnataka and 14) Over view of *D. asper* trial at the age of 40 months in Bangalore, Karnataka

Conclusion

Optimum requirement of auxin and cytokinin vary with the species for shoot initiation, multiplication and rooting. Multiplication rate also varied with species. Large scale production of clonal planting material of *D. asper*, *D. stocksii* and *G. angustifolia* can be carried out from the explants collected from field grown mature clump. Where as, in case of *D. strictus* shoot necrosis and comparatively low rate of rooting (about 60%) from the shoots of mature clump. Comparatively, *B. bambos*, *D. asper* and *G. angustifolia* are easy to root than other species tested.

Field evaluation of five micropropagated bamboo species viz., *B. balcooa, B. bambos, D. asper, D. stocksii, and D. strictus* revealed that, the *B. balcooa* is most suitable species, followed by *D. strictus* based on the survival rate and growth performance in all the three locations. Based on the 40 months performance, it is concluded that *D. asper* is not suitable for semiarid conditions. The micropropagated plants of *B. bambos, B. balcooa, D. stocksii* and *D. strictus* can be used for establishment of plantations in the localities similar to the study sites. The results on field performance of two exotic species such as *D. asper* and *G. angustifolia* indicated the best performance under high rain fall areas than semiarid conditions. The results clearly indicate that, these two exotic species can be used for large scale plantation only in high rainfall tropical humid climatic zones with good deep loamy soils.

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Identifying new *Fargesia* Introductions and Predicting their Cold Tolerance using AFLP markers

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Abstract

New collections of bamboos from Sichuan and Yunnan have enriched the sortment of ornamental clumping bamboos in horticultural trade in Western Europe and North America. Various of these bamboos have been under study by collectors for almost two decades and some species have proven a success in the market. However, a lot of uncertainty remains about precise identity of these clones and their placement in genera and species. In order to resolve at least some of these issues, AFLP™ was used. The main result is that bamboos group according to geography, with a clearly delineated *Fargesia* group from Sichuan, and a group comprising *Fargesia/Borinda/Yushania* from Yunnan. As a corollary AFLP™ markers can be used to predict winterhardiness and growth performance.

New *Fargesia* bamboos in the horticultural trade

Up to the late eighties only a few types of bamboo could be found in gardens or the horticultural trade. One century earlier, over 100 different bamboos were found in European collections, following the first introduction of *Phyllostachys nigra* (Black Bamboo) in 1827. The turbulent twentieth century however, led to the destruction of many collections. In botanic gardens more types survived of course, but in Western Europe one could find only about four types of bamboo which were more or less widely distributed in gardens. These were two clumping types, namely *Fargesia murieliae* (Umbrella Bamboo) and *Fargesia nitida* (Fountain Bamboo), and two types with running rhizomes (although they behave more or less reasonably in our climate conditions), namely *Phyllostachys aurea* (Golden Bamboo) and *Pseudosasa japonica* (Arrow Bamboo).

The large scale monocarpic flowering of *Fargesia murieliae* led to the death of millions of plants in the eighties and nineties. All these plants originated from one original mother plant, collected by Ernest Wilson in the early twentieth century. Its history is a fascinating one, and during the past eighty years, the species has been subject of various name changes. During the twentieth century, *Fargesia murieliae* became one of the most popular garden bamboos, but all plants died during the flowering (Gielis et al., 1999). This flowering started in the seventies in Denmark, and peaked in the mid nineties. Also in another popular garden bamboo, *Fargesia nitida* (fountain bamboo) flowering has started in the early nineties of last century. Contrary to *Fargesia murieliae*,

Fountain Bamboo is not descending from a single plant, but is a collection of types regenerated from seeds collected by Berezowski in 1894.

Large scale flowering has prompted collectors to search for bamboos which could replace Umbrella and Fountain bamboos, mainly in SW China, where the original *Fargesia*'s were selected. These expeditions by various collectors as well as introductions from botanical gardens in China has led to a variety of new introductions in Europe and the US such as *F. denudata, F. dracocephala* (Figure 1)*, F. rufa* and *F.* 'Jiuzhaighou'. Many of these collections have been under observation for over 10 years in Europe now, and some recent articles by Jos Van der Palen (see Publications at www.kimmei.com) give extensive descriptions of the best of these new introductions.

Many of these are still under observation with collectors, but a few such as Jiuzhaighou, *F. scabrida, F. robusta* (Figure 1) and *F. rufa* are already very successful in trade. *Fargesia rufa* has been introduced at large scale since 2000, with a Silver Medal in Boskoop, and in Germany *Fargesia* Jiuzaighou and *Fargesia scabrida* have been named Bamboo of the Year by the bamboo society EBS-Germany, in 2006 and 2008 respectively.

Identifying and placing the new Fargesia where they belong

Since time immemorial, bamboo has been a real challenge to taxonomist, and has been very cumbersome in many cases. The Southwest Chinese bamboos, growing in colder regions of Gansu and Sichuan are very hard and comprise the 'core' *Fargesia*'s. *F. murieliae* and *F. nitida* were collected there, and also the more recent *F. rufa* and *robusta*, among others were collected there. The problems arises when one goes more south, towards Yunnan; here one finds bamboos which are less frost resistant, and which have a taller stature and more open growth. This has caused confusion and, although no clearcut distinction could be made, many bamboos were transferred provisionally to *Borinda* (Stapleton, 2009). Even more south, one will find subtropical species, some of which tend to have long but very tender shoots, which rather climb than grow upright. In the whole southwest of China, one will find a large diversity of clumping bamboos.

In the 1980's Chao and Renvoize (1989) grouped all these bamboos into one large clade, the "Sinarundinaria" group. This however, was not satisfactory because it was clear that many of the species and genera were too different from each other to belong to just one genus (Stapleton, 2009). In botany, one has to rely on flowering for classification, but for most of these species, flowering has never been observed. For example in the genus *Fargesia*, only in one third of the species flowers have been described. So taxonomists have had to rely on other characteristics such as the rhizomes, the culms and internodes and the growth habit.

Table 1: Differerence between *Fargesia* and *Borinda* (according to Stapleton), and the current description in the Flora of China (right column)

Characteristic	Borinda	Fargesia	Fargesia (incl. Borinda) in Flora of China
Plant	**Shrub-like to subarboreous, usually densely clumping**	**Shrub-like, densely clumping**	**Small (ca 1 m) to subarborescent (15 m) bamboos.**
Rhizomes	**Pachymorph, necks similar in length,up to 30cm**	**Pachymorph, necks to 30 cm**	**Pachymorph, short relative to culm height 10-30-(50) cm with short neck**
Growth Habit	**In single dense to loose clump (unicaespitose)**	**Unicaespitose**	**Unicaespitose**
Culms	**To 7 m tall and 3,5 m in diameter, erect or curving at base, apically nodding to pendulous**	**To 6 m tall and 2,5 cm in diameter, basally erect, apically nodding to pendulous**	**Basically erect, apically nodding to pendulous; New shoots May-Sept.**
Internodes	**To 50 cm, terete, usually finely ridged, without fine purple spots, usually blue-grey with light persistent wax, becoming glossy**	**To 30 cm, terete, usually smooth and not finely ridged, glabrous, finely purply spotted, rarely with light to dense wax at first, becoming glossy**	**Terete, smooth or finely ridged**
Nodes	**Scarcely to moderately raised**	**Scarcely to moderately raised**	**With level or weakly prominent supranodal ridge, usually narrower than sheath scar**
Branches	**5-7(-14) per mid-culm node at first, above promontory, subequal, initially erect, becoming deflexed, lateral branch axes lacking subtending sheaths**	**5-10 per mid-culm node at first, 7-20 later, often above promontory, subequal, initially erect, becoming deflexed, lateral branch axes lacking subtending sheaths.**	**Branches initially 7-15 per node in mid-culm, above promontory, initially erect becoming deflexed, subequal.**
Buds	**At mid-culm lanceolate, with 2 often very tall, single keeled bracts, open at front, closed at culm base, 3-9 initials visible within**	**At mid-culm ovate to lanceolate, with 2 tall single keeled bracts, dorsally fused in lower culms open at front (closed at culm base), several initials visible**	**Ovoid to lanceolate, branch sheathing reduced**
Culm sheaths	**Usually long-triangular, papery and deciduous (rarely oblong, thickened and persistent)**	**Oblong, shorter than internode, deciduous,**	**Linear, rounded or triangular**
Blades	**Long, reflexed, deciduous**	**Usually reflexed**	**Usually reflexed**
Leaf sheaths	**Usually persistent**	**Persistent**	
Blade	**Usually matt, thin, venation distinctly tesselate, either persistent or deciduous in winter**	**Small to medium sized, usu. glossy and thickened, normally not deciduous, transverse veins prominent**	**Small to medium sized; transverse veins prominent, blades glossy and thickened, or matt and delicate.**

Inflorescence	**(Synflorescence) ebracteate, semelauctant, branching paniculate, erect, never unilateral, ususally long exserted from narrow subtending sheath, often fasciculate in dense panicles**	**(Synflorescence) ebracteate or branches subtended by a series of small persistent delicate sheaths, semelauctant, compressed, branching racemose, unilateral**	**Racemose to paniculate, compressed or open, ebracteate or branches subtended by a series of persistent small delicate sheaths, unilateral or not**
Spikelets	**Several flowered**	**Few flowered**	**Several flowered**

This has led Dr. Chris Stapleton, then at Kew Botanic Gardens, to establish a new genus, *Borinda*. His initial studies were done in Bhutan and Nepal (Stapleton, 1994 a and b), which directly border the South-West of China, but back in England he expanded *Borinda* to include some of the *Fargesia* (Stapleton, 1998). He considers the difference between *Fargesia* and *Borinda* mainly in terms of the open growth of the (known) inflorescences (synflorescences). In colder regions, the true *Fargesia*'s are smaller and the inflorescences are very compact. More to the south similar bamboos grow taller, more open, and the inflorescence is also more open, like a panicle (see Table 1).

In the most recent *Flora of China*, which is a contemporary snapshot of the state of the art in taxonomy of this group, all the *Borinda*'s are still included under *Fargesia*, and molecular work of Chinese taxonomists has not found real evidence for the existence of a separate genus *Borinda* (Guo and Li, 2003). A very recent article (Stapleton et al., 2009) discusses this situation, in particular the state of knowledge in this group of bamboo with molecular markers at the time of publication of the Flora of China (Li et al., 2006).

The new introductions, often made by non-taxonomists, should be carefully named in order not to confuse matters further. Especially since flowering of *F. nitida* and *F. murieliae* clones has also led to the introduction of numerous seedlings under a variety of trade names. Within the group of new seedlings of *Fargesia murieliae* and *F. nitida*, a lot of mixing has taken place in trade, which adds to the confusion about the correct names. In the past we have used ALFP for various purposes, e.g. assessment of genetic stability (Gielis et al., 1997, 2001, 2004). In this study AFLP was used to unequivocally identify bamboos with the aim of specific grouping of genera and species, and additionally the hope of, either confirming the validity of a separate genus *Borinda*, or providing evidence against a seperate genus for pachymorph bamboo with open inflorescences in Yunnan.

AFLP molecular markers for identification

Both for identification and positioning of new introductions, and for the precise identification of the progeny of *F. nitida* and *F. murieliae,* AFLP™ was undertaken. AFLP™ (Amplified Fragment Length Polymorphism in full) is a method of molecular markers, which is probably the most sensitive method to identify plants correctly. In *Phyllostachys* for example, we has been used to distinguish among species and even cultivars (unpublished results). It uses DNA of the plants under study, and compares the precise DNA sequences, allowing to group the plants more closely when their DNA matches most. When the DNA diverts too much between two genotypes, they will be grouped in different groups.

For this analysis we collected material at the garden of Jos Van der Palen (www.kimmei.com) in Valkenswaard, The Netherlands, with main emphasis on the true, very hardy Fargesia's, but also less hardy bamboos from Yunnan were included. These bamboos included species which Chris Stapleton would place under *Borinda* (and these names were also used in Figure 2), and we also included *Yushania* and *Bashania* from the same region, for comparison. Also even less hardy bamboo, from India, Nepal and Bhutan were included, of the genera *Himalayacalamus, Drepanostachyum, Ampelocalamus* and *Thamnocalamus.* As a very distant relative, which is custom in DNA analysis,Thamnocalamus of South Africa was included as well. The *Fargesia murielieae* seedlings Bimbo, Kranich and Mae were included as well.

To obtain good and reproducible AFLP™ patterns, the method of material collection and storage is crucial. Suboptimal treatment or storage of the plant material will lead to DNA degradation and unreliable AFLP™ patterns. The easiest method for use in field situations, and this method is actually yielding very good DNA, is as following: Fresh, young leaves are collected and directly stored in plastic bags containing silica gel (for example Silica gel blue in bags, 1 kg, Fluka, catnr: 93505). To avoid contact between the leaves and the silica, silica in small paper bags is to be used (contact with silica results in low DNA quality!!!). To protect the DNA from degradation, the silica is renewed every day to dry the material as quickly as possible. Silica can be reused after drying it (dry silica is blue, humidity changes the color to pink).

The dried leaf material can be transported at room temperature, but for long term storage, -80º C is preferred. Alternatively, freshly harvested material is immediately frozen in liquid nitrogen and stored on dry ice for transportation to -80º C conditions.

DNA-extraction and AFLP™ analysis

DNA extraction was carried out with DNeasy Plant Mini Kit (Qiagen) according to the manufacturers instructions. The DNA is eluted in a volume of 100 µl.

Aliquots from the DNA preparations were used for AFLP™. AFLP™ analysis was performed essentially as described by Vos *et al.* (1995). Primary template DNA was prepared in a restriction-ligation reaction. Genomic DNA (250 ng) was digested with 2,5 U of *Eco*RI (Invitrogen) and 2,5 U of *Mse*I (Invitrogen) for 2 h at 37 °C in a final volume of 25 µl containing 10 mM MgOAc, 10 mM Tris-HCl buffer (pH 7,5) and 50 mM KOAc. An *Eco*RI- and a *Mse*I-adaptor, designed to avoid the reconstruction of the restriction sites, were ligated to the restriction fragments by adding 24 µl of a mix containing 5 pmol *Eco*RI-adaptor (Invitrogen), 50 pmol *Mse*I-adaptor (Invitrogen), 10 mM ATP, 10 mM Tris-HCl, 10 mM MgOAc, 50 mM KOAc and 1 µl T4 DNA-ligase (1U) (Invitrogen) and keeping for 2 h at 37 °C. The resulting primary template was diluted to 100 µl with 10 mM Tris-HCl (pH 8,0) and 0,1 mM EDTA. AFLP fingerprints were generated using a two-step PCR amplification. The first step, a preamplification, was performed with primers complementary to the *Eco*RI- and *Mse*I-adaptors with one additional selective 3' nucleotide. The PCR reactions were performed in a 50 µl volume of 5 µl primary template, 25 ng of each primer (Invitrogen), 1 U *Taq* DNA Polymerase (Applied Biosystems), 0,2 mM of each dNTP, 10 mM Tris-HCl (pH 8,3), 50 mM KCl and 1,5 mM $MgCl_2$. The PCR amplifications were carried out in a Gene Amp PCR system 9600 (Perkin Elmer) using 20 cycles, each cycle consisting of 30 s

at 94 °C, 60 s at 56 °C and 60 s at 72 °C. The preamplification products were diluted tenfold in 10 mM Tris-HCl (pH 8,0) and 0,1 mM EDTA and used as template in the fluorescent selective amplification.

The selective PCR amplification was performed using an *Eco*RI-primer tagged with a fluorescent dye and an *Mse*I-primer. The primer combinations *Eco*RI-GCT/*Mse*I-ACTA, and *Eco*RI-GCT/*Mse*I-ACTT were used. The primers contained the same sequences as those used in the preamplification but with three or four selective nucleotides at the 3' end instead of one. The reactions were carried out in a total volume of 20 µl consisting of 3 µl diluted preamplification product (1/10 of their initial concentration), 1 µl *Mse*I primer (Invitrogen) at 5 µM, 1 µl *Eco*RI primer (MWG Biotech) at 1 µM, 1 U *Taq* DNA polymerase (Applied Biosystems), 2 µl 10 x PCR Buffer (Applied Biosystems) and 0.2 µl of dNTP's (20 mM each)(Amersham Biosciences). A GeneAmp PCR system 9600 (Perkin Elmer) was used, according to the following parameters: 1 cycle of 2 min at 94 °C, 30s at 65 °C, 2 min at 72 °C, followed by 8 cycles in which the annealing temperature decreases 1 °C per cycle and the denaturation was carried out at 94°C for 1 s, followed by 23 cycles of 1 s at 94 °C, 30s at 56 °C and 2 min at 72 °C. The sample were kept at –20°C until further analysis.

The AFLP-reaction mixtures were loaded on a 3130 Genetic Analyzer (Applied Biosystems) for fragment separation according to the manufactures instructions. GeneScan-500 Rox labelled size standard (Applied Biosystems) was loaded in each lane in order to allow the automatic sizing of the DNA fragments using GeneMapper 3.7 (Applied Biosystems). The results were submitted for manual size correction. The database presents all the markers in the sample along with the marker name (e.g. GCT-ACTA-350 for the marker of 350 bp obtained after selective PCR with primers *Eco*RI-GCT + *Mse*I-ACTA), the calculated size, the annotated size and the peak height (signal intensity). These data are used to generate in MS Excel a 1/0 matrix representing the presence or absence of each marker (50-450 bp) in each plant. All AFLP data are grouped andavailable in an AFLP database with marker positions, size and height of the peak.

AFLP molecular markers reveal cold tolerance

The results are straightforward and very interesting, as can be seen from Figure 2 and Table 2, with three to four distinct groups. Table 2 lists the hardiness as it is assumed in Western European horticulture (see for example the species list of Jos Van der Palen at www.kimmei.com). The AFLP™ groups coincide precisely with the division into hardiness groups. The "Sichuan" group (Figure 2,blue arrow) is the core *Fargesia* group of very hardy bamboos, of the type *rufa, scabrida, denudata, robusta, dracocephala*, *nitida* and Jiuzaighou. Some of the names, like Wolong and Xian, indeed refer to the places where these bamboos have been collected, which is in very cold Panda region of Sichuan.

The second group is the "Yunnan" group (Figure 2, red arrow) which groups the less hardy Fargesia, like *F. utilis* and *F. angustissima*, and all of the *Borinda*. Also *Yushania* types and *Bashania* group with these *Borinda*'s indicating that geographical speciation has an important role in bamboo taxonomy, apparentely even more important than the differences in growth habit, or inflorescence.

This is also clear in the subtropical group "Himalaya" (green and yellow), where no clear distinction can be made between the various genera. Also here, it is geography, rather than anything else, which determines the group. *Thamnocalamus crassinodus* and *T. aristatus*, which clearly form a separate group.

Table 2: Groups according to winter hardiness in Europe

Group	Region	Hardiness	Genera
"Sichuan"	Sichuan, Gansu, Shaanxi	-20 to -25°C	*Fargesia*
"Yunnan"	Yunnan (Sichuan)	-8 to -20°C	*Fargesia, Borinda, Yushania, Bashania*
"Himalaya"	India, Bhutan, Nepal, Tibet	0 to -8°C	*Himalayacalamus, Drepanostachyum, Ampelocalamus, Thamnocalamus*

Fargesia resolves to be a nice clade, with distribution in cold areas (mainly Sichuan). The problematic second group consists of species of *Fargesia, Borinda, Yushania* and *Bashania fangiana.* Many of the Yunnan *Fargesia species* were transferred to *Borinda* by Stapleton, although in the Flora of China (2006) *Borinda* is included in *Fargesia.* So far, molecular markers have not been able to resolve these issues. However, when he published the genus, Stapleton (1994a and b) pointed out that *Borinda* inflorescences are similar to those of *Yushania*. The species were not transferred to *Yushania* however, because *Yushania* has usually been interpreted as a genus of spreading bamboos with long, running rhizomes while species placed in *Borinda* are all clump-forming with short rhizomes (Stapleton, 2009).

In our study it becomes clear that biogeographical considerations seem to be more important than morphological differences. Characteristics considered special to *Borinda*, such as ridged culms might have other functions, e.g. adding extra strenght to taller culms. With this grouping of *Fargesia/Borinda, Yushania* and *Bashania fangiana* into one large "Yunnan" group, it might be considered to recognize *Fargesia* in Sichuan as a separate genus, and one large clade from Yunnan, perhaps as *Yunarundinaria* in analogy to *Sinarundinaria* of Chao & Renvoize (1989), although this will obviously lead to new questions and difficulties, for example in the vicinity of separated biogeographical zones. This will be discussed in more depth in a forthcoming paper.

The professionalisation of bamboo cultivation and trade in horticulture

The production and trade of bamboo in horticulture is increasing rapidly, and sales are rising year after year, despite problems related to flowering and dying of bamboo in the past. In present times, bamboo has become an interesting tradename. The market for ornamental bamboos in Europe has increased by a factor of ten compared to the early nineties, and an estimated 5 million bamboos are produced and sold today. In the US the market is slowly emerging, in part because the market structure for ornamentals differs considerably from Europe.

A shift is also taking place however in species in trade, in production and distribution channels. More and more growers produce bamboo in larger numbers. In addition a shift towards clumping bamboos is observed. At Oprins Plant NV, the main production of *Fargesia* is through tissue culture, and the annual production is over half a million per year for this group alone. In addition, marketing and distribution has been completely changed for bamboo, compared to one decade ago. Then plants were offered sporadically at high prices, with limited availability. Today, millions of bamboo plants find their way to the market through different distribution channels. Also marketing bamboo has been revised completely: From plants with confusing latin names, today bamboos are marketed and sold under trade names like Asian Wonder, Great Wall, Green Panda and Green Screen, and under brand names like BambooSelect (www.bambooselect.com) with clear information on planting and control.

As bamboo production and trade is becoming more and more professionalised, also the quality needs to be carefully monitored, not only throughout the production and sales chain (Figure 3), but there is a clear need to identify bamboos unequivocally, to avoid any of the confusion which has plagued the sector in the past. We have applied AFLP™ since 1997 to identify genotypes, to assess genetic stability of our propagatin methods and to aid in understanding taxonomy (Gielis et al., 1997, 2001, 2004).

With molecular markers like AFLP we can resolve some important problems. It is not only possible to clearly identify bamboos and place them, but we can even predict their winterhardiness, and to some extent, how they will grow, and their overall appearance. Our results can also aid in resolving taxonomic questions and difficulties in this fascinating group of bamboos, or proposing new solutions. In any case, from a horticultural point of view we see no need to change names and genera from *Fargesia* to *Borinda* as the latter genus has no support from molecular studies, neither studies focusing on phylogeny (Guo and Li, 2003), nor from this study.

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Figure 1: Hedge of *F. robusta* Pingwu (left) and new shoots of *F. dracocephala*

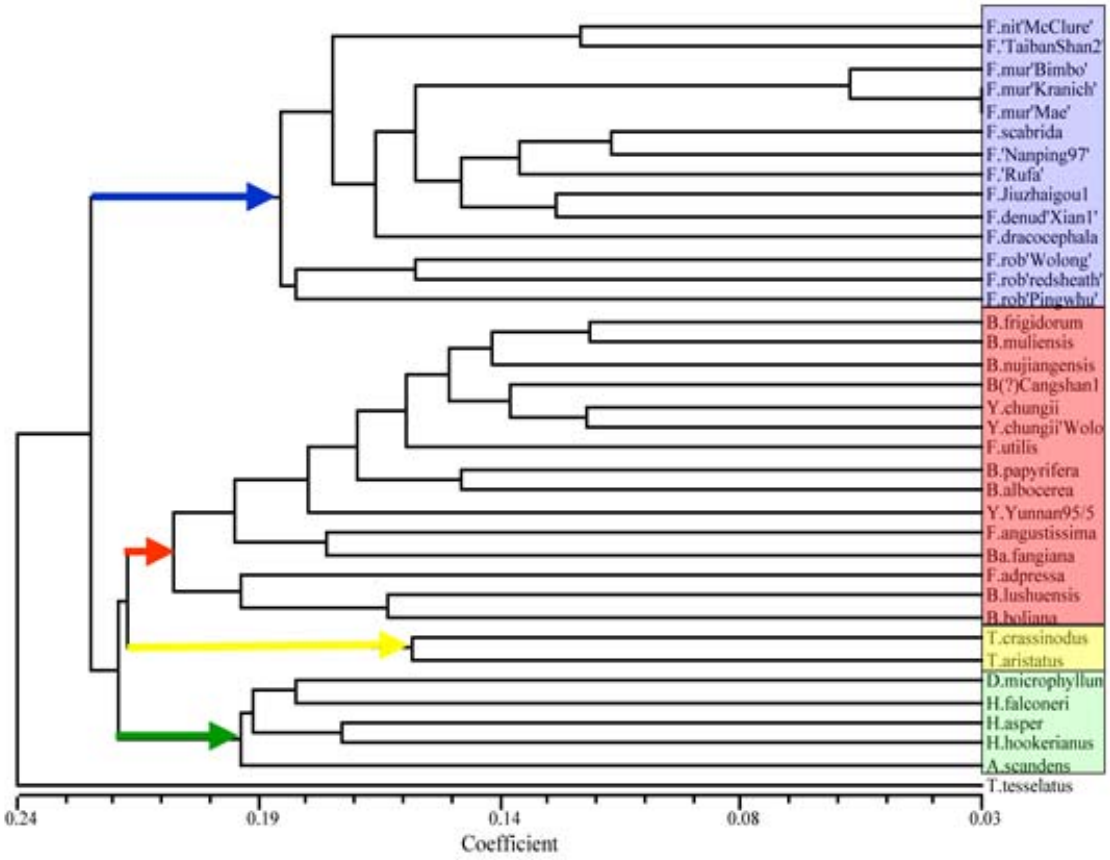

Figure 2: Dendrogram based on AFLP data

Figure 3: Large scale *Fargesia* production at Oprins Plant NV, Belgium

Allelopathic Effect of *Parthenium hysterophorus* L. on Germination and Growth of Seedlings of *Bambusa bambos* (L) Voss and *Dendrocalamus strictus* Nees

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Abstract

The allelopathic effect of *Parthenium hysterophorus* on *Bambusa bambos* (L) Voss and *Dendrocalamus strictus* Nees was investigated with water soluble extracts. The experiment was carried out under laboratory condition, using the aqueous extracts of *Parthenium hysterophorus* to determine its effect on seed germination, shoot and root length of 12 day-old seedlings over a different range of extract concentrations. The aqueous extract at 6-10% concentrations significantly inhibited seed germination and seedling growth of both the bamboo species, and the degree of inhibition increased with the incremental extract concentration. The inhibitory effect was much pronounced in root and lateral root development as compared to germination and shoot development of the test species. Number of roots increased with increasing concentrations of the extract. However the length of root was greatly reduced at high concentration. Formation of lateral roots and root hairs was inhibited in the extract treated seedlings. In 2% aqueous extract (100%) relative germination ratio (RGR) was observed in *Dendrocalamus strictus* while (61.1%) RGR occurred in 10% aqueous extract. Reduction in Vigour Index (VI) was noted in all the cases in comparison to control.

Keywords: Allelopathy, aqueous extracts, *Bambusa bambos*, *Dendrocalamus strictus*, Germination, *Parthenium hysterophorus*, Seedling length.

Introduction

Bamboos are one of the most versatile groups of plants with peculiar flowering behavior such that most of them flower at the end of a long vegetative phase which is followed by death of the culms. After flowering, germination and seedling establishment are the most vulnerable period in the life cycle of bamboos. Seedling mortality is often high with seedlings being unable to tolerate environmental fluctuations (biotic, abiotic) easily endured by mature plants. Bamboo is enduring versatitle and highly renewable resource with multifarious impact on environment and ecology. As bamboo can tolerate diverse soil and moisture regime, it has the ability to stitch and repair degraded areas, conserve soil and moisture and act as drought proof material. Its foliage shelter topsoil from the onslaught of tropical downpours while its leaf litters (up to 10cm in a year) also cushions the soil from the impact of rain and eases the soil's absorption and retention of moisture. Bamboo

preserves many exposed areas, providing micro-climates for forest regeneration and watershed protection (the plants vast underground rhizome network may cover upto 100m around one bamboo clump). It is known to be hardy, light and flexible and sought for its nutritional and environmental value, all these features impart bamboos a unique quality of resilience required for sustainable growth and development of any resource. Bamboo should be promoted as an important component of agro-forestry system and as an agri-horticultural crop as it is amenable to annual harvesting particularly edible shoots.

Parthenium hysterophorus L (Family:Asteracea; common names: Bitter weed, Parthenium weed, Ragweed, white top, etc; vernacular names: Kanike ghans, Bethughans or Padke phul) is an annual, erect and profusely branched herb. *Parthenium hysterophorus* appears to be potentially harmful weed that affect the growth and development of many crop plants. Present study reports the potential of *Parthenium hysterophorus,* the effect of its aqueous extracts on seed germination and seedling growth of two bamboo species, *Bambusa bambos* and *Dendrocalamus strictus* considered as important timber yielding plants in India. The study can be further assessed for understanding the interactions between plants like bamboos that possess high growth potential and weeds like Parthenium which can cause severe damage to the existing flora of an area due to their allelopathic effects.

Material and Methods

Plant Materials

The *Parthenium hysterophorus* L. plants growing naturally in the Delhi University campus were uprooted and collected during the month of August, 2007, sun dried, crushed and stored at room temperature (30±2°C).

Preparation of aqueous extract of the weed

Aqueous extracts were prepared by soaking 10g of crushed plant material in 100ml of sterilized distilled water at room temperature for 24 h followed by filtration through Whatman filter paper No.1 and the final volume was made up to 100ml, making a 10% aqueous extract. The extract was considered as stock solution and a series of solution with different strengths (2, 4, 6 and 8%) were prepared by further dilution of the stock solution. Twenty uniform and surface sterilized seeds (0.045% $HgCl_2$ for 5 seconds) of two commonly used varieties of bamboos, *Dendrocalamus strictus* and *Bambusa bambos* were germinated in sterilized 9.0 cm Petri dishes lined with blotting paper and moistened with five milliliter of different concentrations of aqueous extracts. Each treatment had three replicates (total number of test seeds: 20x3=60). One treatment was run as control with sterile distilled water only. The Petri dishes were maintained under laboratory conditions at the temperature 25±2°C.

Determination of seed germination and seedling growth

The emergence of plumule and radicle was considered as the criteria for seed germination. The results were determined by counting the number of germinated seeds which was recorded daily beginning from the first day of germination up to ten days and expressed as per cent seed germination. Number of lateral roots was recorded

and the length of primary root and main shoot were a measured. Ratio of germination and elongation were calculated as suggested by Rho and Kil (1986).

$$\text{Relative germination ratio (RGR)} = \frac{\text{Germination ratio of tested plants}}{\text{Germination ratio of control}} \text{ x } 100$$

$$\text{Relative elongation ratio (RER) of shoot} = \frac{\text{Mean length of shoot of tested plant}}{\text{Mean length of control}} \text{ x } 100$$

$$\text{Relative elongation ratio (RER) of root} = \frac{\text{Mean length of root of tested plant}}{\text{Mean length of control}} \text{ x } 100$$

The response index (RI) was calculated according to Williamson and Richardson (1988):

Germination of treatment (T) was higher than control (C)

RI= 1-(C/T)

When germination of treatment (T) was lower than control (C)

RI= (T/C)-1

If RI>1= Treatment stimulates germination

If RI=0 Effect of treatment is nil

If RI<1= Treatment inhibits germination

Statistical Analysis: Significance of the difference in root and shoot length of seedlings under different treatments were tested and compared using Analysis of Variance (ANOVA). All statistical analysis was done using Statistical Package for Social Sciences (SPSS version 11.5, 2002).

Results

Germination

In control, seeds germinated within 72h. Whereas in seeds treated with equal amount of different concentrations of the aqueous extract of *Parthenium hysterophorus,* the rate of germintion varies from three days to six days. In 2% concentration, seeds germinated after three days while in 10% concentration it took place after five days of treatment. As compared to the control, the aqueous extract of *Parthenium hysterophorus* exhibited significant ($P<0.05$) inhibition on seed germination. With the increase in concentration of aqueous extract, the inhibitory effect increased progressively. In both the test species maximum inhibitory effect was found in 10%

concentration. Maximum (100%) relative germination ratio (RGR) was found in *Dendrocalamus strictus* at 2% concentration while minimum (61.1%) RGR in *D. strictus* was observed at 10% concentration (Fig. 1A). *Bambusa bambos* was less sensitive to the application of crude aqueous leaf extracts of *Parthenium hysterophorus* as compared to *D. strictus*.

Seedling growth

Analysis of variance showed significant difference ($P< 0.05$) between treatments in influencing seedlings shoot and root length of the test species. As compared to control, aqueous extracts had deleterious effect on shoot and root length. In control, bamboo seedling showed fully developed leaf with well expanded leaf lamina after two weeks (Fig. 2 A&B). At 2-4% concentration of treatment there was no significant ($P< 0.05$) difference in the length of shoots as compared to the control. However, the shoot length was significantly different from that of control at 6% concentrations of *P.hysterophorus* leaf extract. At 8-10% concentration in both the test species the length of and the formation of leaves got highly suppressed (Table 1). The inhibitory effect of treatments got progressively pronounced with the increase in concentration of the extract. Among the germinated seedlings, the maximum (98.25%) relative elongation ratio of shoot was observed in *D.strictus* followed by *B.bambos* (94.52%) in control treatment while the minimum (46.73%) was in *B.bambos* followed by *D.strictus* (48.16) at 10% concentration of the aqueous extract (Fig. 1B).

ANOVA showed significant difference ($P< 0.05$) between treatments in root length of the test species. In control, bamboo seedling showed formation of primary root from the radicle. The primary roots elongated and formed several lateral roots with numerous root hairs. At 2-4% concentration, there was no significant difference in the length of roots as compared to the control but the primary roots formed less number of lateral roots and root hairs in the treatment. 6% aqueous extract of *P. hysterophorus* leaves cause significant difference in the root length in comparison to control. At 8-10% concentration, in both the test species the length of roots was highly reduced. In 85% of the tested seeds at 6-10% concentrations, there was rudimentary roots formation (three to four small root-like short, dark and thick protrusions appeared at the base of each shoot) and lateral roots and root hairs were completely absent. Maximum (97.24%) and minimum (3.10%) relative elongation ratio (RER) of root were observed in *B.bambos* at control and 10% concentration of the extract treatment, respectively (Fig. 1C).

The vigour index (VI) was also greatly affected by *P.hysterophorus* extract in both the species of bamboo. According to Williamson and Richardson (1988), the values of Response Index (RI) indicates stimulatory (if $RI>1$), inhibitory (if $RI<1$) and no effect (if $RI=0$) on seed germination. In the present study, from 6-10% concentration of the extracts, RI values of *P.hysterophorus* was ($RI<1$) inhibitory in both the varieties, indicating that *P.hysterophorus* extracts exhibited allelopathic effect on seed germination of both the test species.

Discussions

This study demonstrated that aqueous extracts of *Parthenium hysterophorus* exhibited allelopathic activity on bamboo seed germination as well as seedling growth. The degree of inhibition was significantly dependent on

the concentration of the extract being tested. These results indicate that the allelochemicals present in the aqueous extract of *Parthenium hysterophorus* adversely affect seed germination, growth and development of shoot, root, root hairs and lateral roots. The effect was more pronounced at higher concentrations, where the effect was so severe that, the 10% concentration completely inhibited the growth of roots in both the test species. Overall growth of seedlings was also reduced in almost all the treatments as compared to the control as also reported by Donger and Singh (2007). A number of studies have suggested that the degree of germination, shoot and root growth inhibition increased with increasing extract concentration of allelopathic species (Han et al. 2008; Kumar and Gautam 2008; Rai and Triparthi 1984; Rizvi and Rizvi 1987).

In the present study, there was significant inhibition in seed germination at high concentrations of aqueous leaf extracts. Among the treatments, 8% and 10% aqueous extracts had the strongest inhibitory effect on germination. However, complete suppression of seed germination was not observed in both the test species even at the maximum (10%) concentration. It is in contrast with the report of Tefera (2002) who found that 10% aqueous extracts of *Parthenium hysterophorus* resulted in complete failure of seed germination in *Eragostis tef*. The complete inhibition of seed germination could occur only when some allelochemicals present in the leaf extract prevented growth of embryo, or caused the death of embryo (Rajendiram 2005). Maharjan et al. (2007) also reported that 10% aqueous extracts of *Parthenium hysterophorus* completely inhibited seed germination of *Oryza sativa, Triticum aestivum, Ageratina adenophora, Artemisia dubia, Raphanus sativus, Brassica campestris* and *Brassica oleracea*.

From the analysis of variance it was found that the shoot length of both the test species (*B.bambos* and *D.strictus*) at 2-4% concentration was not significantly different from that of the control. Reduction in shoot length was significantly different at 6% and above concentrations. At higher concentration (10%) there was formation of more than one shoot from the embryonal end of the caryopsis of *D.strictus*. However there was complete failure of leaf formation in both the test species and the shoot length was significantly different from the control. Similar effects of leaf extract of *Parthenium hysterophorus* was reported by Maharjan et al. (2007) on some cultivated and wild herbaceous species, Tefera (2002) on *Eragostis tef* and Rajan (1973) on wheat. Singh et al. (2005) also reported a strong positive correlation between extract concentration of residues of *Parthenium hysterophorus* and reduction in seedling length of *Brassica* species.

In the present investigation, roots appeared more sensitive to the allelopathic extracts than shoots. Lateral root development was significantly decreased with increasing concentrations of the extract. This finding is congruent with the results of Amoo et al. (2008) who found that the root length is a more sensitive indicator of phytotoxic activity. The stronger inhibitory effects on roots might have been caused by the fact that roots were in direct contact with the extract and subsequently with inhibitory chemicals (Bhowmik and Doll 1984; Quasem 1995). The reduction in root length may indicate that cell division was affected as allelopathic chemicals have been found to inhibit gibberellin and indole acetic acid function (Tomaszewski and Thimann 1966). Such an outcome might be expected, because it is likely that roots are the first to absorb the allelochemical compounds from the environment (Turk and Tawaha 2002).

Present results showed that the aqueous extract of *Parthenium hysterophorus* inhibited seed germination and seedling growth of *Bambusa bambos* and *Dendrocalamus strictus.* Reduction in shoot length, formation of more

than single shoot and reduction in root formation as observed in the present study corresponds to the function of growth regulator (cytokinin) which is known to induce multiple shoots and reduction in root formation. However, further studies are required to identify and check the levels of its concentration in different parts of this weed. It can be concluded that there are compounds in the leaves of *Parthenium hysterophorus* which may cause allelopathic effects and mimic the effects of growth regulator on the germination and seedling growth of both the test species.

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Table 1. Effect of the aqueous extracts of Parthenium hysterophorus on length of shoot, length of root, number of roots and lateral roots of *Bambusa bambos* and *Dendrocalamus strictus.*

Bambusa bambos

Treatment	Shoot Length	Root Length	No. of roots	No. of lateral roots
0%	4.41±0.16	3.63±0.19	1.1±0.10	11.8±0.72
2%	4.17±0.15	3.57±0.05	1.0±0.14	9.5±0.10
4%	3.95±0.22	3.14±0.31	1.8±0.13	8.2±1.52
6%	3.0±0.09*	0.53±0.12*	2.6±0.13	0.09±0.10*
8%	2.91±0.17*	0.39±0.03*	2.8±0.19	0.03±0.61*
10%	2.51±0.11*	0.35±0.29*	3.2±0.41	0

Dendrocalamus strictus

Treatment	Shoot Length	Root Length	No. of roots	No. of lateral roots
0%	5.07±0.19	3.92±0.40	1.0±0.22	13.5±1.92
2%	4.69±0.21	3.85±0.16	1.30±0.15	11.7±0.30
4%	5.02±0.22	3.53±0.27	1.5±0.52	5.5±0.71
6%	3.99±0.12*	0.99±0.19*	1.8±0.13*	3.9±0.83*
8%	3.45±0.23*	0.79±0.16*	2±0.21*	1.6±2.9*
10%	3.09±1.68*	0.36±0.03*	2.2±0.20*	0.9±0.31*

Values are mean±SE of ten replicates. *indicates significant difference

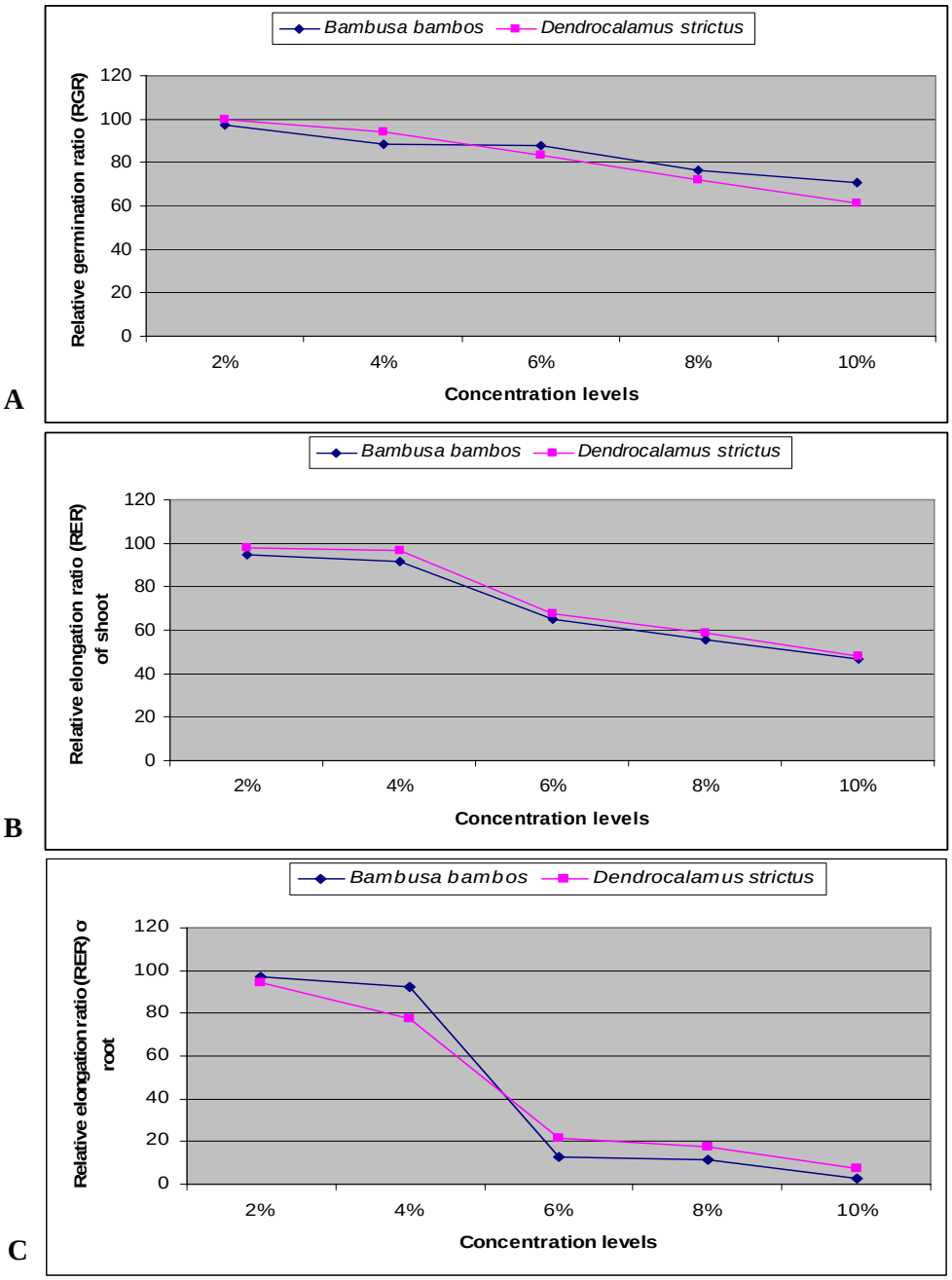

Figure 1. Line graph showing (A) the relative germination ratio (RGR), (B) the relative elongation ratio (RER) of shoot and (C) the relative elongation ratio (RER) of root on bioassay studies of *B.bambos* and *D.strictus* caryopses treated by different concentrations of water soluble extracts of *Parthenium hyterophorus*.

Figure 2. Effect of *Parthenium hysterophorus* plant aqueous extracts on seedling growth of *Bambusa bambos* (A) and *Dendrocalamus strictus* (B)

Exploring the Nutraceutical potential and Food Safety Aspect of Bamboo shoot of Some Indian Species

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Abstract

Young bamboo shoots are extensively eaten as pickle, vegetable or as a fermented product in most of the eastern countries like China, Japan, Thailand etc. The nutraceutical potential of bamboo shoots remains unexplored despite these being rich in dietary fiber and protein content and low in fat percentage. Similarly, cyanogenic toxicity in bamboo shoot - an important aspect related to food safety has not been given sufficient attention. The present study is designed to investigate the functional properties of bamboo shoots harvested from 4 edible species namely *Dendrocalamus strictus, Bambusa tulda, B. vulgaris and B. balcoa* in order to explore their nutracentical potential. Bamboo shoot samples are analyzed for protein, vitamin C, total phenol content and antioxidant activity by DPPH assay and TAA. The protein, Vitamin C & total phenolic content of the shoots ranged between 18.74-25.84g/100g, 5.0-6.6 mg/100g and 153.91-222.81 GAE/g dry powder, respectively. It was found that amongst all the species *B. balcoa* contained highest content of total phenolics (222.81 GAE/g dry powder), crude protein (25.84%) and vitamin C (6.6%). It also possesses highest antioxidant activity by DPPH assay (39.85% free radical scavenging power) and TAA (3.15 mg GAE). Raw fresh shoots of *D. strictus and B. vulgaris* were found to contain 386 and 200 ppm of cynogenic glycoside respectively which can be reduced to permissible limit by suitable processing methods. The results obtained indicate a strong correlation between the nutrient components and antioxidant power in bamboo shoot and its potential as a nutraceutical for prevention of metabolic disorders. Since studies on the antioxidant properties and toxicity related issues of bamboo shoots are scanty, R&D work on preparation of bamboo shoot based nutraceutical formulations as well as recipes after eliminating the toxicity would open new avenues in the area of nutraceuticals.

Introduction

Bamboos a group of giant arbores cent grasses belong to the family Poaceae and sub- family Bambuseae. More than 1250 species belonging to 75 genera have been reported to be distributed worldwide out of which 125 species are growing in India spreading over an area of 9.57 million hectare. India has rich bamboo resources after China. The North Eastern states are endowed with more than 50% of the Indian bamboo genetic resources (Sharma et al 1992)

Application of bamboo in the structural and building materials along with its use in cottage industry is globally recognized. Recently, R&D work on bamboo as a modern engineering material for structural and agricultural applications has been taken up at IIT Delhi. Similarly the edibility of tender shoots has generated a lot of business potential in countries like China, Japan, and Thailand etc. The tender shoots of a few species are consumed either as vegetables or in curries or as pickles. Extensive practice of fermenting shoots is carried out in the North Eastern states of India and other countries since ancient times (Singh et al, 2003). Surprisingly in India despite of several edible species being grown in certain states, potential of bamboo shoot as food has not been explored in areas other than North Eastern Region.

Bamboo shoots contain several nutritional components like protein, carbohydrates, fat, vitamins, minerals, enzymes, coenzymes, reducing and non-reducing sugars, lactic acid and citric acid (fermented products) etc. Bamboo shoot being rich in fiber and protein and low in fat (Yamaguchi M, 1983) may be considered a nutraceutical product. It also contains lignans and phenolic compounds which may contribute to its antimicrobial activity and antioxidant property. Fermented bamboo shoots are an excellent source of phytosterols which are the precursors of pharmaceutically important steroidal products such as sex hormones and oral contraceptives. (Srivastava and Sarangthem, 1994). Recently compounds of nutritional importance like α-tocopherol (0.26 mg/100 g), γ-tocopherol (0.42 mg/100 g), β-carotene (1.9 μg/100g) and lutein (35.6 μg/100g) have been reported in raw bamboo shoot (Kim et al, 2007).

Along with above excellent food and nutritional characterteristics, raw bamboo shoots have been found to contain cyanogenic toxicity. Taxiphyllin (4-hydroxy-(R)-mandelonitrile-b-D-glucopyranoside), a cynogenic glycoside (Conn 1969) has been found to be the potential toxic component. The acute lethal dose of HCN for humans is 0.5-3.5 mg/kg body weight (Jones 1998). But FAO/WHO Codex Alimantarius has defined a safe limit for human consumption which is 10mg HCN equivalent per kg dry weight (FAO 1991). However, when the dose is relatively small, humans are able to detoxify and excrete in the urine. Chronic cyanide poisoning sets in due to lack of nutrients like riboflavin, protein, vitamin $B_{12,}$ sodium & methionine. Chronic sub-lethal dietary cyanide has reportedly caused serious reproductive effects (Food standards Australia 2005).

In view of the above, present study aims at exploring the nutraceutical potential of bamboo shoot of 4 bamboo species namely *Dendrocalamus strictus, Bambusa tulda, B. vulgaris and B. balcoa*. Cyanogenic toxicity in bamboo shoot – an important but overlooked aspect is also studied for food safety. Cyanide and its removal by optimum processing method have been attempted thus reflecting light on the processing methods by which toxicity in bamboo shoots can be eliminated.

Nutrition and Nutraceuticals

The term "Nutraceutical" was coined from "nutrition" and "pharmaceutical" in 1989 (DeFelice 1995). In 1992 De Felice defined Nutraceuticals as any substance that may be considered as food or a part of food and provide medical and health benefits including prevention and treatment of disease. Nutraceuticals may range from isolated nutrients, dietary supplements, herbal products and processed products such as cereals, soups and beverages (DeFelice 1992). Based on the chemical characteristics, nutraceuticals are broadly put up into seven different classes (Wildman 2006) as shown in Figure 1. In order to have a close look at the nutritive value of

bamboo shoot of different species, a brief compilation of reported data has been done (Table 1). It indicates the need of systematic scientific investigation of bamboo shoot of selected species for exploring its nutraceutical potential.

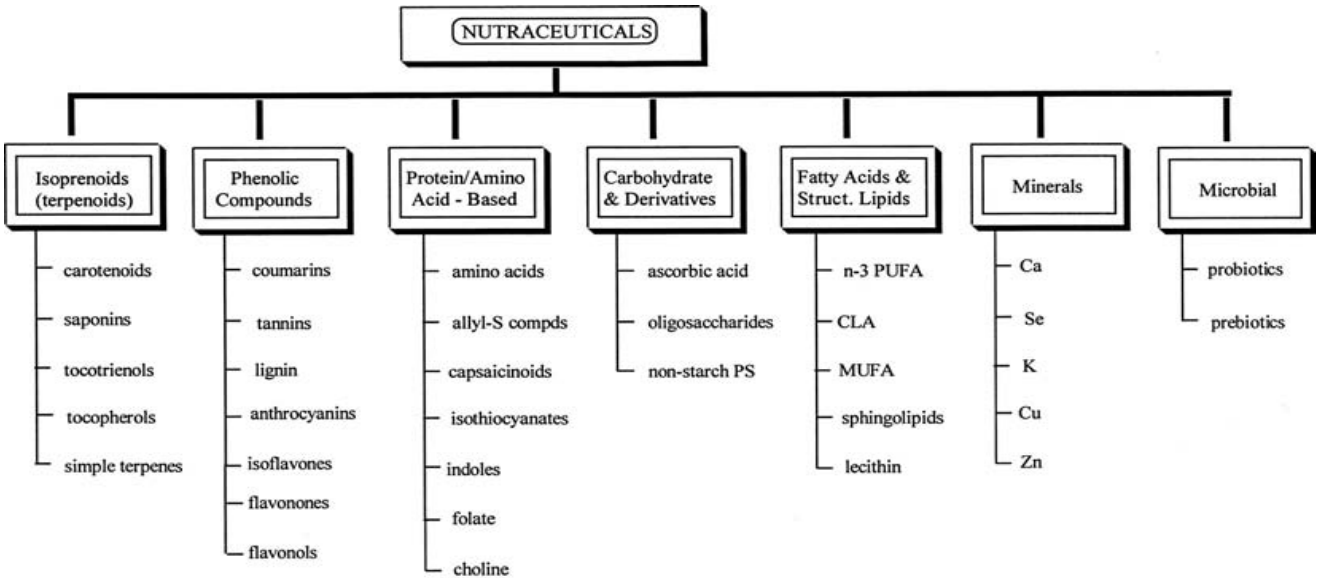

Figure 1: Classification of nutraceuticals

Table 1: Nutritive value of Bamboo Shoot – General Scenario

S.No	Species	Calories (Kcal)	Moisture (%)	Crude Protein (%)	Crude Fat (%)	Carbohydrate (%)	Ash (%)	Crude fiber (%)	References
1	*Bambusa arundinaea*	—	54.0	5.33	—	10.0	—	—	Bhargava et al, 1996
2	Species not mentioned	294	11.6	29.6	0.4	43	8.5	6.9	Rajyalakshmi & Geervani, 1994
3	Species not mentioned	27	91	2.6	0.3	5.2	—	—	Yamaguchi M, 1983
4	*Bambusa bamboos*	--	89.83	3.57	3.55	5.42	1.38	3.535	Nirmala et al, 2007
5	*Bambusa balcoa*	15.5-15.6	84-86.3	3.3-3.87	0.6-1.0	5.2-5.23	3.1	26.4	Bhatt et al, 2003
6	*Dendrocalamus. strictus*	—	—	19.2	—	2.6	0.90	0.98	Kumbhare and Bhargava, 2007

Materials and methods

Collection of raw material (bamboo shoot) and sample preparation:

Bamboo shoots of four species of viz. *Dendrocalamus strictus, Bambusa tulda, B. vulgaris and B. balcoa* were procured from Bamboo Forest TERI Gram, Mandi Village, near Delhi (India) during rainy season. The samples were washed with water and the sheaths were removed in a concentric manner from the base to the top. Nodes and internodes were separated. Internodes were oven dried at 60 ± 2°C for 8-10 hours and finely powdered for further analysis. For toxicity determination the shoots were washed, peeled and cut into rings as above. 200mg of fresh shoots were taken for cyanide analysis. The samples were analyzed in triplicates.

Analysis of bamboo shoot for nutrients

Preparation of methanolic extract

The dried and finely ground shoot samples (0.4g) were extracted with 20 ml methanol in a shaking incubator at 45°C for 2 h. The mixture was centrifuged at 5000 rpm for 10 min and subsequently decanted. The residue was re-extracted for 2 h and supernatants were mixed together. The mixture was concentrated using a rota evaporator and stored at 0°C in freezer until analyzed for total phenolics and antioxidants.

Determination of Total Phenolics (TP)

Amount of TP was assessed using Folin–Ciocalteu reagent procedure as described by Li et al, 2008. 0.5 ml of Folin–Ciocalteu reagent and 7.9 mL deionized water were added to a test tube containing 0.1 mL of methanolic extract of bamboo shoot. The mixture was kept at room temperature for 10 min, and then 1.5 mL of 20 g/100 mL sodium carbonate was added. The mixture was heated on a water bath at 40°C for 20 min and then cooled in an ice bath before absorbance at 755 nm was measured. The results are expressed as gallic acid equivalents (GAE) per g of dry matter.

Determination of Vitamin C

Extract 0.5g of the sample in 4% Oxalic Acid and make up to 100ml and centrifuge. Pipette out 5ml of the supernatant and add 10ml of 4% Oxalic acid and titrate against the dye containing 2,6-dichlorophenol indophenol till a light pink colour appears and persists for a second. Similarly titrate the standard solution containing ascorbic acid of 100µg/ml concentration (Harris and Ray 1935)

Protein estimation

Crude protein was estimated using elemental analyzer (Elementar analysensysteme GmbH, Germany) model Vario EL III, in which 10 mg of dry powder was sealed in a tin boat and introduced into the instrument. The nitrogen value was obtained as percent total nitrogen content and it is factored with 6.25 to get the crude protein content.

Antioxidant analysis

Free radical scavenging activity using 1,1-diphenyl-2-picryl hydrazyl (DPPH)

DPPH, a commercial oxidizing radical is reduced by antioxidants. The disappearance of the DPPH radical absorption at a characteristic wavelength is monitored by decrease in optical density (Singh, Murthy and Jayaprakasha, 2002). To 0.1mL methanolic extract of bamboo shoot, four ml of 60µM methanolic solution of DPPH was added. The tubes were shaken vigorously and allowed to react for 30 min at room temperature in the dark. The control prepared without any sample was used for base line correction. Changes in absorbance of samples were measured at 515 nm. Free radical scavenging activity was expressed as inhibition percentage and was calculated using the following formula.

$$\% \text{ Free radical scavenging activity} = \frac{(\text{Control OD} - \text{Sample OD}) \times 100}{\text{Control OD}}$$

Total Antioxidant Activity (TAA)

The assay was based on the reduction of Mo (VI)-Mo (V) by the extracts and the subsequent formation of a green phosphate/Mo (V) complex at acidic pH (Prieto et al, 1999). 0.1 ml of the methanolic extract of bamboo shoot was combined with 3 ml of reagent solution (0.6 M sulphuric acid, 28 mM sodium phosphate and 4 mM ammonium molybdate). The tubes were incubated at 95°C for 90 minutes, after which the mixture was cooled to

room temperature; the absorbance of the solution was measured at 695 nm against blank. The total antioxidant activity is expressed as Gallic acid equivalent.

Determination of Total Cyanide content

Total Cyanide content was determined by the acid hydrolysis method (Rezaul Haque & Howard Bradbury 2002). Fresh bamboo shoot samples (200mg, triplicate) were taken in a stopperd test tubes followed by 20ml of Phosphoric acid (0.1M). The tubes were centrifuged and then 10 ml of the supernatant solution was mixed with 10 ml of H_2SO_4 (4M). The mixture was boiled for 10 minutes and then ice cooled. Further 10 ml of NaOH (3.6M) was added and make up to 25ml in a volumetric flask. Absorbance solution was prepared by using 3 ml of the solution from the flask with little NaOH (0.04M) and 0.5ml acetate buffer. After adding 1ml of Chloramine T, the solution was allowed to stand exactly for 2 minutes. Then 5ml of Pyridine-Barbituric acid reagent was added dilute to 25ml with NaOH (0.04M) and let stand exactly 8 minutes. Measurements were taken at 578nm using UV-Visible spectrometer (PerkinElmer Inc., USA).

Results and discussion

Data of bamboo shoot samples analyzed for protein, vitamin C, total phenol content and the antioxidant activity for different species of bamboo shoots namely *B. balcoa , B. vulgaris, D. strictus and B. tulda* are presented in Table 2. cyanoglucoside content in these samples is also given in the last column.

Table 2: Analysis of bamboo shoot for 4 different species

Bamboo shoot species	Total phenolics (GAE/g dry powder)	DPPH (% free radical activity)	TAA (mg/ml) gallic acid equivalent	Protein (g/100g dry matter)	Vitamin C (mg/100g)	Cyanoglucosides (ppm)
D. strictus	153.91	13.97	1.12	21.51	5.8	386
B. tulda	162.66	15.94	0.88	18.74	5.0	77*
B. vulgaris	191.41	28.21	1.31	20.60	5.0	200
B. balcoa	222.81	39.85	3.15	25.84	6.6	67*

*Bamboo shoot stored at -18°C for 2 months

Nutraceutical Potential

Proteins

The protein content ranged from 18.74 – 25.84 % on dry weight basis, highest being in *B. balcoa* and lowest being in *B. tulda*. Yamaguchi M (1983) had reported protein value of 2.6 g in shoots but investigations made by Kumbhare and Bhargava (2007) gave higher values for crude protein content which ranged from 9.6 to 17.2% on fresh weight basis and 19.2 –25.8% on dry weight basis. Ferriera et al (1992) reported much higher values in the apical and basal portion of *D. giganteus* which were 46.1 and 40.4% respectively. The wide variation in the protein content of bamboo shoots reported in literature may be attributed to differences in species, growing site, climatic factors and method of analysis.

Vitamin C

Ascorbic acid values ranged from 5.0-6.6 % in different species when determined by the titremetric method. *B. tulda* and *B. vulgaris* were found to contain the same amount of ascorbic acid. The results were in accordance with the earlier investigations made by Yamaguchi M (1983) who reported a value of 4%. Vitamin C content reported by Bhargava et al (1996) in a few species was as high as 23%. Bhatt et al (2003) has also reported vitamin C content for a number of bamboo species ranging from 3.0 to 12.9, highest being in *D. hamiltonii* and lowest being in *D. sikkimensis.*

Total phenolics

The most commonly observed and predominant phenolic acids have been reported to be ferulic acid and p-coumaric acid. p-coumaic acid content increases in good accordance with the increase of lignin content while ferulic acid is inversely proportional to the lignin content. It has been observed that the chemical composition varies from top to bottom in immature moso bamboo (Fujii et al 1991). Total phenolics in the present study were present in the range of 153.91-222.81 GAE/g dry powder in different species of bamboo shoots. *B. balcoa* was found to contain the highest content of phenols (222.81GAE/g dry powder). Values obtained were higher than previously reported values in different species of shoots. Total phenols in three species of bamboo shoots viz. *Dendrocalamus latiflorus, Phyllostachys nigra, Bambusa oldhamii* were found to be 31.7, 115, 114 mg per 100 g shoots (Huang et al, 2002). The total phenolic content in *Kaeng kae* and *Kaeng naw mai bai* (northeastern Thai foods) containing 6.9 % and 21.6 % Bamboo shoot as the main ingredient was found to be 111.69±1.45 and 60.79±6.57 mg. gallic acid equiv./100g food for *Kaeng kae* and *Kaeng naw mai bai* respectively (Tangkanakul et al 2006)

Antioxidant activity

The methanol extracts of bamboo shoot were evaluated for their antioxidant effect by DPPH scavenging activity and total antioxidant activity (TAA).

DPPH is a stable free radical that accepts an electron or hydrogen radical to become a stable diamagnetic molecule. The reduction in DPPH radical was determined by the decrease in its absorbance at 517 nm induced by antioxidants (Blois 1958). Hence, DPPH radical is usually used as a substrate to evaluate the antioxidative action of antioxidants. Methanol extracts of *B. balcoa* exhibited higher ability (39.85 %) in scavenging DPPH

free radical than that of *D. strictus* which has a free radical scavenging potential at 13.97%. Earlier reports suggest that methanol extracts of culm of moso bamboo (*Phyllostachys pubescens*) showed a higher free radical scavenging activity (41.41%) as compared to madake bamboo (*P. bambusoides*) (29.44%) when determined by DPPH scavenging assay (Jun et al, 2004). Bamboo shoot exhibited a value of 17.8 mmol Trolox Equivalent (TE) kg−1 fresh weight and hence seemed to show moderate antioxidant capacity as compared to the other light colored vegetables (32.3-0.7 mmol TE/kg) when determined by hydrophilic assays such as the oxygen radical absorbance capacity (ORAC) (Cho et al, 2007). *Kaeng kae and Kaeng naw mai bai* (northeastern Thai foods) containing 6.9 % and 21.6 % Bamboo shoot as the main ingredient were found to possess some antioxidant activities. *Kaeng kae* exhibited moderate antioxidant capacity at a level of 54.77±0.29 mg.vit.C equiv./100 g food where as *Kaeng naw mai bai* possessed a lower value at 30.25±1.23 mg.vit.C equiv./100 g food (Tangkanakul et al 2006).

Total antioxidant capacity of bamboo shoots is expressed as number of equivalents of gallic acid. The assay is based on the reduction of Mo (IV) to Mo (V) by the extract and subsequent formation of green phosphate/Mo (V) complex at acid pH. The result of the study shows that total antioxidant activity varied from 0.88 to 3.15 (mg/ml) gallic acid equivalent was in the order of *B. balcoa* > *B. vulgaris* > *D. strictus* > *B. tulda*. Because of scarcity of literature the value were matched with some Nigerian vegetables which possessed similar TAA by this assay in the range of 0.13-1.60 gallic acid equivalent (Salawu et al 2006)

Food Safety aspect

Raw bamboo shoots of *B. vulgaris* and *D. strictus* contained higher cynogenic glucoside content of 200 and 386 ppm. The values were found to be low as compared to the WHO Report (1993) where immature bamboo shoot tip contained as high as 8000 mg of HCN/kg (WHO 1993). However, some Asian species like *D. giganteus Munro* and *D. hamiltonii* Nees et Arnott have been reported to contain only 90-100 mg HCN/100g fresh weight (Schwarzmaier 1977). However, the tip usually contains higher HCN content (1600 ppm) as compared to (110 ppm) in the base (Rezaul Haque and Howard Bradbury 2002). The toxic content varies with different parts, geographical and climatic conditions, soil conditions and also with method choosen for analysis.

The toxic content in the present investigation was found to decrease when two different species namely *b. balcoa and B. tulda* were stored at -18°C for 2 months. The toxic content reduced by 82.7 % upon storage. The significant reduction in the toxic content may be due to degradation of the toxic compound taxiphyllin into HCN. Cyanide content has been reported to reduce with prolonged fermentation by lowering the pH through microbial activity (Bhardwaj et al 2007). Other methods of removing HCN include processing (boiling, canning, soaking, and fermentation) before consumption. Boiling bamboo shoot in an open vessel for 3-4 hours can reduce the toxicity by 97% (Ferreira et al 1995). If not processed by proper means, food borne botulism has been found to be associated with the consumption of home canned bamboo shoots (Swaddiwudhipong and Wongwatcharapaiboon 2000)

Conclusions and future prospects

In the present study the chemical composition in relation to protein, vitamin C and total phenol content and the antioxidant activity of different species of bamboo shoots was evaluated. It was found that amongst all the species *B. balcoa* contained the highest content of total phenolics, crude protein and vitamin C. It also possesses highest antioxidant activity. *D. strictus and B. vulgaris* were found to contain 386 and 200 ppm of cynogenic glycoside respectively which can be eliminated by boiling bamboo shoot in open vessel or pressure cooker for a specified time.

Based on the data obtained from this study it can be concluded that the selected species of bamboo shoots possesses an exceptionally high level of protein almost comparable to certain legumes, moderate amount of vitamin C required as an antioxidant in the body and total phenols. The shoots also exhibited good antioxidative capacity which may limit free radical damage occurring in the human body. Overall, this reveals that consumption of bamboo shoots may supply essential nutrients and substantial antioxidant which may provide health promoting and disease preventing effect. Cynogenic toxicity present in bamboo shoot can be minimized by suitable processing method.

Since studies on combining the antioxidant capacity and nutritional composition of shoots are very scarce. Therefore further research is warranted on this important aspect along with variations with changes in parameters like season, climate etc. Cynogenic toxicity in young shoots has generally been ignored, indicating the need of developing methods by which the toxicity can be eliminated without affecting the nutritive value of bamboo shoot. Thus bamboo shoots would exhibit a great potential to prevent metabolic diseases and with R&D inputs suitable nutraceutical formulation can be prepared through rural entrepreneurship.

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Production of Quality Planting Material of Sympodial Bamboos for Raising Plantations in India

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Abstract

Production of quality planting material of bamboos is one of the most important aspects for raising successful industrial and commercial plantations. The main problem faced in the establishment of large scale plantations is the non availability of quality planting material in sufficient quantities. Although large number of plantlets are being produced through micro-propagation: tissue culture or somatic embryogenesis but this requires highly trained staff and sophisticated expensive infra-structure. Macro-propagation methods using conventional methods appear to be of limited value because seed availability is rare due to very long seeding cycles. The seeds are short lived hence cannot be stored for longer time. Rhizome and off-set plantings, culm and branch cuttings are useful only for propagation on a very small scale. However, macroproliferation technology developed for mass propagation of bamboos, offers the possible solution to the ever existing problem regarding production of field planting stocks on mass scale for raising large plantations. Macroproliferation technology shall be able to play major role in production of field planting stocks of sympodial commercially important bamboos identified by National Bamboo Mission (India) in order to increase the coverage of area under bamboo in potential forest and non forest lands with suitable species to enhance yields. This technology is being used by forest managers, scientists, farmers and bamboo growers for multiplying quality planting material for raising plantations. Further, it has been found highly advantageous in enhancing the multiplication rate of tissue culture plants which results in reduction of the cost of production of tissue culture saplings remarkably. The paper highlights the usefulness of macroproliferation technology for further mass multiplication of saplings developed earlier by conventional methods of propagation and also through tissue culture.

Keywords: Sympodial, Bamboos, Macroproliferation, Technology, Massive planting stocks, Plantations

Introduction

Bamboo is one of the most important and valuable plants occurring wild as well as grown in India and entire south-east Asia. It is linked with the rural life and culture for its multifarious uses ever since the beginning of civilization. In India, its versatility has led to the coinage of such sobriquets as “bamboo culture”, “green gold”, “poor mans timber” and “cradle to coffin timber”. There are over 75 genera and 1,250 species of bamboos

found in tropical, subtropical and temperate regions of the world (Sharma, 1980). India has the world's second richest bamboo genetic resource after China with about 130 species occurring over an area of 8.96 million hectares which is about 12.8 per cent of the total forest area of the country and represents 20 per cent of the India's total production of forest produce (Shanmughavel, 1997). Bamboos are widely grown in homesteads on unproductive lands and also occur as an understorey in natural forests. Looking to the diverse and varied uses of bamboos in rural areas, bamboo farming has great potential in rural development. The constant use of bamboo for various products and its economic value as raw material for paper industry and cottage industries is continuing to result in gradual disappearance of its natural source in forests and rural areas. Emphasis has now been given to introduce bamboos in agroforestry systems, on the harsh and eroded lands, hill slopes and ensure productivity and quick returns (Kishwan *et al.,* 2005).

Bamboos are natural choice to encourage sustainable integrated farming systems like agroforestry, and an excellent resource for development, income and employment generation opportunities (Melkania, 2008). Recently, the social and industrial demand of bamboo has increased at a much faster rate than its supply. In order to enhance the production of bamboo to meet the increasing demand, the expansion of bamboo areas in and out side the forest has become the necessity. The agroforestry and farm forestry are possible approaches for sustained supply of bamboo for commercial purposes. Bamboos grow much faster than trees and begin to yield from three to four years of planting. Plantation establishment needs very little capital investment with routine plant cultivation skills of farmers and foresters. Bamboos are highly suitable for agroforestry system in India. These are suitable for intercropping, soil conservation, wind break and yield value added products such as 'bamboo timber', forages, edible shoots, fiber and craft. Bamboo based agroforestry models can provide higher economic returns to the farmers, improve the soil fertility, bridge the gap of targeted national forest cover (33 per cent) and provide raw material to industry as well as for domestic use of the rural community. By the use of various intercrops, produces are obtained even during the initial stages of bamboo plantings and the income would be much higher than any other system. Bamboo can be harvested every year from third or fourth year onwards and hence regular income starts much earlier than from any other woody component. Agroforestry practice will also benefit the bamboo plants due to sharing of the inputs of irrigation, manure and fertilizers, weeding etc. applied to agricultural crops, hence bamboo growth and yield here would be better than in unmanaged plantations. Hence the total returns are likely to be much higher than other wood based agroforestry systems (Ahlawat *et al.,* 2008). Economically bamboo cultivation ensures internal rate of return (IRR) of more than 25%, almost equal to the *Eucalyptus* but returns are recurrent on annual basis after 5-6 years upto 30 years or more without recurring investments on plantations (Ashutosh *et al*., 1996).

More than 4,000 traditional uses of bamboos have been estimated (Hsiung, 1991). Bamboo is a very important raw material for several small and large scale industries besides it is also used as construction material. Several thousands of rural people are engaged in the traditional bamboo based crafts of making mats, baskets etc. to earn their livelihood. Intensive bamboo propagation is necessary not only to increase biomass and conservation of rare and threatened species but also to cultivate the economically important species for financial gains and to supply bamboo to meet the market demands (Rao, 1992). Increasing demand and over exploitation is continuously depleting the bamboo production in most of the Asian countries. A time has come to take this matter seriously and devise ways, means and measures for management of bamboo areas properly to bring back to rejuvenation and enhance productivity. As a highly renewable and versatile resource, bamboo receives more

attention from many sectors of modern civilization. In the post industrial world the outstanding productivity of this plant and versatility of the material will ensure the global importance of bamboo (Hanke, 1990).

Troup (1921) described the seed germination and seedling growth pattern followed by the 'seedling division' as one of the methods of propagation besides other methods viz. off-set planting, culm cuttings and branch cuttings etc. for propagation of *Dendrocalamus strictus*: "The 'seedling division' consisted in dividing up the mass of rhizome and transplanting the culms in small clump of two or three with rhizomes attached; transplanting is best carried out immediately before the growing season commences". Banik (1987) reported the growth pattern of *Bambusa tulda* from seed to seedling and observed that its seedling attains 4 -5 culms stage at the age of nine months. Seedlings at this stage are ready for multiplication and may be separated into three units in such a way that each piece has roots, old and young rhizome with buds and shoots. Thus every year the seedlings get multiplied three times of the initial stock. Out of this, two-thirds of the seedlings may be planted in the field, the rest can again be multiplied after nine months (April-May) and the process can be repeated every year. However, Banik (1987) further continued, "detailed scientific study is essential on such a macroproliferation of bamboo seedlings to develop a new dependable technique for bamboo propagation at least for a few years". Adarsh Kumar (1991, 1992, 1993) studied the bamboo propagation and developed a new low cost universal macroproliferation technology for mass propagation of sympodial bamboos, for desired number of years without dependence on seed production in nature, from second year onwards.

Rapid Increase in Bamboo Demand

The estimated bamboo resources of the world are about 20 million hectares and the estimated current market of bamboo is US $ 10 billion that is expected to increase to US $ 20 billion by 2015. In India, it encompasses about 8.96 million hectares of forest area which is equivalent to 12.8% of the total forest cover consisting of 130 MT with estimated annual harvest being 13.47 MT. The current market of bamboo/ bamboo products in India is estimated to be Rs. 4,500 crores which is expected to increase to Rs. 20,000 crores by 2015 with major contribution from wood substitute, processed bamboo shoots, industrial products (activated charcoal etc.) and structural applications segments (Gupta, 2008). The employment potential of bamboo is very high and the major work force constitutes of the rural poor, especially women and 432 million work days per annum are provided by the bamboo sector in India (Adkoli, 1994).

Rapid increase in the demand of bamboos in the industrial sector coupled with increase in domestic demand due to rising population have caused depletion of the natural bamboo resources which calls for concerted efforts for the awareness to raise bamboo plantations in land hitherto barren, degraded or in association with agriculture crops. With the trend of decrease in production and rise in human population, the gap between supply and demand is going to be larger. Srinivasan (Anon., 1994) stressed that in India the demand for bamboo planting stocks are 90-120 million per annum, which is expected to increase to up to 300 million seedlings per annum. Large scale cultivation is the only way to prevent further depletion of bamboo resource, and to ensure a regular and sustained supply of raw material for growing industrial uses (John, *et al.,* 1995). This situation elucidates the need for increase in bamboo production. Due attention on raising bamboo plantation under various programmes has not been paid so far. Now farmers and villagers need to be involved in bamboo cultivation /

production. Apart from protecting natural vegetation of bamboos, the activity has to be brought to the non forest lands (Kamesh Salam, 2002).

National Bamboo Mission (India)

The requirement of "bamboo wood" for multiple uses by the industries and the common man will definitely increase in far greater dimensions. In India, the total demand of various bamboo consuming sectors is estimated at 26.9 million tonnes. The estimated supply is only 13.47 million tonnes i.e. only half of the total demand. The pulp and paper industry, construction, cottage industry and handloom, food, fuel, fodder and medicine annually consume about 13.4 million tonnes of bamboo amounting to Rs. 2042 crores. Demand of bamboo for industrial use is met from state owned forests, while for non industrial purpose it comes from private as well as state owned resources. Keeping abreast of versatility of bamboo uses and its potential to build up the rural economy, Government of India launched massive programme viz. National Bamboo Mission for over all development of bamboo sector in the country and also to improve the Indian representation in global bamboo market. Bamboo has also been recommended for plantations for a greener, pollution free environment along with economic prosperity.

Based on India's rich culture, bamboo utilization has triggered several programmes in the country for economic and industrial development through the use of bamboo. Large targets for plantations across the country have been fixed. The National Bamboo Mission (India) envisages covering over 1.76 lakh hectare area through bamboo. This will need over 70 million field plantable saplings to raise bamboo plantations. The emphasis of the National Bamboo Mission is on an area based regionally differentiated strategy, for both forest and non-forest areas. A number of activities are proposed to be taken up for increasing production of bamboo through area specific species/varieties with high yield, plantation development and dissemination of technologies through a seamless blend of traditional wisdom and scientific knowledge, along with the convergence and synergy amongst stakeholders. Besides ensuring proper post-harvest storage and treatment facilities, marketing and export National Bamboo Mission is committed to assure appropriate returns to growers/producers. Also, bamboo development is viewed as an instrument of poverty alleviation and employment generation for skilled and unskilled persons, especially unemployed youth particularly in the rural sector through eco-rehabilitation purposes.

Selection and Propagation

The selection of clump is carried out to obtain significant quantum of genetic gain as quickly and inexpensively as possible keeping in view the end use and habitat suitability. Banik (1995) described selection criteria and species selection for specific end use listing various bamboo species fitting in different criteria. Individual selection of phenotypically superior clumps from a large population is the common practice. Bamboos are reported to be highly cross pollinated, this gives enormous opportunities for selection of superior seedlings having desired combination of characters (Venkatesh, 1984). Natural seedling population of bamboos with genotypic diversity may afford an opportunity for selecting superior clones and individual plants (McClure 1966). Thapliyal *et al.,* (1991) stated that propagation through seed is desirable to maintain genetic diversity in

bamboo plantations. It also helps to develop *ex-situ* conservation strategies through seed which is the easiest and cheapest method of propagation. Gurumurti *et al.,* (1995) are of the opinion that identification of patterns of variation, collection of suitable material followed by mass multiplication would help in strategically enhancing the genetic quality of bamboos. Banik (1997) described seedling selection methods for *Bambusa tulda* and *B. polymorpha*. Ombir Singh (2008) has listed several traits regarding selection of candidate plus clumps.

The abundant seed production after gregarious flowering and scanty seed production through sporadic flowering in some bamboo species is utilized for production of base population of seedlings. The base population is further multiplied using macroproliferation technology. After selection of natural variations existing in bamboos, followed by clonal propagation, is utilized for production of quality planting stock. Only the best performers are selected based on certain desired morphological characters. The germplasms of selected performers are established in a centralized germplasm bank cum vegetative multiplication garden. The base population saplings are produced through clonal propagation using conventional methods of propagation viz. off-sets, culm and branch cuttings and through tissue culture. These are further multiplied using macroproliferation technology repeatedly (Prasad and Pattanaik, 2002). The production of clonal base population (saplings) needs to be carried out at the centralized nursery also having tissue culture laboratory. After selection, the seedling stocks can be raised through macroproliferation technology for establishment of pilot plantations. These pilot plantations after evaluation are screened for growth performance, culm production and other desired characters for identifying 'elite clumps'. Then the elite clumps have to be further multiplied to produce field planting stocks through macroproliferation technology for raising commercial and industrial plantations. A part of the base population (saplings) so developed is transferred to the farmer's nurseries for mass multiplication through macroproliferation technology for production of field planting stocks for raising plantations.

Constraints for Mass Propagation of Bamboos

Prof. Liese (1985) was of opinion that vegetative propagations by cuttings from culm, branch or rhizome is commonly practiced. So far several methods are applied, but for practical purposes especially for establishing larger plantations, the degree of failure is still rather high. Prof. Liese (1991) again stated that in spite of intensive efforts made at various institutions, universally applicable method for vegetative propagation of bamboo is not yet available. Bamboo seems to be a difficult species to multiply, no body seems to understand the bamboo just enough to propagate it in massive numbers (Anon., 1990). None of the conventional methods of propagation is universal and effective for all the species of bamboos. Each carries its own inherent risks (Anon., 1994). Sharma (1990) stated that Pathak (1899) was perhaps the first to attempt the propagation of the common 'male bamboo' (*Dendrocalamus strictus*) by cuttings. Since then several papers have appeared dealing with the vegetative propagation of bamboos. None of these earlier attempts have standardized the technique of bamboo propagation by vegetative methods. The vegetative methods of bamboo propagation viz. off-set planting, rooting of culm and branch cuttings are of limited value for the large scale propagation of clump forming sympodial bamboos. The propagules, thus produced are bulky, heavy, difficult to handle and transport. Thus to generate field planting stocks of bamboos on mass scale for raising industrial and commercial plantations is definitely an uphill task. Rao and Rao (1990) stated that vegetative propagation by offsets and culm cuttings has proved to be of limited value as the daughter clumps are bound to flower at the same time as the parent clump. Nawa Bahar

and Singh (2008) mentioned that bamboos can be multiplied vegetatively with ease but large plantations are difficult to raise because lack of regular and plentiful supply of seed / propagation material is a serious constraint for mass propagation of bamboos. Similarly, Manoj Chandran (2008) has also cautioned that propagation from rhizome, offset and culm cuttings, of unknown age, is also unreliable as the saplings developed and planted in the field for raising bamboo plantations, may flower, dry and die before their economic use starts or much before utilization of full potential of bamboo culm production of the plantation. Sastri (2008) is of opinion that supply of planting material for large scale commercial plantations of the desired species could be a limiting factor due to lack of seed and/or other propagules. Srinivasan (Anon. 1994) mentioned that the key to the success will be cost effective and simple plant propagation technique.

Bamboo Propagation

Bamboo is a unique plant, which has not easily lent itself to modern methods of macro-propagation and genetic improvement owing to its long vegetative phase and monocarpic behaviour. Conventional breeding is difficult because of the near impossibility of getting two desirable parents to flower simultaneously (Rao and Rao, 1990). Thus for meeting the raw material demand scientific management of bamboo forests is *sine qua non*. Regeneration of bamboos takes place sexually as well as asexually. However, both the methods of propagation are beset with many problems that restrict their large scale use. In view of the constant increase in demand, the scarcity of planting material and the problem associated with the conventional methods of vegetative propagation, development of an effective method of vegetative propagation of different sympodial bamboos is highly required. Bamboo propagation can be carried out by the under mentioned some of the important methods:

(i)	**Seed sowing**	**(ii)**	**Rhizome / Off-set planting**
(iii)	**Culm cutting**	**(iv)**	**Branch cutting**
(v)	**Macroproliferation technology**	**(vi)**	**Tissue culture**

Depending on the availability of seeds, technical feasibility of propagation by vegetative propagation techniques and suitability of micropropagation protocols for large scale multiplications, the bamboo species can be propagated either by clonal methods or through tissue culture or both.

(i) Propagation by seed: It is the easiest method of propagation requiring low technical skills. Bamboo seeds are sown directly in the soil already dug up to a depth of 15-20cm or deeper in case of poor soils either in lines 5-6 m apart or in pits of 30-45 cm^3 dug at the spacing of 5m x 5m or 6m x 6m apart and cleared of weeds. As direct sowing in lines is often liable to fail due to relatively (i) uneven germination (ii) slow growth of resultant plants and (iii) exposure to animal damage etc. The usual procedure is to raise plants, by seed sowing in a nursery bed and then transplanting entire plants. But the seed of commercially important bamboo species is not available every year because of very long interval of time of the flowering cycles ranging from 30 to 60 or more years. Secondly, the bamboo seeds when available are short lived hence cannot be stored for longer durations. The availability of seeds is a major constraint and it would be difficult to multiply bamboos on a large scale

through seed alone. Therefore, in order to sustain large supply of planting material year after year the focus should be towards producing planting material by vegetative methods and tissue culture.

(ii) Propagation by rhizome / off-set planting: This is the traditional and common method of vegetative propagation. The off-set consists of one year old culm of about 1m length and a part of rhizome with roots attached excavated from the ground. Off-sets are planted in the field on the advent of monsoon season. This traditional method is applicable only in cultivating few clumps. The various limitations with this method are:

1. Limited availability of rhizome/offsets
2. The method is very expensive as it is labour and time intensive
3. Off-sets and rhizomes are bulky and very heavy as such it is difficult to handle and transport
4. The survival success is low

(iii) Propagation by Culm cutting: Bamboos can be propagated by rooting culm cuttings (Pathak, 1899; Dabral, 1950; Mc Clure, 1966; Adarsh Kumar *et al*., 1988; Seethalakshmi and Surendran, 1990; Reddy, 2006). This method is well studied. One to two years old culm is cut into 1, 2 or 3 noded segments placed in the nursery bed horizontally and covered with soil during April – May. In some species solution of growth promoting substances like IBA, NAA, boric acid, coumarin etc. are filled singly in the internodes before planting in the nursery for improvement in rooting percentage. This method has a limited use because of the limited availability of the planting material. This method is also labour intensive, expensive and propagules are difficult to transport.

(iv) Propagation by Branch cutting: Propagation of bamboo through branch cuttings appears to be a promising method. Branches with 3 nodes from 1-2 year old culms are planted in sand after treatment with 100 ppm IAA. Normally branch cuttings develop roots after only 3-6 months and rhizomes after 12-15 months. Propagules bearing roots, rhizomes and shoots are essential for the successful establishment and development of bamboo plantations. Bakshi and Rakesh (2008) reported IBA 100 ppm was found to induce rooting 75%, sprouting 80% and survival 80% of branch cuttings of *Bambusa vulgaris*.

(v) Propagation through Macroproliferation technology for Mass Propagation of Bamboos: A major breakthrough (Anon. 1992) was achieved for mass production of field plantable saplings of economically important sympodial bamboos viz. *Bambusa bambos, B. tulda, Dendrocalamus hamiltonii* and *D. strictus* vegetatively through macroproliferation. This technology (Adarsh Kumar, 1991, 1992 & 1993) was developed for production of field plantable saplings in large numbers for any desired number of years depending upon the targets and the facilities available, solves the ever existing problem pertaining to non-availability of planting stocks for raising large plantations. According to this technology:-

In July, bamboo seeds are sown in germination boxes or in the nursery beds. After one month, in August young seedlings of 3-5 leaf stage are pricked out: *Bambusa bamboos* - 7,000 nos.; *Bambusa tulda*– 5,000 nos.*; Dendrocalamus hamiltonll* – 4,000 nos.*; Dendrocalamus strictus* - 6,000 nos. are planted in polybags. From August to March bamboo seedlings are maintained by regular watering, weeding and soil working. The tillers

ranging from 3-10 in number developed in each polybag of *B.tulda*, *D. hamiltonii* and *D.strictus.* Whereas in *B. bambos* their number ranged between 6 to 14. The averages being *B. bamboos* = 7.0; *B. tulda* = 5.0; *D. hamiltonii* = 4.0 and *D. strictus* = 6.0.

In the first week of April, the saplings are carefully removed from the polybags. Each proliferated tiller alongwith some rhizome and roots is separated by cutting the rhizome. These act as propagules. On an average *Bambusa bambos*- 49,000; *Bambusa tulda– 25*,000*; Dendrocalamus hamiltonii– 16,*000*; Dendrocalamus strictus -3*6,000 propagules are produced. Each propagule is planted in polybag in April. From April to June, these propagules are maintained by regular watering, weeding and soil working to grow into saplings by the first week of July.

In the first week of July, field plantable bamboo saplings are available in massive members. *Bambusa bambos*- 49,000 saplings; *Bambusa tulda– 25*,000 saplings*; Dendrocalamus hamiltonii – 16,*000 saplings*; Dendrocalamus strictus -3*6,000 saplings are available. Out of these, 1000 or in multiples, as per the requirements, are retained in the nursery for future propagation work. The field planting stock of remaining saplings in sufficient numbers i.e. *Bambusa bambos* – 48,000 saplings; *Bambusa tulda– 24,*000 saplings*; Dendrocalamus hamiltonii – 15*,000 saplings*; Dendrocalamus strictus* -35,000 saplings are available for raising plantations.

In August, the propagules (*Bambusa bambos* - 7,000; *Bambusa tulda* – 5,000*; Dendrocalamus hamiltonii* – 4,000*; Dendrocalamus strictus* - 6,000) are prepared by separating the tillers of 1000 saplings of different species retained in the nursery by cutting the rhizome and planted in polybags. These are maintained by regular watering, weeding and soil working till April. Again the tillers ranging from 3-10 in number developed in each polybag of *B.tulda*, *D. hamiltonii* and *D.strictus w*hereas in *B. bambos* these range between 6 to 14. The averages being *B. bambos* = 7.0; *B. tulda* = 5.0; *D. hamiltonii* = 4.0 and *D. strictus* = 6.0 as was found earlier. In the first week of April, as in the previous year, each proliferated tiller along with some rhizome and roots is separated by cutting the rhizome. These act as propagules. On an average *Bambusa bambos*- 49,000; *Bambusa tulda– 25*,000*; Dendrocalamus hamiltonii– 16,*000 and *Dendrocalamus strictus -3*6,000 propagules are produced and planted in polybags for further growth and development into field plantable saplings by July.

Thus 49, 25, 36 and 16 field plantable saplings can be developed from each of the propagule in one year in case of *Bambusa bambos*; *B. tulda*, *Dendrocalamus strictus* and *D. hamiltonii* respectively as under:

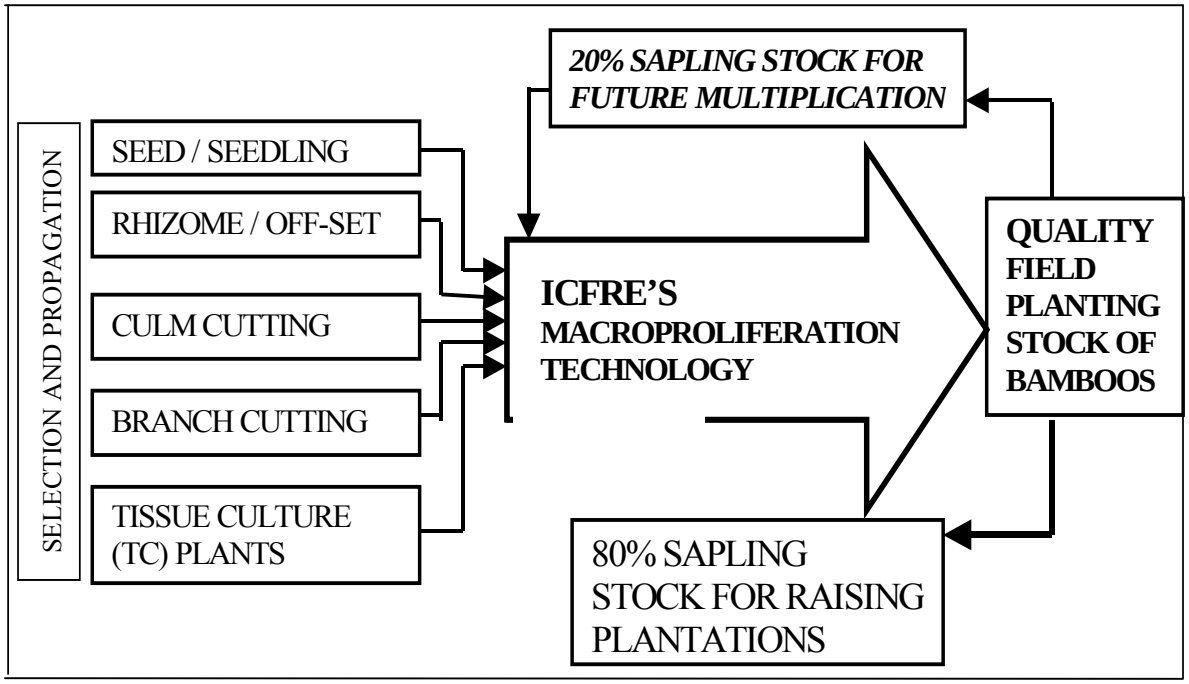
Productivity of Macroproliferation Technology

Species	No. of tillers developed in one seedling / sapling		
	Range	Mean	Multiplication index per year
B. bambos	6-14	7	49
B. tulda	3-8	5	25
D. hamiltonii	3-7	4	16
D. strictus	3-10	6	36

From second year onwards, the whole methodology as mentioned above is repeated and field planting stocks of bamboo are produced year after year for any numbers of years. The dependence on bamboo seed production in nature is totally eliminated from second year onwards for production of field planting stocks.

The macroproliferation technology of vegetative propagation is universally applicable and can be used for mass production of field plantable saplings of sympodial bamboos. Dransfield and Widjaja, (1995) stated that vegetative propagation system called 'macroproliferation of seedlings' has been successfully developed in India for large scale propagule production. This method ensures a continuous supply of propagules. Kishwan *et al*. (2005) considered macroproliferation technique as the current technique of mass multiplication of bamboos. This technology shall also be able to play major role in production of huge quantities of field planting stocks of commercially important sympodial bamboos identified by National Bamboo Mission (India) in order to increase the coverage of bamboo in potential forest and non-forest areas with suitable species to enhance yields.

Multiple Approaches to Macroproliferation Technology: The saplings available from selected superior / elite mother clumps, through (i)seedlings raised by seed sowing (ii) conventional methods of macro-propagation of bamboos *viz.* off-sets, culm and branch cuttings etc. and (iii) micro-propagated tissue culture plants may be successfully used for multi-way approachable this technology for production/enhancement of bamboo planting stocks during the prolonged vegetative phase of sympodial bamboo clumps for raising industrial and commercial plantations as shown in the plan -1.



Plan-1. Multiple approaches to macroproliferation technology for massive production of quality planting stock of bamboos from macro and micro (tissue culture) propagated saplings.

This technology is approachable through:

(i) Seeds of Bambusa bambos, B. tulda, Dendrocalamus hamiltonii and D. strictus (Adarsh Kumar, 1991, 1992, 1993, 1995).

(ii) Off-sets of Bambusa balcooa and B. vulgaris (Koshi and Gopakumar, 2005).

(iii) Culm and Branch Cuttings: Rain Forest Research Institute, Jorhat, India, has developed a protocol to induce juvenility and generate saplings from the mature culms, followed by mass multiplication through macroproliferation technology (Katwal, 2002); Dubey et al. (2008) developed the quality planting stock by using macroproliferation technology on the saplings developed from the two noded culm cuttings of Bambusa vulgaris var. vittata, B. balcooa, B. bambos, B. nutans, B. tulda, and Dendrocalamus hamiltonii with survival rate of 90-100 per cent. Through this technique 60-180 nos. of bamboo saplings (propagules) could be produced in a year (April to March) depending upon the species selected from a single bamboo node. Dubey et al. (2008) further stated that the best part of the technique is that it can produce bamboo planting stock round the year without involving many technicalities. Koshi and Gopakumar (2005) studied the rooting of branch cuttings of Bambusa vulgaris and B. balcooa which were further propagated by macroproliferation technology to enhance the production of planting stock.

(iv) Tissue culture plants: Preetha et al. (1993); Arya and Arya, (1999) used macroproliferation technology for enhancement of the multiplication rate of tissue culture (TC) bamboo plants several times for production of field plantable saplings quickly and economically in large quantities.

Earlier Adarsh Kumar and Mohinder Pal (1993) found that conventional methods are still useful for raising planting stocks on very small scale, but for large scale propagation of bamboos, macro-proliferation method has many benefits and can be directly used in the forest nurseries. Recently, Banik (2008) has also stated that macroproliferation method has subsequently also been used to multiply plants generated by culm cuttings, branch cuttings and micro-propagated tissue cultured (TC) plants.

Farmer's Friendly Macroproliferation Technology: Macroproliferation technology very well meets the requirements of farmers, NGO's and other agencies involved in the production of bamboo field planting stocks for raising multipurpose massive plantations as this technology is simple, easy and involves the use of locally available materials involving the routine plant cultivation skills of farmers and foresters. It neither requires highly trained staff nor sophisticated high value infra structure for mass production of bamboo planting stocks for raising plantations.

(vi) Propagation by Tissue culture: Details of the study on *in-vitro* seed germination are provided in recent publications by Saxena and Dhawan (1991), Rao *et al.* (1985; 1990), Preetha *et al*. (1993), Dhawan (1993) Rout and Das (1994), Ravikumar *et al.* (1998) and Arya *et al.* (2002) where a large number of plantlets are produced either through micropropagation or somatic embryogenesis. However, this is an expensive technique and requires highly trained staff and sophisticated expensive infrastructure.

Enhancement of Multiplication Rate of Tissue Culture Bamboo Plants: The macroproliferation technology of mass propagation of bamboos has also been found highly advantageous by the tissue culture scientists to multiply *Dendrocalamus asper* plants which were earlier developed through tissue culture (Arya and Arya, 1999). They reported that this technology enhanced the multiplication rate of tissue culture (TC) bamboo plants and ensured a very high rate (95 per cent and above) of establishment and survival in the field in a short interval of time. These plants were multiplied twice a year for two years as per this technology. Preetha *et al.* (1993) used the technology to enhance the quantity of *Dendrocalamus stictus* and *Bambusa bambos* rooted plants which were developed through tissue culture and hardened in the shade house for 20-30 days. Thus the field planting stock was increased 4-5 times. Shanmughavel *et al*., (1997) suggested that in order to increase the tissue culture plants before transfer to the field, macroproliferation should be practiced. This technology shall also effect reduction in the cost of production of field plantable tissue culture saplings remarkably.

Economics of Planting Stock Production: Nautiyal *et al*. (2008) found that unlimited planting stock may be produced at the lowest cost i.e. @ Indian Rs. 2.50 (=US$ 0.05) per sapling through macroproliferation technology. They have worked out the comparative economics of bamboo planting stock production by different methods of vegetative propagation as under:-

Sl No.	Method	Cost per plant(Rs.)	Remarks
1.	Off-set planting	50.00	Labour intensive, heavy planting stock
2.	Rhizome planting	30.00	Labour intensive, heavy planting stock
3.	Whole culm cutting	15.00	Labour intensive
4.	Layering	05.00	Labour intensive
5.	Culm cutting	08.00	Limited planting stock may be produced
6.	Branch cutting	03.00	Unlimited planting stock may be produced
7.	Macroproliferation Technology	02.50	Unlimited planting stock may be produced

Conclusion

Regeneration of bamboos takes place sexually as well as vegetaively. However, both the methods of propagation are beset with many problems that restrict their large scale use. Macroproliferation technology is both, cost and time effective and without doubt is the best method for bamboo planting stock production, when more than million plants annually are required to be produced. The bamboo saplings remain in field plantable size which is light in weight, easy to handle and transport. Further the farmer's friendly macroproliferation technology is simple, easy, involves the use of locally available materials. It neither requires highly trained staff nor sophisticated high valued infra-structure for mass production of bamboo planting stocks for raising plantations. Unlimited planting stocks may be available at the lowest cost i.e. @ Indian Rs. 2.50 (=US$ 0.05) per sapling through macroproliferation technology. Ever since this technology was developed in 1991, great interest is being continuously shown by the bamboo scientists, researchers and growers to further explore the full potential of macroproliferation technology. Once some saplings are produced through offsets, culm or branch cuttings of selected superior clumps or by any other means viz. tissue culture etc., they can be used for further propagation by macroproliferation technology for production of quality field planting stocks for raising bamboo plantations. In short, it can be said that every action counts, every person counts, bamboo plantations could emerge as "Green Gold Mines world over" in near future.

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Clonal Propagation of *Bambusa vulgaris* Schrad ex wendl by Leafy Branch Cuttings

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Abstract

***Bambusa vulgaris* Schrad ex wendl** is a widely cultivated bamboo species in rural Bangladesh for its versatile uses. The species does not set seed after sparse flowering which makes seedling progenies unavailable and rendered vegetative propagation as the only viable alternative. But information on convenient vegetative propagation methods of the species is still lacking. We therefore carried out a low-cost propagation trial to explore the clonal propagation techniques for the species with two types of small branch cuttings - nodal leafy cuttings and tip cuttings. The cuttings were treated with 0%, 0.1%, 0.4% and 0.8% IBA solutions and kept in non-mist propagator for letting them root with the objective of assessing the rooting ability. The cuttings were rooted in four weeks and were allowed to grow in the polybags for ten months under nursery condition to assess their steckling capacity. The study revealed that both types of branch cuttings are able to develop roots, shoots, to survive and to form rhizome in the nursery condition. Rooting ability of the cuttings was significantly enhanced by the application of rooting hormone - IBA. The highest rooting percentage in nodal leafy cuttings and the tip cuttings (56.67 and 51.0, respectively) were observed in 0.8% IBA treatment followed by 0.4% IBA and the lowest (34.3 and 30.0 respectively) was in control. The highest number of root developed per cutting (9.77 and 8.33 in nodal leafy cuttings and the tip cuttings, respectively) was also obtained from the cuttings treated with 0.8% IBA solution followed 0.4% IBA treatment and the lowest (3.1 and 2.1 respectively) was in the cuttings without treatment. However, the length of the longest root varied significantly neither with the cutting types nor the concentrations of IBA solution. Survival percentage of the stecklings in nursery condition was significantly enhanced by IBA.

Keywords: *Bambusa vulgaris*, leafy branch cuttings, non-mist propagator, rooting ability, steckling capacity.

Introduction

Bamboos of Poraceae Family and Bambosidae Sub-family are the fastest growing woody species. These multipurpose plants (Shanmughavel et al. 1997) play vital roles in every-day life of millions of people the South-East Asia by meeting their basic needs in the forms of food, fodder, fuel, clothing, medicine, shelter and

raw materials for industries including paper and pulp, furniture, construction etc. Their versatile use (Banik et al.1997) is due to their excellent splitting ability (Banik 2002), tensile and compressive strength, amenability of being harvested within five years after planting (Negi 1996) etc. With the swelling population, the demands for bamboos in housing, agricultural activities and paper industries are in rise. However, the area and quantity of bamboo stocks in the country are declining alarmingly due to destruction of tropical forests, indiscriminate harvesting associated with increasing demand, lack of proper knowledge and suitable technique for cultivation (Banik 1995). It is, therefore, an urgent need to develop and maintain the bamboo resource bases through massive plantation program with genetically improved planting materials.

Among 75 genera and 1250 species in the world (Sharma 1980), 33 are grown in Bangladesh - of which 7 occur naturally in forests and rest are cultivated in homestead throughout the country (Banik 1980). *Bambusa vulgaris* Schrad ex wendl is the most prevalent and preferred bamboo species in rural homesteads in Bangladesh. However, flowering is sparse in the species (Koshy and Pushpangadan 1997) and the flowering that is seen is not good enough to set viable seeds due to the cumulative effect of a number of physical and physiological factors (Banik 1979; Koshy and Jee 2001). This indicates the inadequacy of seedling progenies for the species (McClure 1966). Consequently, the knowledge on alternative means of obtaining propagation materials became inevitable wherein vegetative propagation methods for the species fits perfectly (Banik 2000; Koshy and Pushpangadan 1997).

Rhizome cutting, offset planting, culm or stem cutting, branch cutting are the various approaches of vegetative propagation for bamboos with known issues for some of them like the low rate of multiplication, need for skilled workforce, or high capital investments etc. Among these approaches, rhizome cutting is popular in the villages but the lower rate of survival and bulkiness (4-30Kg) of rhizomes makes it an expensive option in terms of obtaining and transporting propagules let alone the limited availability of rhizomes due to the risk of detrimental effect of removing rhizomes on the regeneration potential of the source clump. Pre-rooted and pre-rhizomed branch cuttings (Banik 1989) are the other good choices, however, pre-rooted branch cuttings is limited only to the wet seasons and very few branches attached with the mother culms can develop root at their base which makes it inapplicable for large-scale propagule production. The recently developed branch-cutting technique can overcome many of these problems (Seethalakshmi et al. 1983) as it is inexpensive, produces a bulk of propagation materials with high survival potential in short time and reduces the labor and transportation cost (Banik 2000**)**. A branch with the base or one node from the main branch and 3–4 nodes from secondary branches is cut for propagation (Banik 2000**)**. In our previous studies (Hossain et al. 2005; Hossain et al. 2006), we have shown that the cuttings start to develop active buds within 7–10 days and produce profuse roots in the propagation beds within 4–8 weeks, depending on the season. However, the numbers of suitable branches (larger than 5mm diameter with base or node) available from a clump to produce root in the propagation bed is inadequate and the branch cutting method limited only to rainy season during June-July. Our approach to overcome the issue is to use small, leafy branch cutting for vegetative propagation to produce cuttings in high quantity from a single clump, inexpensively round the year. In this research we are reporting the rooting ability of small leafy branch cuttings (around 20 cm in length and 3mm in diameter) in non-mist propagator with or without rooting hormone IBA and their steckling capacity in the nursery condition so that large number of propagules can be produced from a single clump of bamboo.

Materials and Methods

Study area and climatic conditions

The study was conducted over a period of one and half year from June 2005 to November 2006 in the nursery of Institute of Forestry and Environmental Sciences, University of Chittagong, Bangladesh. It lies at 22°27′27″ N latitude and 91°48′30″ E longitude (Figure 1) and enjoys typical tropical monsoon with hot humid summer and cool dry winter having a mean monthly temperature between 21.8 and 29.2°C, the maximum and minimum being 26 and 15°C, respectively. Relative humidity is lowest (64%) in February and the highest (95%) in June to September and mean annual rainfall is about 300 cm, which occurs mostly between June and September (Gafur et al. 1979). Mean monthly day length varies between 10 h 35 min in December and 13 h 20 min in June (Hossain et al. 2005).

Methodology

Clump selection

Vigorous five-years old clumps were selected based on 1) maturity in terms of their ability to produce sufficient number of branches, 2) growth potential in terms of the number of culms per clump, height, diameter and length of internodes and 3) disease- and pest-freeness.

Preparation of cuttings

Cuttings were collected from the selected branches of the pre-selected clumps by excising the small secondary or tertiary branches. Two types of small branch cuttings were made - nodal leafy cuttings and tip cuttings. The nodal leafy cuttings were the small branches with one node from the primary or secondary branch (approximately 2 cm from both side of node as the base of leafy branch) along with 3-4 nodes and fleshy leaves with tip (Figure 2 and table 2). Tip cuttings were the healthy leading shoot apex along with 2-3 nodes of the secondary or tertiary branch without swollen base. Average length of tip cutting was 18.94 to 20.97 cm and diameter was 2.24 to 3.05 mm (Figure 2 and table 2).

Treatment of the cuttings

A total of 480 cuttings, taking 240 of each type, were used for the rooting trial in the study. Cuttings were immersed briefly in a solution of fungicide, Diathane M45 (Rohm & Co. Ltd., France; 2 g. per litre of water) to avoid fungal infection. Then they were rinsed and kept under shade for 10 minutes in open air. Finally the cuttings of each type were treated with 0%, 0.1%, 0.4%, and 0.8% (w/v) Indole 3-Butyric Acid (IBA) solution to assess the effect of applied rooting hormone on rooting ability of cuttings by dipping the base of cuttings briefly into the solution.

Rooting trials

The cuttings were planted in the perforated plastic trays filled with coarse sand mixed with gravel. Each tray contained 10 cuttings which made 60 replicate cuttings for each of the treatment (six trays; 10 cuttings in each

tray). Trays containing the cuttings were placed in the non- mist propagator (Kamaluddin 1996) for rooting (Figure 3).

Propagator environment

About 85-90% humidity was maintained within the propagator. Every day the propagator was opened briefly in the early morning and the late afternoon for gaseous exchange to avoid excessive heat accumulation. Again, the propagator was kept under bamboo made shed to avoid excessive heat on the propagator. Further shading was achieved by putting jute mat over the roof of the shed. Thus the photosynthetic photon flux inside the propagator was reduced to about 12% of full sun . During the experiment mean maximum temperature were 32ºC and the mean minimum temperature 25ºC.

Four weeks after setting the experiment, the rooted cuttings were subjected to weaning before transferring to polybags, particularly towards the end of rooting period during root lignifications. For weaning the shed was kept open at night for three days and then day and night for another three days.

Transferring of rooted cuttings

The rooted and weaned cuttings were then transferred to the polybag (25cm x 15cm) filled with soil and decomposed cow dung at a ratio of 3:1 and were placed in the nursery bed. They were allowed to grow for ten months for assessing the steckling capacity of the cutlings developed under various treatments. Proper care and maintenance were done from the time of setting the experiment up to the final assessment.

Record keeping

During transferring the rooted cuttings from the rooting medium to the growth medium (polybags filled with soil and decomposed cowdung) the rooting percentage, root number, root length, cutting length and cutting diameter of each cutting were recorded. Survival percentage of the cutlings was assessed by counting the number of rooted cuttings survived and thrived ten months after transferring them into the poly bags in the nursery condition.

Data Analysis

All data were analyzed with Microsoft Excel and SPSS ver.13.0 (SPSS Incorporation, Chicago, USA) Possible treatment variations were explored by analysis of variance (ANOVA) and Duncan multiple range test (DMRT). Rooting percentage values were adjusted accordingly by using arc sign root square before putting the data into analysis since the percentage of cuttings rooted were distributed between the range of 30 to 60 and proportions were based on equal denominator.

$$Y = \mathrm{Sin}^{-1} (x)^{1/2}$$

Where, Y= Arc sign transformed value

X = Proportion of number of cuttings rooted to the number of cuttings substituted (100-1/4 n) where ‘n’ is the number of units upon which the percentage data is based i.e., the denominator used in compiling the percentages.

Results and Discussion

Rooting Ability of Cuttings

Rooting percentages

Rooting percentage of *B. vulgaris* branch cuttings varied from 36.7 to 56.7 in nodal leafy cuttings and 30.0 to 51.7 in tip cuttings. Rooting percentages of both types of cuttings were significantly varied among the treatments. Exogenous rooting hormone IBA and its various concentrations affected the rooting percentage of cutting types (nodal leafy cuttings and tip cuttings) remarkably. In the nodal leafy cuttings, the highest rooting percentage (56.7) was observed in the cuttings treated with 0.8% IBA solution followed by the cuttings treated with 0.4% IBA (48.3) and the lowest (36.7) was in control (Figure 4). The highest rooting percentages (56.7) in tip cuttings was also obtained from the cuttings treated with 0.8% IBA solution followed by 0.4% IBA (42.3) and the lowest rooting percentage (30.0) was in cuttings without any treatment (Figure 4). However, the rooting percentage in nodal leafy cuttings was significantly higher than the tip cuttings among the treatments.

In the present study, rooting percentages of branch cuttings of *B. vulgaris* varied significantly among the treatments with the varying concentrations of IBA solution. This finding is validated by several reports in the influence of IBA on the rooting percentage of bamboo branch cuttings. For instance, Somashekar et al. (2004) reported the highest rooting percentage (85, in leafy branch cuttings with tip and 80 in nodal cuttings) in the cuttings treated with 2500 ppm IBA. Hossain et al. (2005) observed that rooting ability of cuttings and growth performance of cutlings were affected significantly by IBA treatment. They recorded the highest rooting percentage (84) in 0.2% IBA treated cuttings compared to untreated cuttings (73.3). In a separate experiment Hossain et al. (2006) reported that the highest percentage of rooting (63.33) was observed in the *B. vulgaris* var. *striata* branch cuttings treated with 0.4% IBA followed by 0.2% IBA (60) and the lowest (30) was in the cuttings without treatment. Sharma (1980) reported that hormone treatment accelerated the success of rooting in branch cuttings and it was 80% in *B. vulgaris.* Moreover, Surendran and Seethalakashi (1985) reported significant enhancement in rooting and sprouting responses of bamboos by the application of growth regulators - IBA and NAA. Sing et al. (2002) found that application of IAA, IBA, NAA, NOA either alone or in combinations have influence on rooting percentage from culm and culm branch cutting as they augment the endogenous level of auxins promoting early and high rate of root induction as compared to the control. In cuttings with low endogenous auxin contents, applied auxin causes significant increases in both percentages rooting and number of roots (Bowen et al. 1975).

Number of roots per cutting

Number of roots per cutting varied from 3.1 to 9.8 in nodal leafy cuttings and 2.1 to 8.3 in tip cuttings. In nodal leafy cutting, the highest number of roots (9.8) was observed in 0.8% IBA treated cuttings followed by the cuttings treated with 0.4% IBA (7.0) and the lowest number of roots (3.1) was in cuttings without treatment (Figure 5 and 6). Similarly, in tip cuttings, the highest number of roots for (8.3) was obtained in cuttings treated with 0.8% IBA solution followed by 0.1% IBA (7.3) and the lowest (2.1) was in untreated cuttings (Figure 5 and

6). The number of root developed in the nodal cuttings was significantly higher than the tip cuttings in all concentrations of IBA treatment.

In both types of cuttings, the number of roots were significantly increased by IBA treatment which strengthen previous reports, for instance, Hossain et al. (2005) observed significant increase in the number of roots in IBA treated cuttings (6.8 to 7.9 in 0.2% IBA treated cuttings) compared to in untreated cuttings (4.1 to 6.6). In a separate work Hossain et al. (2006) reported that the number of roots in the branch cutting of *B. vulgaris* var. *striata* was the maximum for 0.4% IBA treatment followed by 0.2% IBA treatment and the lowest was in the control cuttings. Similar result was reported by Castillo (1990) as they observed the maximum number of roots in base cuttings treated with 1000ppm IBA. Kamaluddin et al. (1996) reported a significant increase in root number as well as rooting percentage with the application of IBA in vascular plant, *Artocarpus heterophyllus* and recorded the highest number of roots (9.4) in cuttings treated with IBA.

Applied auxin is known to intensify root-forming process in cuttings. For instance, polysaccharide hydrolysis is activated under the influence of applied IBA, and as a result, the contents of physiologically active sugar increases providing materials and energy for meristematic tissues and later for root primordia and roots in cuttings of vascular plants (Ermakove and Zhuravieva 1976). Hassig (1983) examined the function of endogenous root forming components of vascular plants and demonstrated that auxin is required for the development of callus in which root premordia are initiated.

Root length of cuttings

Average lengths of longest roots in nodal leaf cuttings were within the range between 10.1 cm to 14.0 cm and in tip cuttings between 9.9 cm and 12.1 cm without any significant difference in the average lengths of the longest roots among the treatments or between the cutting types. However, in nodal leafy cuttings, the highest root lengths (14.0 cm) was obtained from the cuttings treated with 0.4% IBA solution followed by the 0.1% IBA (13.9 cm) and the lowest (10.1cm) was found in untreated cuttings (Table 1 and figure 6). Interestingly, the highest root lengths in tip cuttings (12.1 cm) was observed in the cuttings treated with 0.1% IBA solution followed by 0.4% IBA (12.0 cm) and the lowest (8.2 cm) was found in cuttings treated with 0.8 % IBA solution (Table 1 and figure 6) – which is totally reverse compared to nodal leafy cuttings. Further experiment is needed to explain the reason behind this total contrast between nodal leafy cutting and tip cuttings. Hossain et al. (2006) reported earlier that in *B. vulgaris* var. *striata* branch cuttings, average length of the longest roots was maximum for 0.2% IBA treatment followed by 0.4% IBA treatment and the lowest was in the control.

Cutting Morphology

Cutting lengths and cutting diameters

Cutting lengths varied from 25.7 cm to 28.3 cm in nodal leafy cuttings and 18.9 cm to 20.9 cm in tip cuttings (Table 2 and figure 2). Cutting diameter varied from 4.6 mm to 5.4 mm in nodal leafy cuttings and 2.2 mm to 3.1 mm in tip cuttings (Table 2 and figure 2). There was no significance difference among the cutting lengths or cutting diameters between the types of cuttings due to the treatment. However, the length and diameter of the cuttings in each cutting types were kept indifferent to avoid the non-treatment variation in the experiments.

Steckling Capacity

The survival percentage of rooted cuttings of *B. vulgaris* in the nursery was observed significantly higher in the cuttings treated with IBA than control. In nodal leafy cuttings and tip cuttings, survival percentages were 73.3 to 93.3 and 66.7 to 90 respectively (Figure 7). The highest survival percentage in nodal leafy cutting (93.3) was observed in cuttings with 0.8% IBA treatment followed by 0.4% IBA (86.7) treated cuttings and the lowest (73.3) was in untreated cuttings. In tip cuttings, the highest survival percentage (90) was for 0.8% IBA treatment followed by 0.4% IBA treatment (83.3) and the lowest (66) was in control (Figure 7). The cutlings' growth patterns are also shown in figures 8 and 9 - three and ten months after transferring them to polybags.

The survival percentage of cutlings (rooted cuttings) was higher in IBA treated ones in both types of branch cuttings. The result of the present study is in line with the report by Hossain et al. (2005) who observed the highest survival percentage (95.2) was in the cuttings rooted with IBA solution and the lowest (90) in the controlled cuttings. Pattanaik et al. (2004) reported 100% field survivals of *B. balcooa* cutting treated with 200 ppm IBA two years after field planting. However Hossain et al. (2006) reported that the survival percentage did not vary between the cutting types and the concentrations of rooting hormones in the rooted branch cuttings of *B. vulgaris* var. *striata*. The higher survival potential in the cuttings rooted with IBA solution over the control cuttings is due to the higher number of roots produced in the cuttings treated with IBA as evident in figures 5 and 6. However, there was no report found that discussed the inner mechanism behind such augmentation in the survival percentage of the rooted cuttings of bamboo which can be an interesting new field of investigation.

Conclusion

Rooting ability of two types of branch cuttings (nodal leafy cuttings and tip cuttings) of *B. vulgaris* was investigated under four concentrations of IBA solution with respect to a control. The highest rooting percentage and the number of roots developed per cutting were observed in the cuttings treated with 0.8% IBA solution in both the types of cuttings and the lowest was in the cuttings without treatment. In steckling performance IBA treated cuttings showed better survival capacity in the nursery condition than control. The result of the present study could help in opening a new avenue for the propagation of this variety of multipurpose bamboo since both types of branch cuttings showed potential in developing roots, survive and rhizome formation. However the rooting percentage of leafy branch cuttings of *B. vulgaris* in this study was 56 and we believe there is further scope of increasing the rooting ability for the species. Furthermore, the performance of planting stock developed through these methods was not assessed in field due to the limitations in time for the study. This might be one of the important aspects for future study.

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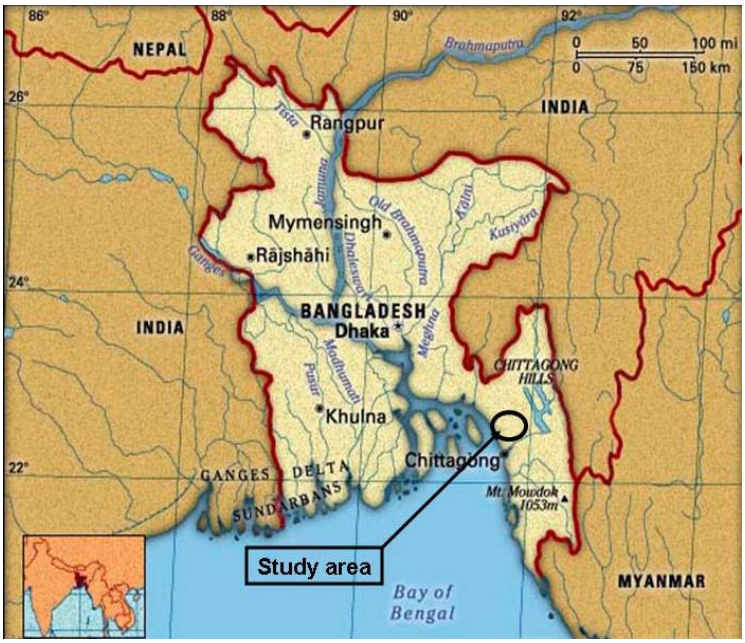

Figure 1: Study area (Adopted from Encyclopaedia Britannica inc. 1999)

Figure 2: Nodal leafy cuttings with base (left) and tip cuttings (right) of *B. vulgaris* are ready for rooting trial.

Figure 3: Non-mist propagator (left) and the cuttings rooted in perforated plastic trays filled with coarse sand mixed with gravel in the propagator (right).

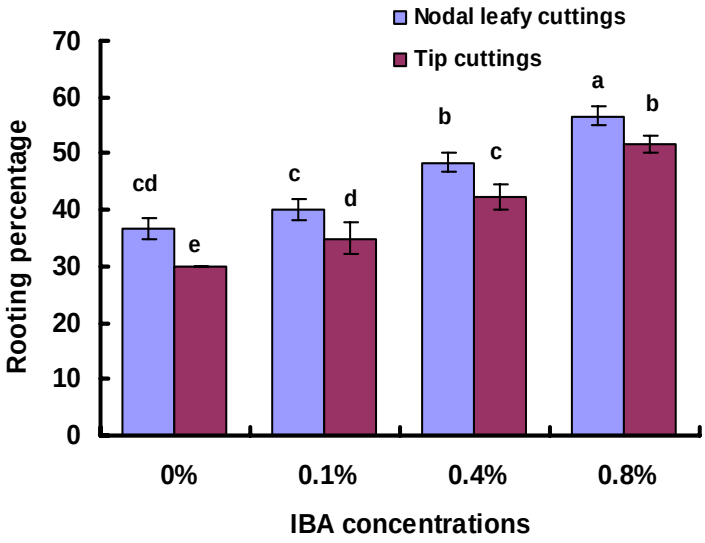

Figure 4: Rooting percentage of nodal leafy cuttings and tip cuttings of *B. vulgaris* under various treatments. Same letters indicate no significant difference at $p<0.05$ (ANOVA and DMRT). Bar indicates the standard error of means.

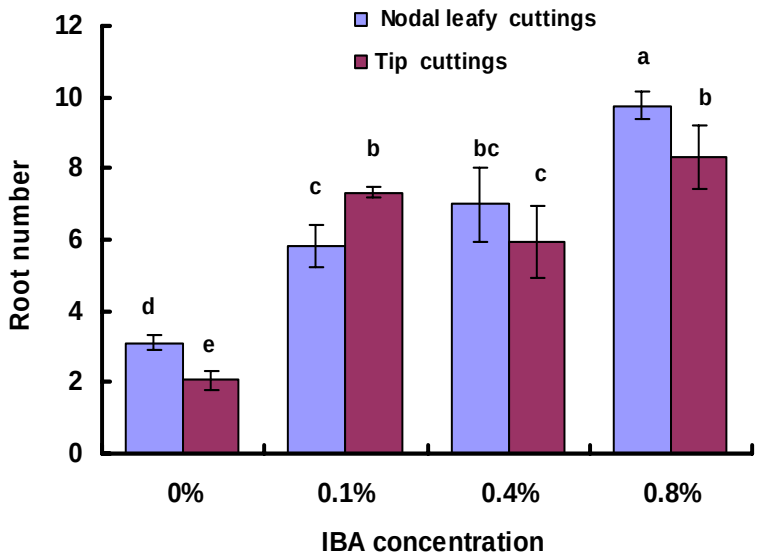

Figure 5: Number of root developed in nodal leafy cuttings and tip cuttings of *B. vulgaris* under various treatments. Same letters indicate no significant difference at *p*<0.05 (ANOVA and DMRT). Bar indicates the standard error of means.

Figure 6: Rooting ability of nodal leafy cuttings (left) and tip cuttings (right) of B. vulgaris under various treatments.

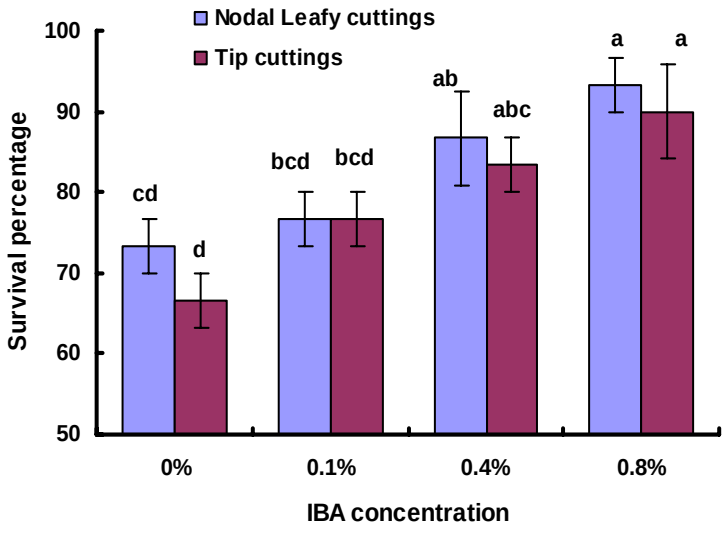

Figure 7: Survival percentage of nodal leafy cuttings and tip cuttings of *B. vulgaris* ten months after transforming the rooted cuttings in to the polybags. Same letters indicate no significant difference at *p*<0.05 (ANOVA and DMRT). Bar indicates the standard error of means.

Figure 8: Steckling performance of leafy cuttings (left) and the tip cuttings (right) of *B. vulgaris* three months after transferring the rooted cuttings in the polybags.

Figure 9: Cutlings of ten months old developed from nodal leafy branch cuttings (left) and tip cuttings (right) are ready for out planting.

Table 1: Average length (cm) of root developed in the cuttings under various concentration of IBA solution. NS: Not significant at *P<0.05* (ANOVA and DMRT).

Cutting types	IBA concentrations				
	0%	0.1%	0.4%	0.8%	*p*
Nodal leafy cuttings	10.1±0.41 [a]	13.9±0.95 [a]	14.0±0.74 [a]	12.8±2.03 [a]	NS
Tip cutting	10.2±0.70 [a]	12.1±2.09 [a]	12.0±1.68 [a]	9.9±0.44 [a]	NS

Note: Same superscript letters indicate no significant difference at $p<0.05$ (ANOVA and DMRT). ± indicates the standard error of means.

Table 2: Length and diameter of nodal leafy cuttings and tip cuttings of *B. vulgaris* under various treatments. NS: Not significant at *P*<0.05 (ANOVA and DMRT).

	Cutting types	IBA concentrations				*p*
		0%	0.1%	0.4%	0.8%	
Length (cm)	Nodal leafy cuttings	28.3±0.15 [a]	26.5±0.55 [a]	26.9±0.76 [a]	25.7±0.75 [a]	NS
	Tip cutting	20.3±0.58 [a]	19.8±0.87 [a]	20.9±0.87 [a]	18.9 ±0.13 [a]	NS
Diameter (mm)	Nodal leafy cuttings	4.6±0.30 [a]	5.4±0.54 [a]	5.3±0.85 [a]	4.7±0.39 [a]	NS
	Tip cutting	2.4±0.23 [a]	2.8±0.23 [a]	3.1±0.10 [a]	3.0±0.16 [a]	NS

Note: Same superscript letters indicate no significant difference at $p<0.05$ (ANOVA and DMRT). ± indicates the standard error of means.

Micropropagation of Economically Important Bamboo *Dendrocalamus hamiltonii* through Axillary bud and Seed culture

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Abstract

An efficient and reproducible protocol for the large scale propagation of *Dendrocalamus hamiltonii* is described. Nodal segments from mature clump and seeds were used as explants for establishment of cultures. To establish aseptic cultures nodal segments were surface sterilized with 0.1% $HgCl_2$ for 10-15 min. while the seeds were disinfected with sodium hypochlorite (4%) for 20 min. For axillary bud break and shoot induction from seeds, sterilized explants were inoculated on MS medium supplemented with cytokinins. Axillary shoots (3-4 shoots) from nodal explants proliferated within 10 days of culture on MS medium supplemented with 1.0mg/l BAP. Multiple shoots were formed within 3-5 weeks of seed culture. 7-8 shoots were obtained when seeds were inoculated on MS medium supplemented with 7.0mg/l BAP. The initiated shoots were excised from mother explants and further multiplied on MS medium supplemented with defined plant growth regulators. Best shoot multiplication was observed on MS medium supplemented with BAP (1.0-10mg/l). A regular subculture in every 3-4 weeks increased the rate of multiplication. To initiate *in- vitro* rooting, pulse treatment was given in 2-step procedure. Excised propagules of 3-5 shoots were inoculated on MS medium supplemented with high concentration of auxin (IBA) for 7 days, later on these *in- vitro* shoots were transferred to half strength MS medium without auxin for 10-15 days to obtain well rooted plants. Plantlets were hardened, acclimatized and established in soil, where they exhibited normal growth.

Keywords: *Dendrocalamus hamiltonii;* bamboo; micropropagation; nodal segment; seed.

Introduction

Bamboos are versatile multipurpose forest product, which are important economically and are often referred to as 'GREEN GOLD'. The bamboos occupy a special place in the lives of rural poor and rural industries, especially in Asia.The most important use of bamboo is as a raw material in pulp, paper and rayon industries. Apart from industrial use, bamboos are utilized in the making of mat boards, roofing, furniture, agriculture implements, and baskets for construction and for numerous traditional uses (Anonymous 1978; Rao et al. 1990).The multifarious uses of bamboos, have increased their demand much beyond the availability. Bamboo is threatened because of its monocarpic habit and increased market demand. It has traditionally been propagated through seed or through vegetative means, but these methods besets with many problems. Seeds of most

bamboo species have short viability, and lasts only for a few months (Nadgir et al. 1984). The conventional vegetative propagation through cuttings and rhizome is undependable due to the bulky size of the propagules in the required number (Rao et al. 1990). The potential of micropropagation has raised high hopes and a lot of research has been focused on the development of protocols for rapid and large scale propagation (Rao et al. 1985; Nadgauda et al. 1990, Godbole et al. 2002; Sood et al. 2002). The *Dendrocalamus hamiltonii* is one such economically important species which is distributed in the North- West Himalaya, Sikkim, Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Tripura of India, Bhutan and Bangladesh. Flowering cycle is reported to be 30-40 years. It is popular for its strong culms that are used for construction purposes, the tender shoots are used for preparation of ‘ hiyup’ a sour pickle by the tribals of Arunachal Pradesh in India. Its leaves also serve as a fodder for animals.The present study was undertaken to establish a protocol for efficient *in-vitro* propagation of *D. hamiltonii* from nodal segments of mature clump and by high frequency shoot proliferation from the seeds since seed propagated plants are expected to last a full life span.

Materials and Methods.

Axillary bud proliferation from nodal segments

The efficiency of shoot multiplication from axillary bud proliferation was tested by culturing the nodal segment from the lateral branches of a 10 year old vegetatively propagated plant of *D. hamiltonii* growing at the Bamusetum, FRI, Dehradun. Nodal segments (about 2.5-3.0 cm in length) were disinfected with 0.1%$HgCl_2$ for 10-15 min., rinsed with distilled water for three to four times, both the ends were trimmed & segments were cultured on both liquid and semisolid MS medium supplemented with varying concentrations of cytokinins. The medium was adjusted to pH 5.8 prior to autoclaving at 121°C for 15 min. Cultures were maintained at 25°C ± 2 ^{o}C under a 16h photoperiod with a photon flux density of 2500 lux from white fluorescent tubes.

Seed germination

Mature seeds of *Dendrocalamus hamiltonii* were obtained from The Sheel Biotech Company, New Delhi, India. After dehusking carefully, the healthy seeds were selected and surface sterilized with sodium hypochlorite (4%) for 20 min. followed by three to four rinses with sterile distilled water to remove the traces of sterilant. Disinfected seeds were then cultured aseptically on semi- solid MS medium containing 3% sucrose supplemented with varying concentrations of cytokinin (1.0- 10mg/l BAP/ Kn). The medium was gelled with agar (0.7%), adjusted to pH 5.8 prior to autoclaving at 121°C for 15 min. Cultures were maintained at 25°C ± 2 ^{o}C under a 16h photoperiod with a photon flux density of 2500 lux from white fluorescent tubes.

In vitro shoot multiplication

Well developed *in vitro* shoots from both seeds and nodal segments were excised and transferred to MS medium (Murashige & Skoog’s 1962) supplemented with different concentrations of BAP & Kn alone or in combination for achieving maximum shoot multiplication. Subcultures were performed at intervals of 3 weeks, by separation of shoots in propagules of varying number of shoots to see the effect of size of propagule on *in vitro* shoot multiplication and transferred to fresh medium. Effect of pH ranging from 4.0 to 7.0 in medium was studied for

shoot multiplication. Different concentration of sucrose (0-5%) was studied to see the effect on shoot multiplication. Different strength of MS medium i.e. full, ¾, ½ & ¼ were tried for optimization of multiplication medium.

In vitro Rooting of Shoots

After 3 weeks of incubation, propagules consisting of 3-5 shoots were transferred to rooting medium (MS medium supplemented with 1.0- 10.0mg/l NAA or 5.0-30.0mg/l IBA). To initiate *in- vitro* rooting, pulse treatment was given in 2- step procedure. Excised propagules of 3-5 shoots were inoculated on MS medium supplemented with high concentration of auxin (IBA) for 7 days, later on these *in- vitro* shoots were transferred to half strength MS medium without auxin for 10-15 days to obtain well rooted plants. After 4 weeks in culture, data were collected on the percentage of rooted propagules and the number of roots per propagule.

Hardening and acclimatization of in vitro propagated plants

The rooted plants were removed from the flasks, washed thoroughly with water to remove all traces of medium attached to the roots and then transferred to glass bottles containing 1/3 volume of soilrite. Plants were fed with half strength macro and micro nutrients of MS medium thrice a week in the mist chamber under RH 85-90% with a temperature of 32°C. Acclimatization of these plants was carried out in shade house in polybags containing a mixture of sand: farmyard manure (FYM): soil in ratio of 1:1:1 for two months. Hardened plants were transferred to bigger pots and transferred to net house.

Results and discussion

Tissue culture technique is being applied for *in-vitro* propagation of *D. hamiltonii* using nodal segments from mature clump and seed as explants.

Axillary bud proliferation from nodal segments

In case of nodal explant from mature clump, axillary shoots proliferated within 10 days of culture on MS medium supplemented with BAP. Best bud break with 3-4 shoots was obtained on liquid MS medium supplemented with 1.0mg/l BAP (Figure A, Table 1). BAP when used along with Kn in the MS medium did not improve the seed response as compared to BAP when used alone in the MS medium. After 3 weeks these buds were excised from mother explant and cultured on MS medium containing different concentrations of BAP (1.0-5.0 mg/l).

Seed germination

In the present study 25% of seeds germinated and formed shoots without root formation on semisolid MS medium containing BAP. The ability of the seeds to form multiple shoots was dependent on the concentration of BAP in the medium (Table 2). Maximum germination was recorded at a concentration of 7.0 mg/l BAP supplemented in the MS medium where 7-8 shoots were formed immediately after seed germination within 3 weeks of culture (Figure B). BAP induced direct shoot regeneration from aseptic seed culture has also been

reported in *Dendrocalamus asper* (Arya et al.1999). BAP when used along with Kn in the MS medium did not improve the seed response as compared to BAP when used alone in the MS medium. Multiple shoots developed from the seeds were excised and subcultured for further multiplication on MS medium containing 1.0-5.0 mg/l BAP.

In vitro shoot multiplication

The shoots proliferated from the seeds and axillary buds were established on MS medium and were used for *in vitro* shoot multiplication. Best multiplication of proliferated shoots was obtained on MS medium supplemented with 3.0mg/l BAP, when propagule of four shoots was subcultured every four weeks. Shoot multiplication rate of 7-8 folds was obtained from seed culture on MS medium supplemented with 3.0 mg /l BAP in a period of every four weeks (Figure C, Table 3). Subculture period showed its effect on multiplication rate of *in vitro* shoots. Best multiplication rate was obtained when the shoot culture were regularly subcultured on fresh medium every four weeks. Cultures when left without subcuturing for 5 weeks showed necrosis. The shoot multiplication capacity of the *in vitro* shoots was greatly influenced by the BAP concentration in the medium and size of the propagule used for shoot multiplication. Similar results have been reported in *Dendrocalamus asper* (Arya et al. 1999). The best shoot multiplication rate was obtained on MS medium supplemented with 3.0mg /l BAP when propagule of four shoots was subcultured (Table 4). At decreased level of BAP the shoot multiplication rate decreased with an increase in shoot length. Similar results on BAP supplemented medium have been reported in a number of bamboos (Arya and Arya1997; Arya and Sharma 1998; Chambers et al. 1991; Purtpongse Gavinlertvatana 1992).The shoot multiplication rate declined sharply if propagule of less than 3-4 shoots was cultured. On decreased level of BAP (1.0-2.0 mg/l) as well as high concentration of BAP (4.0-9-0 mg/l) the multiplication rate of *in vitro* shoots was reduced. The *in vitro* shoot multiplication cycle were carried out in liquid as well as in semisolid medium. The shoot multiplication was better in the liquid medium as compared to semisolid medium in respect to multiplication rate and shoot development. The shoots were relatively healthy on liquid medium. This may be because of better uptake of nutrients by the cultures. Similar results were earlier reported in *Bambusa tulda* (Saxena 1990), *Dendrocalamus giganteus* (Arya et al. 2006) and *D. strictus* (Nadgir et al. 1984). However, the shoot multiplication cycles were carried out in semisolid medium due to easy handling of cultures and to avoid vitrification of shoots. The hydrogen ion concentration of the medium effect growth of the tissue by altering pH of the cells, because higher 'H' ion concentration induced precipitation of phosphates, gelatinization of agar and destruction of vitamins and growth regulators. In the present study, slightly acidic medium favours increase in shoot multiplication rate whereas, alkaline medium reduced multiplication rate. Maximum multiplication of shoots was obtained on MS medium having 5.8 pH. Effect of different strengths of MS medium supplemented with 3.0 mg/l BAP was also tested for *in vitro* shoot multiplication. Full strength MS salts yielded best shoot multiplication and overall growth of shoots and leaves. At reduced strength pale yellow leaves and thin shoots developed. Sucrose has been widely used as carbon source for various plant tissues in cultures. Therefore, study was conducted to see the effect of different concentrations of sucrose ranging from 0.0-5.0 % on *in vitro* shoot multiplication rate. Addition of sucrose in the medium enhanced shoot multiplication. 3.0 % of sucrose in the MS medium was found to be the optimal requirement for shoot multiplication. At lower concentration of sucrose, reduced multiplication rate was obtained along with yellowing of leaves.

In vitro rootingof shoots

The multiple shoots in both types of cultures were found to initiate roots following a pulse treatment in a MS medium supplemented with 20mg/l IBA for 7 days. After incubation in the above medium these were transferred to half strength MS medium for 10-15 days to obtain well rooted plants (Figure D). Effective role of IBA in bamboos for rooting has also been reported in *Dendrocalamus giganteus* and *D. strictus* (Das and Rout 1991).

Hardening and acclimatization of in vitro propagated plants

In vitro propagated plants are generally susceptible to transplantation shock due to delicate root system, reduced amount of epicuticular wax and reduced stomata. This can result in excessive dehydration, poor control of gaseous exchange. Therefore, a gradual procedure of hardening and acclimatization of the plantlets is required. The rooted plants were removed from the flasks, washed thoroughly with water, transferred to soilrite for hardening (Figure E). Plants were fed with half strength macro and micro nutrients of MS medium thrice a week in the mist chamber under RH 85-90% and at 32°C. Acclimatization of these plants was carried out in shade house in polybags containing a mixture of sand: farmyard manure (FYM): soil in ratio of 1:1:1 for two months and established in pots where they exhibited normal growth (Figure F).

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Table 1: Effect of BAP concentration in MS medium on *in vitro* axillary bud proliferation of *D.hamiltonii*

BAP	Response %	Mean shoot number	Mean Shoot Length (cm)
0.0 mg/l	20.12 ± 2.85	3.26 ± 0.01	2.58 ± 0.01
1.0 mg/l	58.17 ± 4.43	4.03 ± 0.03	2.85 ± 0.03
3.0 mg/l	51.00 ± 3.10	3.01 ± 0.04	2.47 ± 0.01
5.0 mg/l	44.47 ± 2.34	2.03 ± 0.02	2.17 ± 0.01
7.0 mg/l	38.20± 3.70	1.47 ± 0.01	2.20 ± 0.02
9.0 mg/l	39.50 ± 4.58	1.27 ± 0.01	2.11 ± 0.01

Mean of 30 replicates ± Standard Error

Table 2: Effect of BAP concentration in MS medium on *in vitro* shoot formation from seeds of *D. hamiltonii*

BAP	Response %	Mean shoot number	Mean Shoot Length (cm)
0.0 mg/l	12.83 ± 1.42	1.11 ± 0.06	1.82 ±0.01
1.0 mg/l	17.87 ± 1.17	1.33 ± 0.05	1.71 ±0.01
3.0 mg/l	19.33 ± 0.76	1.89 ± 0.05	1.75 ±0.02
5.0 mg/l	22.67 ± 1.54	3.05 ± 0.05	1.89 ±0.01
7.0 mg/l	26.77 ± 1.75	8.03 ± 0.03	2.17 ±0.02
9.0 mg/l	22.50 ± 2.08	6.52 ± 0.04	1.96 ±0.01

Mean of 30 replicates ± Standard Error

Table 3: Effect of BAP concentration on *in vitro* shoot multiplication from seed culture of *D. hamiltonii*, after four weeks in culture. Propagules of four shoots were cultured.

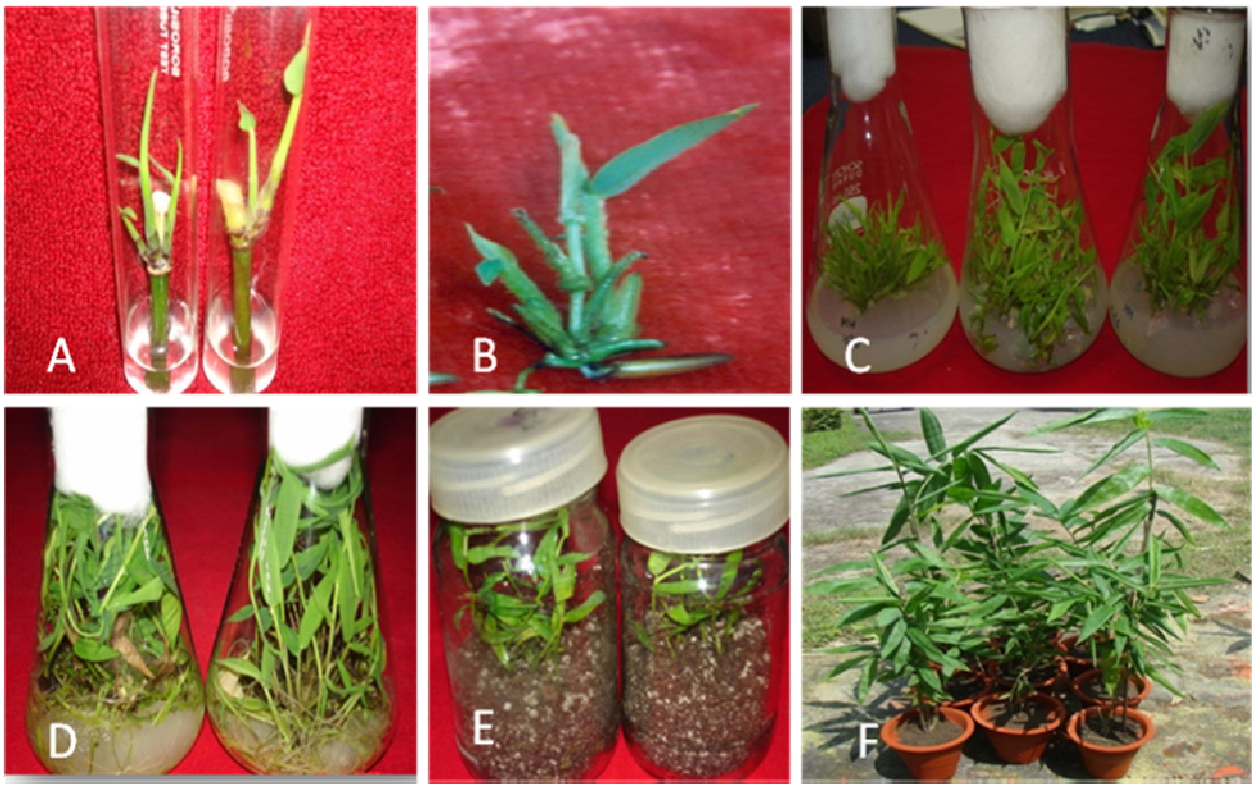
BAP	Mean shoot number	Mean Shoot Length(cm)	Multiplication fold
1.0 mg/l	19.10±0.06	2.04±0.01	4.78±0.01
2.0 mg/l	23.10±0.05	2.27±0.01	5.78±0.01
3.0 mg/l	29.10±0.06	2.32±0.02	7.28±0.01
4.0 mg/l	28.60±0.02	1.94±0.01	7.15±0.01
5.0 mg/l	27.90±0.04	1.88±0.02	6.98±0.01

Mean of 30 replicates ± Standard Error

Table 4: Effect of the size of *D. hamiltonii* propagule on *in vitro* shoot multiplication rate, after four weeks in culture on MS+3.0mg/l BAP.

No. of Shoots inoculated	Mean shoot number	Mean Shoot Length (cm)	Multiplication fold
1 shoot	1.00±0.00	1.72±0.02	1.00±0.00
2 shoots	4.03±0.02	1.75±0.03	2.02±0.01
3 shoots	15.83±0.03	1.90±0.01	5.28±0.01
4 shoots	29.27±0.12	2.20±0.02	7.32±0.03
5 shoots	26.73±0.09	2.18±0.01	5.35±0.02
6 shoots	24.80±0.12	2.13±0.01	4.13±0.02

Mean of 30 replicates ± Standard Error



Micropropagation of *Dendrocalamus hamiltonii* through axillary and seed culture
Fig.A Axillary bud proliferation from nodal segment on MS +1.0mg/l BAP.
Fig.B Multiple shoots formation from seed cultured on MS + 7.0mg/l BAP.
Fig.C *In vitro* shoots multiplication on MS + 3.0mg/l BAP.
Fig. D *In vitro* rooting
Fig. E *In vitro* hardening of plantlets
Fig. F *In vitro* raised plants in pots.

Propagation of Bamboos through Tissue Culture Technology and Field Plantation

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Abstract

An efficient and reproducible technology for the large scale propagation of bamboos is developed. High frequency direct shoot proliferation was achieved through axillary bud culture and through aseptic seed culture. So far tissue culture technology has been developed for nine economically important bamboo species for large scale multiplication. In all these species multiple shoots were induced in *in-vitro* culture of nodal shoot segment containing axillary bud through forced axillary branching in case of *Dendrocalamus asper, D.strictus, D. membranacaeus, D. giganteus, D. hamiltonii, Bambusa bambos, B. vulgaris, Drepanostachyum falcatum, Melocanna baccifera* and direct shoot proliferation obtained in aseptic seed cultures of *D. asper, D. hamiltonii* and *D. falcatum.* Best response towards axillary bud break was obtained on BAP supplemented medium. These axillary shoots were cultured and with the passage of subculture yielded 4-16 fold *in vitro* shoot multiplication. A propagule of three shoots was found to be the best for rapid shoot multiplication in 4 week subculture cycle. 80-98% *in vitro* rooting was obtained with IBA or NAA supplemented MS medium. Aseptic seeds when used as explant were cultured on MS medium supplemented with 1.0-10.0 mg/l BA. Multiple shoots were formed within 3-5 weeks of seed culture without root formation. The shoot forming capacity of seeds was critical and was influenced by the BA concentration in the medium. *In vitro* shoot cultures were established from the initial shoots that developed from the seed. These *in vitro* shoots were later rooted on auxin (NAA &IBA) supplemented medium. In both the cases a very high rate of transplantation (Lab to field) and plant survival was obtained. The success limits to the gradual procedure of hardening and acclimatization of plantlets. Plantation work undertaken at 5x5 field spacing gave good results and so far thousands of plants have been field planted. Both the procedures described is of high value as clonal propagation is promoted on one hand (through axillary bud culture) with genetic widening of planting stock is achieved on other hand through seed culture.

Introduction

Bamboos, the world's fastest growing and environment- friendly giant grass, has now gained international recognition and priority, leading to its recognition as an important non- woody timber resource and a versatile commodity of considerable economic importance. It perhaps has the singular distinction of being the only natural resource put so many and so varied uses (John and Nadgauda 1995). The multifarious uses of bamboos have increased their demand much beyond the availability. This trend of increasing demand and decreasing supply is expected to continue in future. With respect to vegetative propagation, cuttings, offsets and rhizomes

are bulky, difficult to handle and transport and survival of plantlets is also low (Hasan 1980). The production of seed is irregular with short viability, seed sterility, poor seed setting during off season flowering, and flowering once before culm death (McClure 1966; Janzen 1976; Nadgir et al. 1984). For mass scale propagation tissue culture is the only viable method. Indeed, the order of magnitude of the demand for bamboo planting materials indicates that micropropagation will inevitably be necessary for mass scale propagation (Subramanlam 1994; Gielis 1994).

Attempts have been made in the recent past to micropropagate bamboos, but plants have been produced in small numbers only in species mainly through somatic embryogenesis (Rao et al. 1985; Yeh and Chang 1986a, b, 1987), organogenesis (Huang et al. 1989) and axillary branching (Nadgir et al. 1984; saxena 1990). So far we have successfully developed tissue culture technology for large scale multiplication of nine economically important bamboo species, viz. *Dendrocalamus asper, D. membranaceus, D. strictus, D. giganteus, D. hamiltonii, Bambusa arundinacea, B. vulgaris, Melocanna baciferra* and *Drepanostachym falcatum* through axillary bud culture and aseptic seed culture. So far around 40, 000 plants have been produced and the protocol developed is presently used by Biotech companies producing tissue culture plants in million in India.

Material and methods

Axillary Bud Proliferation

Young and juvenile shoots of different species were collected from the mother plants. Nodal segments with single axillary buds were used as source material. After removal of the leaf sheath, individual nodes were washed with dilute solution of 5-10 drops Tween-20 (HiMedia, India) per 100 ml of distilled water for 10 min. followed by running tap water for 15 min. Pre-disinfection treatments was given to reduce the contamination, where nodal segments were treated with a mixture of aqueous solution of fungicide bavistin (BASF, India) and bactericide streptomycin (HiMedia, India) at a concentration of 0.1% each for 20 min. For surface sterilization, nodal segments were treated with aqueous solution of 0.1% $HgCl_2$ (HiMedia, India) for 8-10 min. After three washings in sterile distilled water the surface disinfected axillary buds were inoculated on liquid MS (Murashige and Skoog's 1962) medium supplemented with cytokinin. Different concentrations of 6-benzylaminopurine (BAP) or 6-furfurylaminopurine (Kn) alone or in combination were used in liquid MS medium for bud break. The pH of the medium was adjusted to 5.8 by using 1 N NaOH or 1 N HCl prior to autoclaving. The liquid medium (10ml) was dispensed into 25 x 150mm test tubes (Borosil, India). The culture tubes with media were autoclaved 121^0C for 20 min. Plants were field planted following simple silvicultural practiced keeping 5x5 m & 4x4 m spacing.

Seed germination

Mature seeds of *Drepanostachym falcatum, D. asper, D. hamiltonii* were collected. After dehusking carefully, the healthy seeds were selected and surface sterilized with sodium hypochlorite (4%) for 20 – 30 min. followed by three to four rinses with sterile distilled water to remove the traces of sterilant. Disinfected seeds were then cultured aseptically on semi- solid MS medium containing 3% sucrose supplemented with varying

concentrations of cytokinin (1.0- 10mg/l BAP/ Kn). The medium was gelled with agar (0.7%), adjusted to pH 5.8 prior to autoclaving at 121°C for 20 min.

Shoot multiplication

Proliferated *in-vitro* shoots were separated into clumps (four shoots) and used for further shoot multiplication. Various concentrations of BAP (0-25µM) or Kn (0-25µM) alone or in combinations were used in liquid and semisolid MS medium. Subculturing was carried out every 4 weeks on fresh shoot multiplication medium. Established cultures were maintained on semi- solid medium. The number of shoots cultured and the number of shoots derived at the end of subculture gave the multiplication rate.

In vitro Rooting

In-vitro raised shoots (three or four shoots) were used for root induction. Half strength liquid MS medium with various concentrations of indole-3-butyric acid (IBA; 5-30µM) or α-napthalene acetic acid (NAA; 5-30µM) alone was used. The number of individual shoot propagules that responded for rooting were counted and expressed as percent rooting.

Culture conditions

All cultures were incubated at 25 ± 2ºC temperature and illumination of 16hrs photoperiod with light intensity of 2400 lux, obtained by white cool fluorescent tubes of 40 watts (Philips, India).

Hardening and acclimatization

Rooted plantlets were taken out from the flasks, washed to remove adhered medium and then transferred to autoclaved 250 ml screw cap glass bottle containing 1/3 volume of soilrite. These plantlets were nurtured with half strength MS medium (without organics) twice a week for two weeks and were kept in tissue culture incubation room. After two weeks these bottles were shifted to mist chamber having relative humidity of 70-80% with a temperature of 30 ± 2^{0}C. The caps of bottles were removed and plantlets were allowed to remain in the bottle for one week before they were transferred to polybags containing a mixture of sand, farmyard manure and soil in a ratio of 1:1:1. In the mist chamber, the plants were kept for four weeks and were irrigated with half strength MS medium. Later, these polybags were shifted to high-density double deck agronet open shade house for acclimatization.

Results

Axillary Bud Proliferation

Axillary bud break was obtained in nodal segments within 15-20 days, when cultured on MS medium supplemented with cytokinin. The morphogenic response of explant towards axillary bud proliferation was markedly influenced by the concentration of growth regulator in the medium. A cluster of 4-15 shoots normaly proliferated from the axilary bud depending on the culture conditions. Under the optimal media conditions the

axillary shoot proliferation reached upto 5-8 axillary shoots in *D. strictus*, *D. giganteus* (MS + 2.0 to 5.0 mg/l BAP), 8-10 shoots in *D. membranaceus* (MS + 1.0 to 5.0 mg/l BAP + 0.5 mg/l NAA), 10-15 shoots in *B. bambos* (MS + 5.0 mg/l BAP), 1-3 shoots in *D. asper* and *B. vulgaris* (MS + 5.0 mg/l BAP), 3-4 shoots in *D. hamiltonii* (MS + 1.0 mg/l BAP) and 10-12 shoots in *Drepanostachym falcatum* (MS + 5.0 mg/l BAP) (Figure 1A). Once the axillary bud break was achieved the axillary shoots production could be increased by regular subculturing on MS medium supplemented with defined concentration of BAP in the MS medium.

Seed germination

In the present study for multiple shoot formation through seeds in *D. falcatum*, maximum germination of 63% was recorded at a concentration of 3.0 mg/l BAP supplemented in the MS medium (Table 3, Figure 2A).In case of *D. hamiltonii* (Figure 2B) and *D. asper* maximum germination was recorded at a concentration of 7.0 mg/l BAP and 5.0 mg/l BAP supplemented in the MS medium respectively. The ability of the seeds to form multiple shoots was dependent on the concentration of BAP in the medium

Shoot multiplication

Response of *in vitro* shoot multiplication varied with cytokinin type and its concentration used in the medium. The proliferated shoots from the axillary buds were excised into groups of shoot clusters and subcultured on liquid (paper bridge) as well as on semisolid MS medium supplemented with 2.0 – 10.0 mg/l BAP for further shoot multiplication. During first to third subculture an average shoot multiplication rate of three fold was obtained in the liquid/semisolid MS medium supplemented with 2.0-5.0 mg/l BAP. Once the shoot cultures were established they were excised into groups of shoots (called as propagule), subcultured and multiplied on MS medium supplemented with 2.0-5.0 mg/l BAP. Regular (four week interval) subculturing of shoot propagules increased the multiplication rate. A propagule of three to four shoots gave best shoot multiplication rate as compared to smaller (1-2 shoots) or larger size (5-6 shoots) propagules in all the bamboos (Table 6). Repeated subculturing in liquid medium resulted in vitrification of shoots except in case of *D. strictus* and *B. vulgaris*(Figure 2D) . Hence semisolid medium was used in subsequent subcultures for other bamboo species. After 4-6 cycles of shoot multiplication the rate of shoot multiplication increased and later a consistent 4-6 folds average multiplication rate was obtained in case of *B. bambos(*Figure 1B*), B. vulgaris, D. strictus* and *D. giganteus* (Figure 2C). In case of *D. asper* 12-16 folds multiplication was obtained after every subcultured cycle (Table 1). In case of *D. membranaceus* the shoot multiplication rate obtained was 6- 15 fold. A multiplication rate of 9 – 11 folds was obtained in case of *D. falcatum* (Table 2) . In case of *D. hamiltonii* and *Melocanna baciferra* multiplication rate was 7-8 and 2-3 folds respectively.

Rooting of in vitro shoots

Shoots of 2-3cm length were used for various *in vitro* rooting experiments. *In vitro* rooting was obtained when *in vitro* grown shoots were transferred on half strength MS medium supplemented with auxins (IAA, NAA, and IBA). Rooting was obtained when shoot propagules were subcultured on MS medium supplemented with 1.0 - 5.0 mg/l NAA or 10-15 mg/l IBA depending on the bamboo species. Best rooting (80-85%) was obtained within 3-4 weeks of subculture on MS + 3.0 mg/l NAA and on MS + 10 mg/l IBA in case of*, B. bambos* (Table 5,

Figure 2E), *D. asper* (Figure 1D) and *D. membranaceus* (Table 4, Figure 2F). In case of *B. Vulgaris* (Figure 1C), MS + 4.0 mg/l NAA gave the best results for *in vitro* rooting. IBA was found to be better for *in vitro* rooting response as compared to NAA in case of *M. baciferra*. Generally 5-8 roots emerged from the basal end of the propagule. Single shoot when placed for rooting did not survive. Thus a propagule of minimum three shoots was required. Size of the shoot propagule was also found to be critical for rooting.

Hardening and acclimatization

Healthy plantlets with good roots and shoot system developed within 5-6 weeks on rooting medium. During hardening and acclimatization the shoots elongated, leaves turned greener and expanded (Figure 2G). After six months new shoots and rhizomes developed and the plants were ready for field transfer. Around 40,000 plants have been transferred in field so far (Figure 1E & F, 2H & I).

Discussion

For tissue culture of bamboo the use of starting material (seeds or adult plants) and the choice of the propagation method are crucial (Gielis 1999). In addition there is a huge variability in responsiveness in tissue culture (Saxena and Dhawan 1994). In the present investigation, nodal segments containing pre-existing axillary bud from mature clumps and seeds were used to initiate the *in vitro* cultures. The suitability of nodal segments is further reported in the micropropagation of bamboos (Nadgir *et al.* 1984; Prutpongse and Gavinlertvatana 1992; Saxena and Bhojwani 1993; Hirimburegama and Gamage 1995; Ramanayake and Yakandawala 1997; Arya and Sharma 1998; Bag *et al.* 2000; Das and Pal 2005; Sanjaya *et al.* 2005; Arya *et al.* 2006; Jimenez *et al.* 2006; Arya *et al.* 2008).

In present study, axillary bud proliferation was more in number on BAP supplemented medium as compared to medium supplemented with Kn. The efficiency of BAP for shoot culture initiation is also reported in *Bambusa ventricosa* (Huang and Huang 1995); *B. bambos* (Arya and Sharma 1998)*; D. strictus* (Mishra *et al.* 2001); *D. asper* (Arya *et al.* 2002); *D. hamiltonii* (Sood *et al.* 2002); *D. giganteus* (Arya *et al.* 2006); *Guadua angustifolia* (Jimenez *et al.* 2006); *Drepanostachyum falcatum* (Arya *et al.* 2008).

The shoot multiplication capacity of the *in vitro* shoots was greatly influenced by the BAP concentration in the medium and size of the propagule used for shoot multiplication. At decreased level of BAP the shoot multiplication rate decreased with an increase in shoot length. Similar results on BAP supplemented medium have been reported in a number of bamboos (Arya and Arya1997; Arya and Sharma 1998; Chambers et al. 1991; Purtpongse Gavinlertvatana 1992).The shoot multiplication was better in the liquid medium as compared to semisolid medium in respect to multiplication rate and shoot development. The shoots were relatively healthy on liquid medium. This may be because of better uptake of nutrients by the cultures. Similar results were earlier reported in *Bambusa tulda* (Saxena 1990), *Dendrocalamus giganteus* (Arya et al. 2006) and *D. strictus* (Nadgir et al. 1984). However, the shoot multiplication cycles were carried out in semisolid medium due to easy handling of cultures and to avoid vitrification of shoots.

The *in vitro* raised shoots failed to root on plant growth regulator free basal medium. Our observation on root induction in shoots of different species of bamboo reveals that IBA and NAA are effective. A very high rate (80-90%) of transplantation and plant survival was obtained in *D. asper, D. membranaceus, B. bambos* and *B. vulgaris*. The success was attributed to the gradual procedure adopted for hardening and acclimatization of the plants. Besides these values, transplantation rates of 70-80% have been reported only in *D. strictus* (Nadgir et al. 1984) and in *B. tulda* (Saxena 1990). Large scale micropropagation of bamboos has so far not been reported. A high rate of shoot multiplication averaging 5-20 folds with 80-90 percent rooting success and a high rate of plant survival are attractive findings of this study.

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Table 1. Effect of cytokinin (BAP) concentration in MS medium on the multiplication rate of D. asper.

BAP (mg/l)	Mean shoot number	Mean Shoot Length(cm)	Multiplication fold
1.0	14.1 ± 2.9	3.3 ± 0.07	5.6± 0.13
2.0	33.4 ± 3.2	2.3 ± 0.02	12.2±0.17
2.5	41.0 ± 5.1	2.2 ± 0.04	15.3±0.15
3.0	46.5 ± 5.1	1.8 ± 0.05	17.2±0.16
4.0	36.5 ± 3.6	1.2 ± 0.05	13.3±0.16
5.0	30.2 ± 6.5	1.2 ± 0.02	12.2±0.14
7.5	16.3 ± 2.5	1.0 ± 0.01	6.2±0.18
10.0	17.0 ± 4.0	0.8 ± 0.02	7.0±0.14

Mean of 30 replicates ± Standard Error

Table2. Effect of cytokinin (BAP) concentration in MS medium on the multiplication rate of *D. falcatum.*

BAP (mg/l)	Mean shoot number	Mean Shoot Length(cm)	Multiplication fold
1.0	13.92 ± 0.53	2.70 ± 0.01	3.48 ± 0.13
2.0	24.00 ± 0.52	2.32 ± 0.02	6.00 ± 0.13
3.0	43.50 ± 0.63	2.30 ± 0.02	10.87 ± 0.16
4.0	39.92 ± 0.38	2.00 ± 0.01	9.98 ± 0.09
5.0	30.83 ± 0.32	1.02 ± 0.02	7.71 ± 0.08

Mean of 30 replicates ± Standard Error

Table 3: Effect of cytokinin (BAP) in MS medium on shoots production through seeds of *Drepanostachym falcatum.*

BAP (mg/l)	Response %	Mean Shoot number	Mean shoot Length (cm)
0.0	33.33 ± 0.58	1.25 ± 0.13	1.03 ± 0.04
1.0	41.66 ± 0.58	1.40 ± 0.15	2.42 ± 0.05
3.0	62.50 ± 0.60	20.50 ± 0.69	2.68 ± 0.04
5.0	58.33± 0.60	12.83 ± 0.73	3.54 ± 0.10
7.0	50.00± 0.57	5.25 ± 0.35	3.12 ± 0.10
9.0	45.83± 0.58	4.50 ± 0.31	2.52 ± 0.10

Mean of 30 replicates ± Standard Error

Table 4. Effect of auxin (NAA) in MS medium on rooting of *in vitro* shoots of *D. membranaceus*, after 4 weeks in culture. Propagules of three shoots were cultured.

NAA (mg/l)	Mean root number	Response %
1.0	8.72 ± 1.9	73.33 ± 3.12
2.0	14.02 ± 1.2	98.26± 2.87
3.0	13.41 ± 2.1	97.08 ± 3.65
4.0	13.45 ± 2.6	91.66 ± 2.43
5.0	12.72 ± 1.5	73.33 ± 2.67

Mean of 30 replicates ± Standard Error

Table 5. Effect of auxin (NAA) in MS medium on *in vitro* rooting of *Bambusa bambos*, after 4 weeks in culture and the plant survival rate in field.

NAA (mg/l)	Rooting %	Plant survival rate (%)
1.0	15.32 ± 2.9	70.14 ± 2.12
2.0	30.33 ± 2.2	88.26± 2.87
3.0	58.66 ± 3.1	94.32 ± 2.65
4.0	85.32 ± 3.6	96.52 ± 1.43
5.0	81.28 ± 2.5	95.36 ± 1.67

Mean of 30 replicates ± Standard Error

Table 6. Effect of the size of the *D. asper* propagule on the development of the number of shoots and shoot multiplication rate, when cultured on MS + 3.0 mg/l BAP.

No. of Shoots inoculated	Mean shoot number	Multiplication fold
1.0	06.54 ± 0.95	06.3 ± 0.8
2.0	20.88 ± 1.09	10.4 ± 1.5
3.0	47.23 ± 1.56	14.7 ± 2.0
4.0	48.74 ± 2.55	12.3 ± 1.8
5.0	46.84 ± 2.33	09.5 ± 1.6

Mean of 30 replicates ± Standard Error

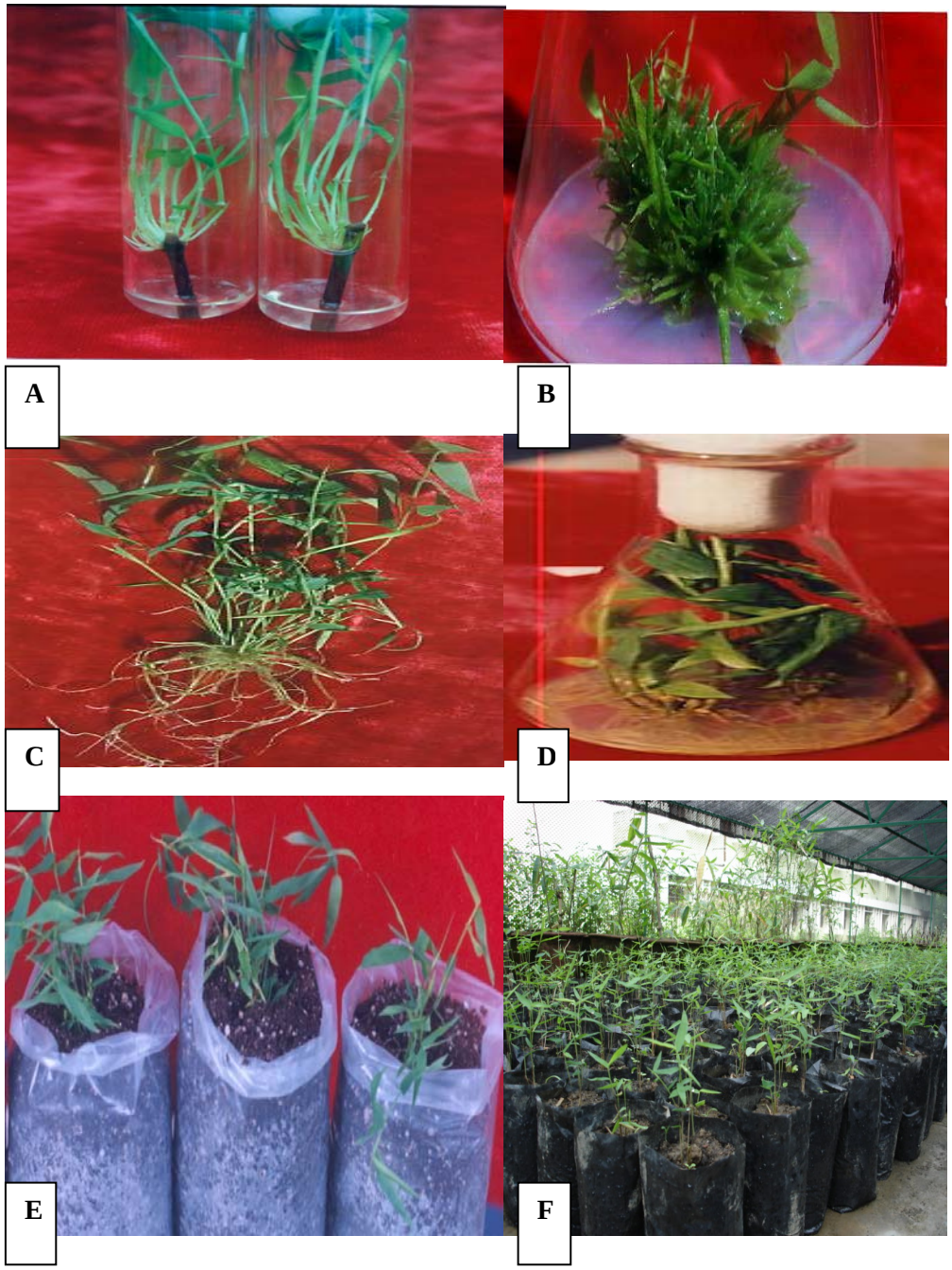

Figure 1:Various stages of plantlet regeneration through micropropagation A. Axillary bud proliferation from nodal segments of *Drepanostachym falcatum*. B. *In vitro* shoot multiplication in *Bambusa bambos*. C. *In vitro* developed roots in *Bambusa vulgaris* D. *In vitro* rooting in *Dendrocalamus asper*. E. *In vitro* raised plantlets of *Dendrocalamus giganteus* after hardening and acclimatization. F. *In vitro* raised plants ready for field transfer.

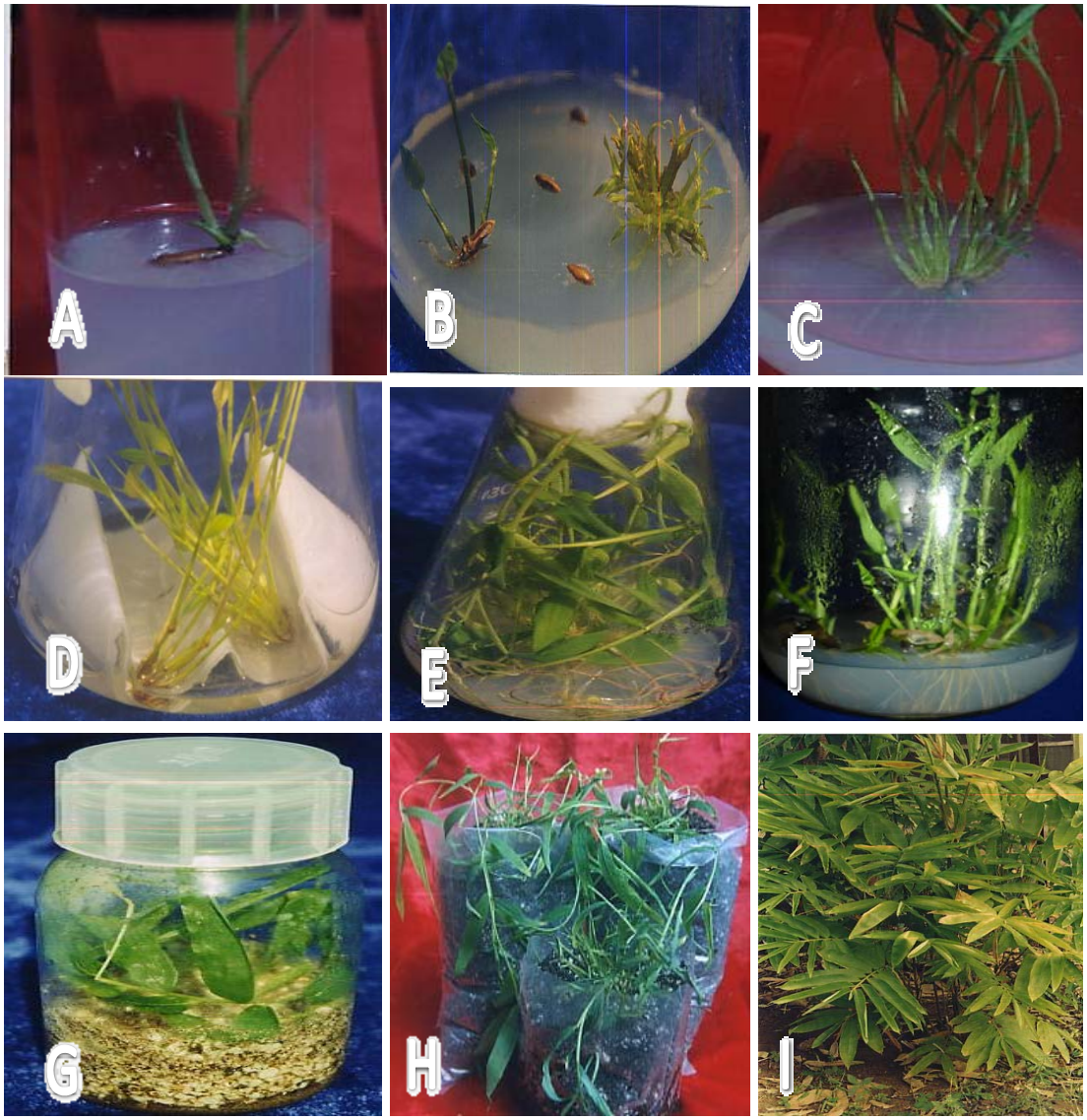

Figure 2:Various stages of plantlet regeneration through micropropagation A. Aseptic seed culture of *Drepanostachym falcatum*. B. *In vitro* shoot formation from seeds in *Dendrocalamus hamiltonii* . C. *In vitro* shoot multiplication of *Bambusa giganteus* in semisolid MS medium.D. *In vitro* shoot multiplication of *Dendrocalamus vulgaris in Liquid* MS medium. E. *In vitro* rooting in *Bambusa bambos*. F. *In vitro* root formation in *Dendrocalamus membranaceus.* G. *In vitro* hardening of plantlets in *Dendrocalamus asper.* H. Hardened and acclimatized plants of *Drepanostachym falcatum.* I. Tissue culture raised plants of *Dendrocalamus asper* in field.

Macro-Propagation of *Oxytenanthera abyssinica* (A. Rich Munro) from Culm Cuttings

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Abstract

Oxytenanthera abyssinica like most bamboos has very erratic and unpredictable seeding years. Vegetative propagation seems to be the best alternative for its regeneration. Therefore the objective of the present work was to investigate the effect of Indole -3 Butyric Acid (IBA), season of the year, number of nodes on culm cuttings and planting method (vertical or horizontal) on rooting and sprouting of cuttings. To fulfill this objective a completely randomized design experiment in a factorial setting was conducted (4 IBA concentrations x 2 seasons x 2 planting methods x 2 types of nodded cuttings (one node and two nodes cuttings) x 3 sources of cuttings from the explants).

Data were subjected to Analysis of variance (ANOVA). Results indicated significantly better rooting percentage in winter (42%) as compared to (30%) in summer. The two-nodded cuttings were significantly better than the one-nodded in both seasons. On the other hand, cuttings taken from the basal part of the culm were significantly better in rooting and sprouting than those taken from the middle, while those taken from the top failed to root. Horizontally planted cuttings were significantly better than the vertically planted ones. IBA at 4000 ppm gave significantly higher rooting of cuttings and sprouting than the 2000 ppm in both winter and summer seasons while the IBA1000 ppm produced significantly lower percentages for the number of roots and number of sprouts. However, cuttings failed to root without IBA application.

Based on the results of the present work and with due consideration to previous studies, it can be concluded that culm cuttings should be taken from the current year culms as they are better than old ones and that winter is the best season for propagating bamboo cuttings in the Sudan. It seems useful for ensured and successful propagation to use culm cuttings having at least two nodes treated with IBA of 2000 to 4000 ppm concentrations and planted horizontally.

Keywords: Macropropagation, *Oxytenanthera abyssinica*, culm cuttings

Introduction

Bamboo is a group of the family Poaceae, subfamily Bambusoideae, tribe Bambuseae. Some of its members are giant bamboos, forming by far the largest member of the grass family (David 2003). There are 91 genera and about 1000 species of bamboos. They are found in diverse climates within the tropical and subtropical regions of the world (Bystriakova *et al*. 2003).They are perennials, fast-growing woody grasses and are capable of producing utilizable annual production. They were not hitherto fully brought under sustainable management despite their vast biogeographical distribution. Consequently, alternative sustainable management and maintenance of the remaining bamboo forest resource of the Sudan has been strongly realized in conjunction with the present day deterioration of the natural forests of the country as a result of over exploitation and desertification. (El Houri. *et al.* 2001) A part from taxonomic studies, only very little and fragmented efforts were made to investigate the various aspects of bamboo growth, productivity, management and utility in the Sudan (Elamin 1990). *Oxytenanthera abyssinica* (A. Rich Murno) and *Arundinaria alpina* (K. Schuni) were the only two indigenous bamboo species endemic to Sudan. The former is considered more important as it has a wider distribution and therefore commonly used than the later.

Oxytenanthera abyssinica has a very long vegetative phase of growth before it flowers and this is followed by the death of the clump (Khan 1972; Kigomo 1989). However, it can be propagated from various vegetative parts using different methods viz. branch cuttings of *Dendrocalamus asper*, *Gigantocheoa aspera*, and G. *ligulat*a. (Saxena 1990; Shudong 1998). Successful propagation of bamboos from culms was reported for many species like *Bambusa valgaris, B. balcoa, B. nutani. Dendrocalamus hamittoni, D. hookeri* (Banik 1980; Das 1988), *Bambusa textitils var. fasca, B. multiplex, B. Gilla,* and *B. chungii* (Zhang 1997).

Difficulties encountered in the use of seeds as a means for regeneration in addition to their scarcity calls for research on alternative means. Vegetative propagation seems to be the best choice considering the encouraging results obtained elsewhere (Saxena 1990; Zhang 1997).

Therefore, the main objective of this investigation was to establish a protocol for a successful propagation of *Oxytenanthera abyssinica* from culm cuttings at normal nursery conditions. The specific objectives were to investigate the effect of season (Summer and Winter), type of cutting (one and two nodded cuttings), method of planting (horizontal-vertical planting), position on the culm from where cuttings were taken (top, middle and basal part of the culm) and different IBA concentrations on inducing rooting of cuttings.

Materials and Methods

Plant Material

Culm cuttings were prepared from new culms (less than one-year-old) from clumps of *Oxytenanthera abyssinica* at Abu Gaili Forest near Sinner (Blue Nile State at latitude 13° 36′ and longitude 23° 36′). The new culms were examined morphologically to ascertain the existence of buds, which may grow and form culms. Two types of cuttings were prepared viz. One-nodded cuttings, approximately 25 cm in length and 5 cm in diameter and two-nodded cuttings, approximately 40 cm in length and 5 cm in diameter.

The cuttings were defoliated and the axillary buds were left intact. Approximately equal proportions of the internodes were left on both sides of the single-nodded and two nodded cuttings. Cuttings were prepared from the top, middle and basal part of the culms.

Experimental Design and treatments

An experiment was performed utilizing a completely randomized design in a factorial setting. Treatments used included IBA concentrations at 4 levels (4000, 2000, 1000 and 0.00 ppm) x 2 methods of planting (horizontal and vertical) x 2 types of cuttings (one nodded and two nodded cuttings) x 3 positions on the culm from where cuttings were taken (top, middle and basal part) x 2 seasons (summer and winter). Treatments were replicated four times using ten plants for each treatment.

IBA preparation and mode of application

IBA was prepared to the required concentrations of 4000, 2000, 1000 and 0.00 ppm as a control. The dip method was used throughout and the basal ends of the prepared cuttings were dipped in the prepared IBA solutions, which were put in a plastic tray. The treated cuttings were left for 16-20 hrs in the solutions at laboratory temperature (24-25°C).

They were then planted in a soil medium consisting of a thin layer of silt covered with sand. This mixture was placed on concrete beds of 150x50x30 cm. The beds were covered with plastic sheets laid on a metal frame about 30-50 cm above the ground to create suitable conditions for rooting and to maintain high relative humidity. Planted cuttings were kept moist by daily watering and were given all necessary care and protection.

Growth Parameters and Data Analysis

Data on shoot length, root length, number of sprouted and rooted cuttings were recorded periodically for five months. Analysis of variance was carried out using Statistical Analysis Systems (SAS) and means were separated using Fisher protected L.S.D.

Results and Discussion

Effect of Season on the Performance of Cuttings:

Culm cuttings planted during winter showed significantly higher sprouting (49.2%) compared to those planted during the summer season (32.0%). On the other hand, winter planted cuttings produced significantly bigger percentage of rooted cutting (42%) than winter planted cutting with (30.0%). In addition, the number of roots produced by cuttings in summer (5) was significantly bigger than winter (2.4). As shown in Table (1) shoot and root growth varied significantly between the two seasons. Shoot length was significantly taller during winter (32.0) than summer, and root length was significantly longer in winter (18.1) than in summer (12.5).

Table (1): Effect of season on performance of *Oxytenanthera abyssinica* cuttings, after five months in the nursery.

Season	Sprouted cuttings %	Rooted cuttings %	Shoot length (cm)	Root length (cm)	Root number
Summer	32.0 [b]	30.0 [b]	22.0 [b]	12.5 [b]	2.4 [b]
Winter	49.2 [a]	42.0 [a]	32.0 [a]	18.1 [a]	4.8 [a]

Means followed by different letters are significantly different at P<0.05 using Fisher protected L.S.D.

Cuttings started to initiate roots in the second month after planting in winter whereas in summer the cuttings started to initiate rooting at the third month after planting. These results agreed with

Lin (1995), who recommended that cuttings taken from *Bambusa odonii* should be taken in winter season. Also, Sirikalyanon *et al*., (1997) concluded that the best season for planting cuttings is winter for *Dendrocalamus hamiltonii*.

Effect Cutting Position on the Performance of the Cuttings

Cuttings taken from the basal, middle and upper parts of the culm and planted during the summer season showed significant differences between them in sprouting percentage (Table 2).

Table (2): Effect of cutting position on the performance of *Oxytenanthera abyssinica* cuttings in summer and winter, after five months in the nursery

Position on the culm	Season	Sprouted cuttings %	Shoot length (cm)	Root length (cm)	Root number
Upper parts	Summer	17.0 [c]	14.9 [c]	0 [c]	0 [c]
	Winter	24.0[c]	17.6 [c]	0 [c]	0 [c]
Middle part	Summer	33.8[b]	22.9 [b]	12.0 [b]	3.4 [b]
	Winter	35.0[b]	24.5 [b]	15.7 [a]	4.8 [a]
Basal part	Summer	38.6[b]	28.6 [a]	13.6 [b]	4.2 [a]
	Winter	44.0[a]	30.4 [a]	16.8 [a]	5.4 [a]

Means in the same column followed by different letters, are significantly different at P<0.05 using Fisher protected L.S.D

The highest sprouting % (38.6%) was recorded by the cuttings taken from the basal part, but this was not significantly different from the sprouting percentage (33.8%) obtained from the middle part of the culm. However, cuttings taken from the upper part produced significantly lower sprouting percentage (17.0%). The same trend occurred in winter season where the percentage of sprouted cuttings taken from the upper part (24%) was significantly lower than those taken from middle and basal parts (35%) and 44% respectively.

Regarding the percentage of rooted cuttings, those taken from the upper part failed to initiate roots in both seasons, whereas those taken from the middle and basal parts initiated roots, giving (32.2%) and (35%) in summer and 36.8 and 41.8% in winter respectively (Fig.1).

The shoot length of the cuttings taken from the upper part and planted in summer were significantly shorter (14.9) cm than those taken from the middle and basal part that attained (22.9) and (28.6) cm respectively. However, the basal part cuttings were significantly taller than those taken from the middle of the culm. In winter the shoot length of cuttings taken from the upper part attained significantly lower length (17.6 cm) than those taken from middle and basal parts attaining lengths (24.5) and (30.4) cm respectively.

Cuttings taken from the upper part of the culm in both seasons failed to initiate roots. However, cuttings taken from basal and middle parts and planted during summer and winter showed no significant differences between them (Table 2.). These findings were in agreement with

Hormilson (1988) who investigated the influence of the position of the nodal buds in the culms on the bud break. The found that the position of the nodal buds on the culm affects bud break and those at the middle and basal part showed higher percentage of bud break and better growth compared with those at the upper part.

Effect of Type of Nodes

Single and double nodded cuttings planted in summer showed significant differences between then in the percentage of sprouted cuttings. Double nodded cuttings produced significantly higher percentage (54.0%) compared to (33.0%) for the single nodded. On the other hand the double nodded cuttings planted in winter showed significantly higher percentage (68.0%) than the single nodded cuttings(Table 3).

Table (3): Effect of type of cuttings in the performance of *Oxytenanthera abyssinica* cuttings in summer and winter after five months in the nursery

Type of node	Season	Sprouting %	Shoot length (cm)	Root length (cm)	Root number
Single node	Summer	33.0 [c]	29.3[a]	13.7 [b]	2.7 [b]
	Winter	38.0 [c]	31.9 [a]	15.2 [a]	2.9 [b]
Double node	Summer	54.0 [b]	30.1 [a]	15.2 [a]	4.2 [a]
	Winter	68.0 [a]	33.1 [a]	16.7 [a]	5.1 [a]

Means in the same column followed by different letters, are significantly different (P<0.05) using Fisher protected L. S. D

However, both types of cuttings showed similar shoot lengths in summer and winter.

The percentage of rooted cuttings was significantly greater in double nodded cuttings (33.4%) and (44.7%) in summer and winter seasons respectively compared with (25.9%) and (35.2%) for the single nodded cuttings in summer and winter respectively.

However, in both seasons the double nodded cuttings produced significantly bigger number of roots (4.2) and(5.1) than the single nodded cuttings (2.7) and (2.9) for summer and winter seasons respectively.

In summer, the double nodded cuttings produced significantly longer roots (15.2) compared to the single nodded (13.7) but in winter they showed no significant differences between them attaining lengths of (16.7) and (15.2) for the double and single nodded cuttings respectively. These results are in agreement with the results reported by Bohidar (1989) who recommended that the two nodded cuttings were usually more successful that one nodded cuttings. They are in contrast with the results obtained by Das (1988) who found a success rate of 80% from single-nodded culm cuttings in *Bambusa nutans* compared with 60% in the two- nodded cuttings of the same species. However, these results confirm the results obtained by Castillo (1990) who recommended the use of cuttings having at least two nodes for *Dendrocalamus merrillianus*.

Effect of IBA

Culm Cuttings treated with 4000 ppm IBA and planted during winter produced the highest percentage of sprouted cuttings (46.0%) while the untreated cuttings planted in winter produced the lowest percentage (22.0%) (Fig.2).

However, results showed no significant differences in sprouting between cutting which were untreated and planted in winter (25.0%), treated with IBA 1000 ppm and planted in summer and those treated with 1000 ppm and planted in winter (28.0%). In addition, there were no significant differences in sprouting between cuttings

treated with IBA 2000 ppm and 4000 ppm and planted in summer and those treated with 2000 ppm and planted in winter with sprouting percentage of (33.2), (38.8) and (33.9) respectively (Table 4.)

Table (4): Effect of IBA concentrations on the performance of *Oxytenanthera abyssinica* cuttings after five months in the nursery

IBA (ppm)	Season	Sprouting cuttings %	Shoot length (cm)	Root length (cm)	Root number
0.00	Summer	22.0 [d]	16.8 [c]	0.0 [c]	0.0 [f]
	Winter	25.0 [c]	27.0 [b]	0.0 [c]	0.0 [d]
1000	Summer	25.9 [c]	26.0 [b]	4.2 [b]	0.5 [c]
	Winter	28.0 [c]	27.0 [b]	6.0 [b]	1.5 [c]
2000	Summer	33.2 [b]	27.0 [b]	14.1 [a]	3.2 [b]
	Winter	33.9 [b]	30.0 [a]	15.7 [a]	4.0 [a]
4000	Summer	38.8 [b]	31.0 [a]	16.3 [a]	4.8 [a]
	Winter	46.0 [a]	33.0 [a]	17.7 [a]	5.9 [a]

Means in the same column followed by different letters, are significantly different ($P < 0.05$) using Fisher protected L. S. D

Cuttings treated with IBA at 4000 ppm initiated the highest rooting percentage (41.4%) and (46.2%) in summer and winter seasons, respectively. They were significantly different from those treated with IBA at 2000 ppm, which initiated rooting percentage of (28.1%) and (34.4%) in summer and winter seasons respectively. The untreated cuttings failed to initiate roots and those treated with IBA at concentration of 1000 ppm initiated roots with percentage of rooting of (10%) and (16.5%) in summers and winter season respectively.(Plate 1.)

Cuttings treated with IBA 4000 ppm and planted in summer and winter and those treated with IBA 2000 ppm and planted in winter showed no significant differences between them in shoot length attaining (31.0 cm), (33.0 cm) and (30.0 cm) respectively. The untreated cuttings which were planted in summer showed significantly shorter shoot length compared to the remainder of treatments attaining (16.8 cm). On the other hand the untreated cuttings planted in winter and the ones treated with IBA1000 ppm planted in summer and winter in addition to cuttings treated with IBA 2000 ppm and planted in summer, showed no significant differences between them in shoot length (Table 4).

Untreated controls failed to initiate roots in both seasons. However, the longest roots were produced when cuttings were treated with IBA 4000 and 2000 ppm. Their lengths ranged from (17.7) cm for the cuttings treated with IBA 4000 ppm planted in winter to (14.1) cm for the cuttings treated with IBA 2000 ppm planted in summer. However, cuttings treated with IBA 1000 ppm showed no significant differences between them in root length with (6.0) cm in winter and (4.2) cm in summer respectively.

The biggest number of roots were obtained from cuttings treated with IBA 4000 ppm planted in winter and summer (5.9) cm and (4.8) cm and IBA 2000 ppm planted in winter (4.0) cm. The fewest number of roots were produced when cuttings were treated with IBA 1000 ppm and planted in both seasons (1.5) and (0.5) cm for winter and summer respectively.

These results are in line with McClure (1986) who recommended the use of IBA for *Bambusa textis*. These findings are also in agreement with Rungnapar (1988) who reported that IBA and NAA as effective hormones increasing rootability *B. arundinacea*, *Dendrocalamus strictu*s and *D. scrpteria*. The results of this study conform to the findings of Abd Razak (1994) who showed that the use of IBA at 2000 ppm promoted the growth of the cuttings of *Gigantochloa Levis*.

These results also confirm the findings of Nagariaiah (1994), who reported an increased rooting percentage of the cuttings of *Bambusa vulgaris* by using growth regulating substances.

Effect of Method of Planting

The method of planting vertically or horizontally, produced significant effect on the percentage of sprouting, rooting cuttings, the shoot and root length. The cuttings planted horizontally gave successful propagules whereas the vertically planted ones especially the two nodded cuttings failed to sprout successfully in summer and winter seasons. So the recommended method of planting would be horizontally, and this agrees with Dong *et al*. (1999) and Pyare *et al*. (1998) who reported that, the best method of planting cuttings is to plant them horizontally.

Generally from the results of the present work and with due consideration of the previous studies discussed it can concluded that culm cuttings should be taken from the current year culms as they are better than old culms and that winter is the best season for propagating bamboo cuttings in the Sudan. It seems useful for ensured success of propagation to treat culm cuttings having at least two nodes with IBA 2000 to 4000 ppm concentrations and planted horizontally (Plate 2.)

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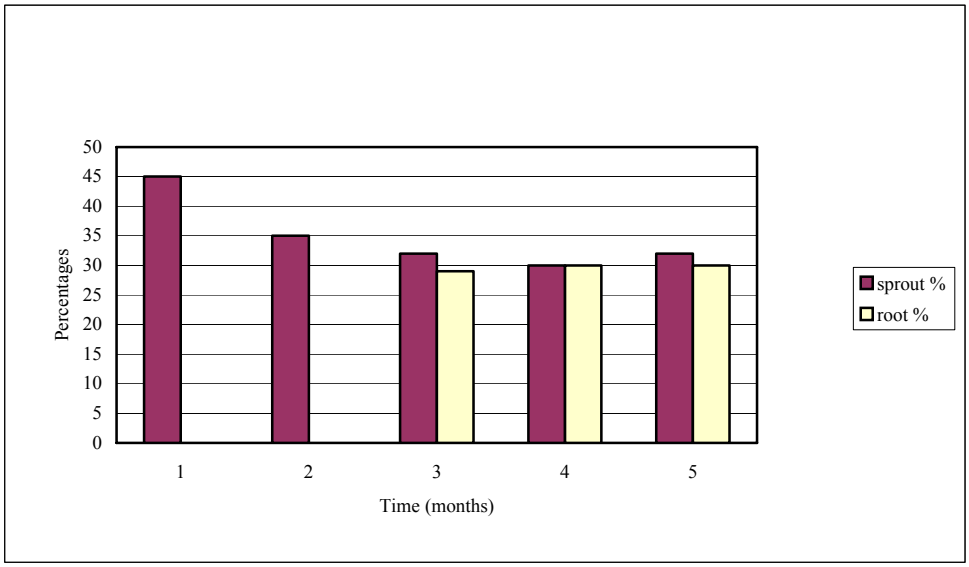

Figure 1. The percentages of sprouting and rooting of *Oxytenanthera abyssinica* culm cuttings during summer, after five month in the nursery

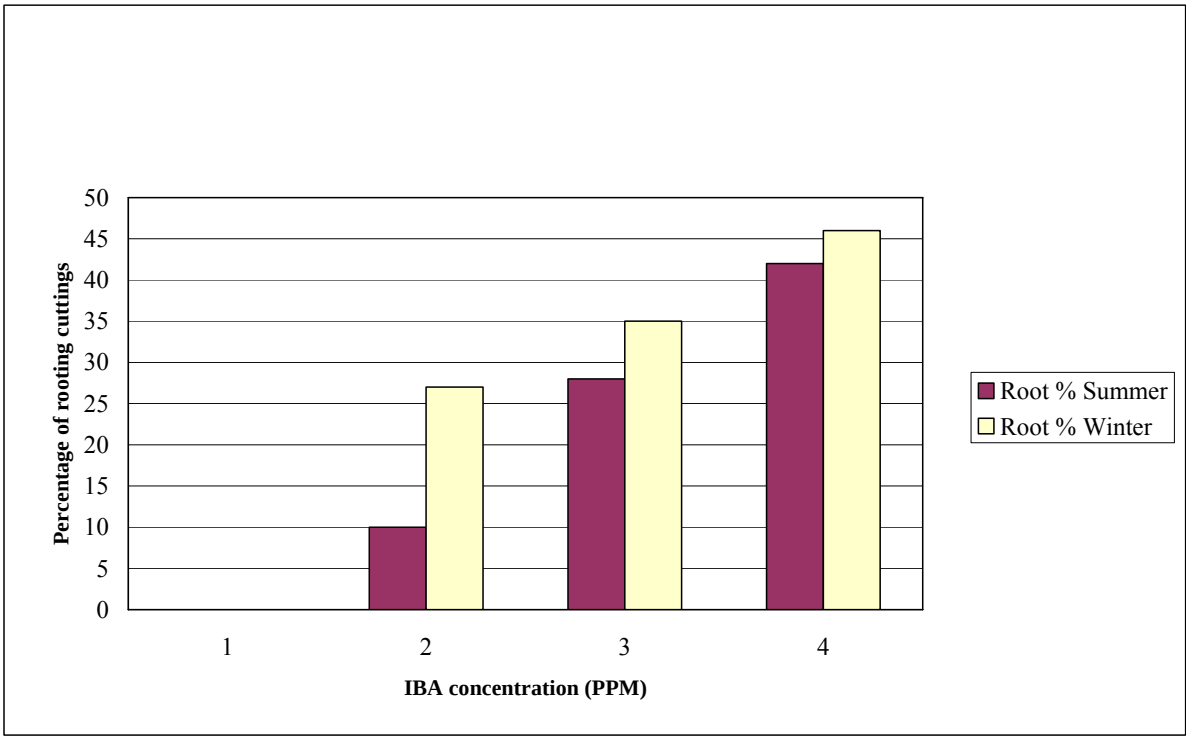

Figure 2. The effect of IBA concentration on *Oxytenanthera abyssinica* rooted cuttings percentage during summer and winter, after five month in the nursery

Plate 1. Successful rooting of *Oxythentherea abysssinica* culm cuttings treated with IBA 4000 ppm In Winter Season

Plate 2. Successful sprouting of *Oxythentherea abysssinica* culm cuttings treated with 4000 ppm IBA in winter

VOLUME 7

Bamboo for Community and Economic Development

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Preface

In most developing countries, bamboo is a resource material that is at people's reach in the community. That being the case, it is still thought of only as a backyard plant for individual and community use. Few of the governments of developing countries realize the potential of bamboo as an appropriate vehicle for industrialization in their country-side despite China's success in demonstrating to the world how it can be done.

In building its bamboo industry, China focused on one industrial product –bamboo floor boards - which substituted for pine and oak floor boards in the West . China developed its floorboard technology with the help of Taiwan while planting bamboo over 16 million hectares of land and building the infrastructure needed to support the industry. Today, China supplies every corner of the world with bamboo floor boards amassing revenues of US $324 million in 2008. They have expanded to over 32 million hectares of plantations and have developed industrial uses for the whole bamboo culm including its leaves and branches.

While some developing countries have become excited over the potentials of bamboo in their countries, none have ventured to develop the industry as boldly as China has. Instead they have opted to develop their bamboo industry with focus on livelihood projects such as craft, giving the community additional income but not ensuring sustained employment as confirmed here by the paper of the State of Kerela. China has demonstrated that to create real wealth it is necessary that rural plantations must first be there and linked to the producers and the industrial plants that are globally competitive - thereby ensuring sustained livelihood and income in the rural communities.

In Africa for example, Ghana may not only develop bicycles to transport their goods in the rural areas but develop factories to produce these bicycles to export to other African countries with similar needs. The same can be done with their school desks. Tanzania, on the other hand, could develop its bamboo industry using their bamboo wine for ethanol. In South East Asia, the Philippines for example, could develop their bamboo industry by linking their successful furniture and housing industry to the bamboo producers and plantations. But, as confirmed by the Philippine paper, the plantations are still not there.

It is exciting to see that many of the papers submitted for this conference emphasizes the need for bamboo plantations, bamboo gardens and bamboo groves. Equally exciting is the paper on Carbon Farming which most developing countries may adapt to sustain the production of bamboo. ITCs paper is an example of how rural communities can be linked to large industries such as the incense stick industry assuring the rural communities of sustained employment.. I am glad to see that efforts have even been made in the North East India states to standardize the equipment for the livestock and poultry industry and for artisans to use bamboo rhizomes for ART objects.

Crafting the development of the bamboo industry properly in developing countries cannot be over emphasized. It will translate to wealth creation in the rural communities - plucking them out of their poverty altogether.

Bamboo – A Renewable Natural Resource and Valuable Raw Material of Cottage Industries

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Abstract

Bamboo craft products are nowadays, used worldwide, Bamboo listed the highest craft products of all the natural resources. It has reported more than 1500 craft product till yet. The people of North Eastern India are highly experienced in designing and producing the different craft product in the traditional way as the hand – made products. The people inhabiting in this region are economically poor, Bamboo provides many facilities in earning as well as used in various practical applications of life, Manipur is one of the State of North East India. Bamboos are abundantly growing in this State. As the state is a hilly State the inhabitants used the rich resources for many purposes viz. in housing, fencing, furniture, designing containers, baskets of various designs and shapes and also as fire fuel. Manipuri's are accustomed to the works of cottage industry. Among the cottage industry, craftworks is the most commonly practice done by many people at the organized and unorganized sectors. People used the different species of bamboo as the common raw material for the handicrafts. But the State has least development in industrial sectors. No mechanized sectors are established till yet even though there are many skilled and unskilled artisans and craftsman. For Bamboo, no part can be left unutilized i.e. the above ground and underground parts. The underground rhizome of Caespitose bamboos like *Bambusa tulda and Dendrocalamus giganteus*, and that of *Melocanna bambusoides* can be processed simply and designed for producing the fine craft productions. The presents study highlights the utilization of underground pachymorph rhizome of *Bambusa tulda* for making the artistic and fine craft products.

Introduction

Bamboo can be regarded as the gift of nature for the craftsmen. The plant has its natural habitat in the South East Asia. India is the 2nd largest producer of bamboo next to China more than half of the total bamboo standing crops are growing in the North Eastern region of the Country. The North Eastern part of the Country is geographically isolated from the mainstream of India. Many small hill ranges and hilly terrains are the general features of the topography of North East India. There are plain areas also surrounded by the hill ranges, so the climate is pleasant, rainfall is abundant and some areas are cool. The vegetation types available are here varied and rich. Among the vegetations, bamboos are specific and also of rich diversities. People living in the North – Eastern part of the country are mostly low income earners and utilize the natural resources as the raw material. Many people used bamboos of different species as the raw material for making the craft product at their homes

for small earnings to meet the various household requirements. People of different age groups and sexes do perform the craft works. Some of the works are found to be very symbolic and innovative in designing. The present study has been made focusing on some specific product of bamboo craft made out of the rhizome of big sized bamboo. Rhizomes of bamboos can be utilized in home/cottage industries. The products are fine and long-lasting also. Not only that the products are designed and made by using very simple tools for cutting, smoothing and drilling etc

Materials And Methods

The growth pattern and mode of vegetative propagation of *Caespitose bamboo*, *Bambusa tulda* Roxb has been thoroughly studied in the field. (Fig 1) A detailed study was conducted in the selected craft centre where the underground rhizomes were kept collected & processed to make the different craft products of special designs. The local skilled and innovative artisan was interviewed personally and the product types were examined regarding the fineness, longitivity, lightness, size, unbreakable, quality, cost-effectiveness etc. The tools used for the purpose were also observed and photograph shown in (Figure 2).

Result And Discussion

Materials	:	Underground Rhizome of *Bambusa tulda*, Roxb (Local name – Saneibi)
Type of Rhixome	:	Pachymorph Rhizome
Special characteristics	:	Long – lasting, More suitable, Mostly Unbreakable, Fine Texture, Highly Resistant to insect Infestation.
Seasoning Period	:	5 to 6 months (for complete Drying)
Size	:	Large 14 – 15 inches long, on average 6 -= 14 inches long ; 3- 4 inches thick
Product type	:	Hand – made craft products, original colour : No polishing required ;
Designs	:	Many ; From miniatures to accountable size of the rhizome used.
% of Rhizome part Used	:	More than 90% ; sometimes 99%.
Availability	:	Quite Abundant.
Tools Used	:	Simple, Knifes for cutting & splitting, Tools used by the goldsmiths, Scrubbers, others designed by the artist himself like for drilling chopping etc. and Pins, Nails etc.
Working Style	:	Somewhat innovative with ideas.

(Sources: Dr. L. Tondon Singh Opthalmologist, Surgeon. Manipur, India)

Results and discussion

Some of the selected Craft products with creative ideas and conveying massages to the society were selected and studied. The products shown in Fig Nos.3 and 4 can be discussed as follows.

Fig 3 – It is the photograph of a bullock- cart. In ancient times and till today, bullock-cart is being the only means of transportation and traveling from one region to another. It is used in transportation of paddy crops from the fields and other valuable goods. Till today, the transportation of bamboo culms in nos. of 50-100 and above from rural areas is done by this cart. Road transportation is the means of movement in rural areas. Signifying the value of bullock cart, the artisan designed this craft product by utilizing the different parts of Bambusa tulda, small iron rod and pieces of wood. The dimension recorded are given below:-

Total weight of the Cart & other creations	=	1.2 kg.
Weight of the Cart alone	=	1 kg.
Weight of the 2 bullock	=	1.6 kg.
Total Length of the Car	=	20 ¼ inches.
Height	=	6 inches.
Breadth	=	6 inches (back), 3 inches (front)
Weight of Father & Son on the Cart	=	1.2g.

Fig 4 – Shows the photograph of the product namely 'THE HEAVEN'. The different features in the designated Craftwork includes- One Male posture, One Female posture, One Skeleton, One sitting boy, a pond with Lotus flowers and Fishes etc, very small Lady handbag, rose flower in the hand Syringes etc. All these miniatures are designed only from the cuttings of rhizome of Bambusa tulda.

No. of rhizome used = 4

Height of Male posture = 14 inches.

Height of Female posture = 13 ¼ inches.

Height of Skeleton = 13 ½ inches.

Total height of product including the based portion = 16 inches.

Length of the base plate form =12 ¾ inches.

Breadth of the plate form = 8 ¾ inches.

Weight = 700 gm.

The total weight of the creations with base = 1.4 kg.

This product conveys the message that by injecting the heroine drugs, the life of the couples knew no bounds. But something in the form of Skeleton warns them to stop and think for the further danger in life. Seeing the odd characters of parents, the boy starts to lament an started to think about the origin, what, why and how etc. Sitting nearby pond with natural beauty but remain restless.

Regarding the different qualities of 3 different species of bamboos the artisans gave the following comparative comments –

Quality	Species		
	Melocanna bambusoides	*Bambusa tulda*	*Dendrocalamus giganteus*
1.Lightness	Light	Heavy	Medium.
2.Softness	Very soft	Hard	Hard.
3.Colour	Light cream	Cream (dark)	Cream.
4.Fibre content	Less	More	More
5.Size	Small	Large	Medium.
6.Utility	Less	Highest	Medium.
7.Insect Resistance	Less	Very high	High
8.Longivity	Less	More durable	Durable.

Form all the above studies made, it can be discussed that if there is proper technical input, the underground rhizomes will be widely applicable in cottage and village industries. It will surely help in uplifting the socio-economic condition of the rural poor.

The underground rhizomes of bamboo (*Caespitose* type) were mostly considered as waste materials. Mostly rhizomes are used as fire fuel and used to burn in the open air because of the release of heavy smokes. When completely dried and totally free from soil particles, the rhizomes can be utilized as the raw material for crafts. Craft products can be made from the rhizomes of *Dendrocalamus* species and *Melocanna baccifera*. But the rhizome size specially for *Bambusa* species are found to be of larger size than *Dendrocalamus* species and more convenient in utilization. The young rhizome growth at the time of vegetative propagation during rainy season of each year is harvested by the local people and used as food. Not only the fresh one but the fermented ones also tasty and delicious. The old rhizome stocks are good in fastening the soil particles and makes the soil less eroded by water. Bamboos are traditionally planted for fencing the boundaries of homelands, farm land etc. *Bambosa tulda* Roxb is clump forming bamboo with branches and hence used for plantation around the boundaries. The culms of these bamboo are used as poles in the construction of houses, splitted pieces for wall

fencing, roofting etc. In spite of these manifold uses, underground part are found to be cent per cent utilizable. The productivity of this bamboo, thus are many and has under application for human benefits.

Conclusion

Bamboos are the forest and non forest natural renewable resources of the North Eastern parts of India. Manipur is abundant with more than sixty (60) different species of bamboos. The hilly terrains and ranges of hills of different altitudes are the favourable natural habitat of bamboos. Since the time immemorial the people of North East India used bamboos for many purposes. People used bamboos in construction works, in fencing, in making musical instruments, in weaving, in waterways transportation, in making intervillage connectivity bridges, in crafts and also as food. Thus, bamboos help much in socio-economic up liftment of the region. People of this state are good artisans and craftsman. Every home is the work place of cottage industry. Hence handicraft is the encouraging area of cottage industry that can be anticipated and supported with technical inputs. The whole plant part of bamboos can be utilized in many ways thus becoming the highest economically potential plant of the region. People should protect the germplasm of different species of bamboos so as to make the sustainable utilization.

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Fig.1 Rooting of Bambosa tulda

Fig.2 Simple Tools used in Bamboo crafts

Fig.3 An artistic bullock cart made up of bamboo and Rhizomes

Fig.4 The Heaven : Craft work related to HIV

Carbon Farming through Village Bamboos in Rural Landscape of Northeast India as Affected by Traditional Harvest Regimes

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Abstract

Homegarden and bamboo grove in the rural landscape of Barak valley, northeast India are endowed with different bamboo species. Traditionally bamboo resources are utilised in household, craft and commercial sector. Two harvest regimes – selective harvest in homegarden and clear-felling harvest in bamboo grove could be identified based on the mode and season of felling. Smallholder farming systems throughout the world are believed to be a potential C sink to remove atmospheric CO_2 to compensate greenhouse gas emission. Village bamboos can be an important reservoir of C stock if managed judiciously. Biomass C stock in above ground vegetation of bamboo in homegarden varied from 7.60 to 10.76 Mg ha^{-1} from 2003 to 2007. The corresponding value for bamboo grove was 6.93 to 40.58 Mg ha^{-1}. The rate of C accumulation in homegarden was 0.60-1.17 Mg ha^{-1} yr^{-1} with a mean of 0.79 Mg ha^{-1} yr^{-1}. Mean rate of C accumulation in bamboo grove was 11.215 Mg ha^{-1} yr^{-1} from 2003 to 2006. Negative rate of biomass C accumulation was recognized in all the components in bamboo grove for the year 2006-2007. Subsequent to clear felling of bamboos from grove leaf, branch, culm and total biomass C loss for 2006-2007 were 1.378, 1.885, 32.781 and 36.044 Mg ha^{-1} respectively. In homegarden under selective felling regime although the C stock and sequestration is low compared to bamboo grove and other agroforestry systems across the world, but nonetheless represents a permanent C stock as C export through harvesting of mature culms are balanced by C gain from new culms produced in the clump. Cost effective homegarden bamboo management as carbon farming is a feasible alternative to be considered under the CDM protocols. Furthermore, a shift in the utilization pattern of bamboos of bamboo grove from industrial utilization to craft sector through value addition and innovative marketing can make this land type a potential C sequestrating system.

Keywords: Homegarden, Bamboo grove, Management system, C sequestration, CDM protocol

Introduction

Homegardening is the oldest land use activity next only to shifting cultivation. It evolved through generations of gradual intensification of cropping in response to increasing human pressure and the corresponding shortage of arable lands (Kumar and Nair 2004). The rural lives in Assam are intricately linked with the bamboos of homegarden (Nath and Das 2008). Under traditional homegarden management system bamboo plantation development is the inherent ecological consistency of local farming practices. In homegardens, bamboo farmers

have developed the bamboo cultivation practices that make an optimal use of the soil for subsistence and commercial use. For practical purpose farmers have divided the homegarden system in to different landforms depending on the suitability of the species for different land quality. Each land form varies by certain environmental factors and specific vegetation types. Mostly the farmers in these locations are subsistence-oriented and they maintain multistrata homegardens including trees, shrubs, and herbaceous plants. Bamboo is one of the more important components of the homegardens, which provides the villagers with a wide range of goods and services (Nath and Das 2008). Bamboos in the traditional homegardening system are grown at the poor land quality or degraded site of the holdings and are often managed in a separate zone or in the adjoining land parcels where bamboo is grown either in pure stands or mixed with dicot tree species like *Lagerstroemia*, *Bombax, Erythrina* and the like. The villagers manage these bamboo groves for commercial purposes whereas the homegarden bamboos are essentially for meeting the felt needs of the rural households (Nath et al. 2006). Due to its site specificity in the homegarden, bamboo builds up a complex interplay between soil and vegetation implying the prevalence of a different microclimate under bamboo canopy than the other parts of the homegarden.

Terrestrial ecosystems play an important role in global C cycle and biomass C from sustainably managed plantation may offer an opportunity to combat GHG emission in the atmosphere. C sequestration potential of bamboo in homegarden systems can be significant sinks of atmospheric C due to their fast growth and high productivity. Carbon management in vegetation through selective felling of bamboos as practiced in homegarden ensures minimal C export from the environment and further strengthens the ecological rationality of homegarden besides sustaining basic community needs. To mitigate the increasing concentration of GHGs in atmosphere cost effective methods for emission reduction has been emphasized. Finding low-cost methods to sequester carbon is emerging as a major international policy goal in the context of global climate change (Montagnini and Nair 2004). Role of agroforestry systems across the world has been prioritized in C sequestration while bamboos in particular remain unexplored. Bamboos form the imperative component of agrisilvicultural system of northeast India and have an important influence on the C balance of ecosystem through assimilating atmospheric CO_2. Bamboos have socio-economic and ecological values and its management can provide benefits on a local, national and global level through livelihood, economic and environmental security for many million of the rural people (Banik 2000; INBAR 2006). The International Panel on Climate Change has recommended a catalogue of remedial measures to mitigate increasing CO_2 emissions. Among these remedial measures, such as re-/ afforestation, the conversion of agricultural land into agrosilvicultural systems has also been included (IPCC 2001). We referred ‘carbon farming’ in the present paper as C storage in the vegetation of cultivated bamboo in rural landscape and its ability to sequestrate C under continuous yield and harvest. Furthermore, the sustainability of the C farming is measured from its permanency i.e. duration of retention of C in vegetation under villagers’ management system. Carbon farming through bamboos in rural landscape can meet the ecological and economic benefits to the rural life and also as an effective choice for climate change mitigation strategy. Only a few studies have demonstrated the potential of bamboos to function as carbon storage and carbon sinks (Isagi et al. 1997; Das and Chaturvedi 2006; Tian et al. 2007; Nath et al. 2008). Therefore, understanding of C storage and C sequestration potential of bamboos is crucial to evaluate the role of bamboo in rural landscape in environmental and economic sustainability. The paper combines the potential for small-holder carbon farming subject to traditional harvest regimes.

Methodology

Site selection

The present study was conducted in Irongmara and Dargakona village, in Cachar district of Barak Valley, Assam, northeast India and is situated between longitude 92°45´ East and latitude 24°41´ North. The study villages dates back from the British colonial rule and most of the inhabitant of villages are tea garden labourers. Socioeconomically the villagers are small-holders with paddy land as the major land use system and day labour as the primary occupation. Average number of people per family is 6.86 (range 2-20) with average number male 3.81(range 1-14) and female 3.06 (range 1-10). Community like Mala, Maal, and Pashi dominates the study villages.

Sampling strategy

Fifty homegardens were selected from the study site. Selection criteria for homegarden was its size (<1ha). Since majority of the homegarden owners were small-holders and large holders represents only a small fraction of the study village, sampling was done mostly for small-holders. 10 bamboo groves studied was the additional land use systems managed by the selected 50 homegarden owner. Therefore, the sampling size for homegarden was 50 and bamboo grove 10.

Climate

The climate of the study site is sub-tropical warm and humid with average annual rainfall of 2226 mm, most of which is received during the Southwest monsoon season (May to September). Southwest monsoon usually operates for a longer spell in the Northeastern region compared to the other parts of India. Average maximum and minimum temperatures were 30.5^0C and 20.3^0C respectively. The average relative humidity varied between 48 percent (January) to 97 percent (June).

Carbon content determination

Sub-samples of culm, branch and leaf from different culm ages for the three species were ground in a Wiley mill and analyzed for carbon content determination. A total of 50% of the ash free mass was calculated as the carbon (C) content. The ash content was determined by igniting 1 g of powdered litter sample at 550 ^{0}C for 6 hr in a muffle furnace (Allen 1989). The carbon storage in the different culm component was determined by multiplying the biomass with carbon content. Detailed of the biomass estimation is described in Nath et al. (2008). The total C storage in the above ground standing biomass was obtained by summing the C content values for leaf, branch and culm component and then expanded to hectare basis.

Result

Traditional harvest regime of bamboo growers

Two harvest regimes – selective harvest and clear-felling harvest could be identified on the mode and season of felling culms. Traditionally bamboo resources are utilised in household, craft and commercial sector. For household and craft sector selective felling is practised and for commercial sector clear-felling is practised. Selective felling is mainly practised in homegardens and clear-felling in bamboo groves. Under selective felling, the mature culms (>2 years) which constitute about 15-30 percent of the total culms per clump are harvested each year. Traditional bamboo growers prefer to harvest *B. cacharensis* under the selective felling system for its multipurpose household uses and *B. vulgaris* and *B. balcooa* under the clear-felling system for paper industry due to their higher green weight. Under the clear-felling system, 85-95 percent of the total culms per clump are harvested; leaving few current and one year old culms at a felling cycle of 5-6 yr. Clear-felling mode of harvest is practised both rainy and winter season. Bamboo growers prefer the clear-felling system during rainy season as the harvested culms are constructed into rafts and ferried through water to reduce the transportation cost. In the study villages 25 percent of the bamboo growers are involved in commercial utilization of bamboo resources and they resort to clear-felling. However, these growers also manage at least 3-5 bamboo clumps under the selective felling system for their household utilization.

Growing stock of bamboos in homegarden and bamboo grove

The detailed characteristic of homegarden and bamboo grove is provided in **Table 1.** In homegarden 53-55% of the total growing stock of bamboo is contributed by *B. cacharensis* followed by *B. vulgaris* (25-27%) and *B. balcooa* (16-18%). In bamboo grove *B. cacharensis* contributes 55-65% of total growing stock. The corresponding value for *B. vulgaris* was 20-24% and *B. balcooa* was 15-22%. Standing culm density for three species in homegarden and bamboo grove is depicted in **Table 2**.

Biomass carbon stock in homegarden and bamboo grove

Biomass C stock in homegarden ranged from 7.60 to 10.76 Mg ha^{-1} from 2003 to 2007. The corresponding value for bamboo grove was 4.53 to 40.58 Mg ha^{-1}. Species wise comparison revealed *B. cacharensis* contributed 40-44% of the total C stock in homegarden. The corresponding figure for *B. vulgaris* and *B. balcooa* was 30-33% and 22-24%. In bamboo grove *B. cacharensis* contributed 50-56% of the total growing stock of C whereas *B. vulgaris* and *B. balcooa* contributed 25-26% and 18-23% respectively. Biomass C in different culm component for three bamboo species in homegarden and bamboo grove is depicted in **Table 3**. Total biomass C stock in different culm component in homegarden and bamboo grove was correlated with five year study period (**Figure 1**). Leaf, branch, culm and total biomass C increased over the study period in homegarden and the variables were strongly correlated (R^2=0.9357-0.9705). In bamboo grove leaf, branch, culm and total biomass C increased with study dates upto 2006 and then sharply declined in 2007. Development of correlation between biomass C stocks in different culm components with their respective time period over the study year revealed the existence of a weaker relationship (R^2=0.0490-0.0555).

Rate of biomass carbon accumulation in homegarden and bamboo grove

The rate of leaf biomass C accumulation in homegarden ranged from 0.017 to 0.089 Mg ha^{-1} yr^{-1}. The corresponding rate of C accumulation in branch, culm and total biomass was 0.025 to 0.071, 0.391 to 1.018 and 0.432 to 1.178 Mg ha^{-1} yr^{-1} respectively (**Figure 2**). Comparison among the species showed rate of leaf biomass C accumulation was highest for *B. balcooa* (0.016 Mg ha^{-1} yr^{-1}) while branch (0.019 Mg ha^{-1} yr^{-1}), culm (0.295 Mg ha^{-1} yr^{-1}) and total (0.327 Mg ha^{-1} yr^{-1}) was highest for *B. cacharensis*. Negative rate of biomass C accumulation was recognized in all the components in bamboo grove for the year 2006-2007. The rate of leaf, branch, culm and total biomass C loss for 2006-2007 was 1.378, 1.885, 32.781 and 36.044 Mg ha^{-1} yr^{-1} respectively. The rate of loss of C for 2006-2007 in all the components was greater than the sum of the rate of C accumulation for all the components for the last three preceding year. The rate of loss of C was highest in *B. cacharensis* for all the components.

Discussion

Socioeconomically studied villagers are small-holders and they maintain bamboos in homegarden and bamboo grove to fulfill their diverse rural needs. Chandrashekara et al. (1997) reported the socio-economic and ecological aspects of developing bamboo resources in homesteads of Kerala, India. The traditional homegardens of the study site are rich in bamboo resources as also in the homegardens of elsewhere (Widjaja 1991). The traditional bamboo growers of the study site have prioritized three bamboo species viz. *B. cacharensis*, *B. vulgaris* and *B. balcooa* under 1 genus against 14 species under 5 genera from the rest of India (NMBA 2004). The major cause for development of bamboo cultivation practice in recent years is to fulfil the household and commercial needs from householder's own holdings that otherwise was met from the forest resources which are gradually diminishing due to unsustainable harvest from increasing population pressure. During the study 4-9% of the farmers were found planting new bamboo offset every year to maintain long term sustainable production. Detailed discussion with these farmers, it was revealed that they do so thereby their future generation would get the benefit of this practice.

The consistent trend of increase in above ground C stock in homegarden might have resulted from the increase in culm density over the study period under the traditional management system. New culm production increased successively over the years and therefore the increase in culm density. The farmers in the study area fell less number of culms per clump than it produce new culms annually and that also contributed in increase in the culm density in homegarden. Standing culm density and C stock in bamboo grove is much higher than homegarden but former is constrained by huge quantity of C loss from the stand following clear felling strategy of harvest that followed at 5-6 yr cycle. Moreover, clear felled bamboos are subject to commercial utilization viz. paper industry and thereby diminishing the scope of sink measure of atmospheric CO_2. Since the culm density of bamboo in homegarden is progressively consistent, C stock in them is increasingly stable. Estimated C stock of 4.87 and 14.62 Mg ha^{-1} in agricultural and agrihorticulture agroforestry systems in terai zone of India has been reported (Koul and Panwar 2008). C stock in agroforestry practices has been estimated as 9, 21, 50, and 63 Mg C ha^{-1} in semiarid, subhumid, humid, and temperate regions (Montagnini and Nair 2004). Biomass C stock ranged from 0.7 to 54.0 Mg C ha^{-1} in traditional and improved agroforestry systems in the West African Sahel

(Takimoto et al. 2008). Since bamboo is one of the components in multistrata mixed species homegardening system, bamboo farming system in homegarden had relatively smaller C stock than other agroforestry systems. Moreover, incomparison to other tree species bamboo is relatively low biomass plant that conversely reduces its ability to store more C. In bamboo the C sequestration potential is determined by the new culms produced annually. In homegarden under farmers' management system new culms are restricted from felling and hence almost all C sequestrated through it can be assumed as a net gain, that further demonstrates the small-holder bamboo farming systems can sequestrate C while also fulfilling basic rural needs from harvesting mature culms. Harvest of products, particularly in single-objective plantations, has a negative impact on the system's C stock and raises concerns of 'permanence' (Roshetko et al. 2007) and the problem holds same in long term C storage for the farmers' deliberate management system of clear felling of bamboo clumps for commercial purposes as observed in bamboo groves. In homegarden under selective felling system although the C stock is low, but represents a permanent C stock as C export through harvesting of mature culms are balanced by C gain from new culms produced in the clump. Long rotation systems such as agroforests and homegardens can sequester sizeable quantities of C in plant biomass and in long-lasting wood products (Albrecht and Kandji 2003) besides having other secondary environmental benefits (Pandey 2002) and important role in reclamation of marginal, sloping agricultural land and degraded land through bamboo plantation (Mertens et al. 2008). Lower C/N ratio in bamboo soil compared to pasture soil signifies higher availability of soil nutrients in the former (Tian et al. 2007) further strengthens the role of bamboo in soil reclamation. For smallholder agroforestry systems in the tropics, potential C sequestration rates range from 1.5 to 3.5 Mg C ha^{-1} yr^{-1} (Montagnini Nair 2004). C sequestration at abandoned agricultural land and degraded forest land sites in Central Himalayan region was 1.79-3.13 Mg ha^{-1} (Maikhuri et al. 2000). Although the amount of C sequestered is less in bamboo farming system of homegarden than any other agroforestry system, bamboo also meet the felt needs of rural household other than providing the villagers with wide range of economic and environmental services. Therefore, potentiality of homegarden bamboo offers a feasible alternative for rural land use management as Tian et al. (2007) emphasized benefits of bamboo in land use conversion from their study from Montane Ecuador.

Carbon farming through bamboos in homegarden can contribute towards a strategy for sustainable development than bamboo grove even though the later is characterized by greater standing stock of C and higher rate of C sequestration. Consistent standing stock of C in homegarden bamboo management may provide small-holder farmer an option of selling carbon credits under climate change agreement. However the study does not include the accounting of C sequestration. In 2005, the concentration of atmospheric CO_2 reached nearly 380 ppm, an increase of ~35% above the preindustrial concentration (Houghton 2007). In December 2003, the 9th Conference of the Parties to the UNFCCC resolved to include small-scale forestry as an eligible activity under the Clean Development Mechanism (CDM) of the Kyoto Protocol. Carbon farming through bamboos in homegarden is cost effective in terms of carbon sequestered can be considered under the CDM protocols. Furthermore, a shift in utilization pattern of bamboos of bamboo grove from industrial utilization to craft sector through value addition and innovative marketing can make this land type a potential C sequestrating system. We also emphasize the need of the harvest protocol for village bamboos from government level for promotion of sustainable utilization of these village resources.

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Table 1. Homegarden and bamboo grove in Irongmara and Dargakona village, Assam, northeast India

Characteristics	Land use type	
	Homegarden	**Bamboo grove**
Size (ha)	0.28 (0.07-1.5)	0.45 (0.13-1.2)
No. of clumps	7 (2-27)	25 (14-96)
Harvest regime	Selective felling	Clear felling
Management system	Harvesting through out the year with higher intensity in winter season	Harvesting mainly in the rainy season
Management purpose	Household requirement, fencing, crafting	Selling in paper industry

Table 2. Culm density in homegarden and bamboo grove (No. ha^{-1}) in Irongmara and Dargakona village,
Assam, northeast India

		B. cacharensis	*B. vulgaris*	*B. balcooa*	Total
	2003	455±39*	228±24	137±23	820±48
		735±45**	230±30	180±28	1145±46
	2004	487±43	235±26	152±23	874±58
		1320±55	485±21	340±27	2145±48
	2005	510±65	248±30	167±21	925±74
		1985±60	743±35	567±40	3295±76
	2006	598±41	278±31	186±20	1062±68
		3150±52	1142±38	985±37	5277±65
	2007	642±45	306±27	212±21	1160±62
		560±37	245±20	225±19	1030±28

*homegarden **bamboo grove; values are Mean±S.E.

Table 3. Biomass C stock (Mg ha-1) in different culm component in (a) homegarden and (b) bamboo grove (Mg ha-1) in Irongmara and Dargakona village, Assam, northeast India

	B. cacharensis				*B. vulgaris*				*B. balcooa*				**Total**			
	Leaf	Branch	Culm	Total	Leaf	Branch	Culm	Total	Leaf	Branch	Culm	Total	Leaf	Branch	Culm	Total
2003	0.11	0.15	3.09	3.34[a]	0.10	0.15	2.29	2.53	0.06	0.09	1.57	1.72	0.27	0.39	6.94	7.60
	0.11	0.20	3.57	3.88[b]	0.06	0.07	1.61	1.74	0.04	0.06	1.22	1.31	0.21	0.33	6.40	6.93
2004	0.12	0.17	3.28	3.56	0.10	0.15	2.43	2.68	0.08	0.10	1.78	1.96	0.29	0.42	7.49	8.20
	0.31	0.44	7.82	8.57	0.13	0.18	3.46	3.76	0.09	0.12	2.49	2.71	0.53	0.74	13.77	15.04
2005	0.12	0.18	3.43	3.73	0.11	0.16	2.55	2.81	0.08	0.11	1.90	2.09	0.31	0.44	7.88	8.63
	0.48	0.69	11.60	12.77	0.26	0.34	6.27	6.87	0.18	0.24	5.04	5.46	0.92	1.27	22.91	25.11
2006	0.15	0.21	3.98	4.34	0.16	0.18	2.89	3.23	0.09	0.12	2.03	2.24	0.40	0.51	8.90	9.81
	0.79	1.12	18.51	20.42	0.40	0.55	9.65	10.60	0.32	0.43	8.81	9.55	1.52	2.09	36.97	40.58
2007	0.16	0.22	4.26	4.65	0.16	0.20	3.20	3.56	0.10	0.14	2.30	2.55	0.43	0.56	9.77	10.76
	0.08	0.13	2.10	2.30	0.03	0.04	1.07	1.14	0.03	0.04	1.02	1.09	0.14	0.21	4.19	4.53

Bamboo - the Emerging Tool for Forest Management and Community Development in Assam, Northeast India

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Abstract

Legal moratorium on forestry practises including timber harvesting operations since 1996 has significantly impacted the revenue earnings of the forest rich states in northeast India. Alternatives to timber operations therefore need to be initiated urgently to bridge the gap between supply and demand and also to give a boost to forest based economies. While conservation policies imply that forest land availability for providing timber alternatives is limited to degraded forest areas, Bamboo which is abundantly available in the region has tremendous potential for its economic benefits and also for its low impact on biodiversity loss. A paradigm shift in forest management policy and the subsequent implementation of Joint forest management in Assam since 2000 has also left much to be desired in terms of long term sustainability by providing a sound economic base. While JFM has achieved success in mainland India, there have been a few apprehensions about its implementation in northeast India where the issue of land ownership and natural resource use are historically much more complex and inter-related. This paper examines the advantages of bamboo plantations carried out through forest development agencies in Assam and the road ahead.

Introduction

The state of Assam is situated in northeastern India between latitudes 24^0 44' N to $27^0$45' N and longitudes $89^0$41' E to 96^0 02'E. The geographical area of Assam is 78,438 sq. km. (2.39% of the country) and it is the largest of the seven northeastern states. The state is blessed with fertile lands and suitable climate ideal for flora and fauna. The state primarily has an agrarian economy with 87% of the state's population dependant on agriculture and allied activities while the dependency on forests and natural resources is also part of the socio-cultural milieu. Forest makes a significant contribution to the direct income to the households. The Tribal population and other households belonging to the most vulnerable section of the society derive a substantial part of their income directly from forest based economic activities. Preservation of Assam's forests in good health and vigor is extremely important from the point of view of these people.

Assam has a total of 26,748 Sq. Km. of recorded forest area, i.e., 3.2% of the country's forests cover. Percentage of forest cover to total geographical area of Assam is 24.58% (SFR, 2005). The major forest types of Assam are Tropical Wet Evergreen, Tropical Semi-Evergreen, Tropical Moist Deciduous, Sub-Tropical Broad Leaved Hill,

Sub-Tropical Pine, Littoral and Swamp Forests. The physiographic, climate and inaccessibility had contributed the richness of vegetation in Assam.

The forests of Assam have been legally classified in three parts namely Reserve Forests, Protected Forests (National Parks & Sanctuaries) and Unclassified State Forests. There are 312 no. of Reserve forests in Assam with a total area of 13,870 Sq. Km. (17.68% of state geographical area). There are 25 nos. of Protected Areas with an area of 3,925 Sq. Km. (5% of state geographical area). Apart from that 5,865 Sq. Km. area is under Unclassified State Forests and 3,103 Sq. Km. area is under Proposed Reserved Forests (145 nos.) category.

Bamboo resources in the state

Bamboos have gained considerable importance in the socio-economic life of people in Assam for the variety of uses they cater to. About 34 per cent (8213 sq km) of Assam's total forest area is under bamboo. Over 42 species of bamboo have been recorded from the state and like the other states in northeast India, bamboo is entwined with the social, cultural and economic aspects of different communities in Assam (Anon, 2002). Some of the species such as Bhulka (*Bambusa balcooa*), Kako (*Dendrocalamus hamiltonii*) and Jati (*Bambusa tulda*) are most commonly available in forest areas and are of immense economic importance. Bamboo is also cultivated widely in Assam and most of the villagers have at least 1-2 bamboo clumps in his homestead to meet the household demands. Besides bamboo, the forest products of the state include tree-borne oilseeds, leaves of Sal for leaf plate making, hill-brooms, seeds and roots of medicinal and a wide variety of other non-timber forest products that contribute substantially to the income of the communities living in and around the forest areas of the state.

Bamboo potential in the state

Bamboo products provide promising linkage between the organised and unorganised sectors, between household activity and organised industry; edible bamboo shoots, processed for the market represent another promising area of economic activity. The Bamboo and Cane policy for Assam government has also been formulated in 2005 with an aim to encourage, promote support the development of the bamboo sector in a comprehensive manner through a multidisciplinary, multi-department and multi-dimensional integrated approach to provide economic benefits to the people of the state. The thrust areas of the policy have been on:

- Manufacture of value added products and applications such as wood and plywood substitutes, composite material, charcoal, activated carbon and energy.
- Low cost and earthquake resistant housing and constructional applications
- Processed edible bamboo shoot
- Craft and small enterprise
- Regeneration and conservation within and outside forest areas
- Capacity building and skill up-gradation and training
- Awareness

- Market analysis and support

Reasons for promoting bamboo through community forestry

The decline in the availability of timber and the emergence of new technologies and product options has spurred interest in the field of wood substitutes and composites. Conservation oriented forest management practices including a moratorium on commercial felling are currently in vogue in India, therefore the main economic role of forests largely relates to the non-timber contributions. Recent studies carried out indicate the total yield potential for the state is around 7, 57,263.31 (Metric Tonnes Air Dried) MTAD per annum (NEPPM, 2008). This yield represents annually 12.5% of the total harvestable bamboo growing stock. While the overwhelming industrial use of bamboo is still for pulp and paper. The paper mills in the state have an installed capacity of 8, 00,000 MTAD per annum. This means that there is an annual shortfall of about 4,2737 MTAD alone in case it is used for the paper industry. Bamboo also supports a number of traditional cottage industries including production of handicrafts, incense sticks and related articles. This further adds on the demand for bamboo and therefore can be addressed only by taking up more bamboo plantations. Within forest areas, bamboo does not often occur in pure patches and also suffers from poor management, low productivity and over-exploitation. At present the yield of bamboo from plantation areas range between 3-4 tonnes / ha which means that an area of atleast 15000 ha will be required additionally to meet the current demands. The yield can also be further improved to 18-20 tonnes/ ha through use of quality planting material of select species and their intensive management (Fig 1), (Fig 2).

Community forestry and advantages of bamboo over tree plantation in JFMC areas

The Peoples' participation in forest management in Assam is quite old but formally and legally started during 1998 with framing of the Assam Joint (Peoples' Participation) Forestry Management Rules, 1998 and constitution of Forest Development Agency in the year 2002-03. There are 28 Forest Development Agencies (FDA) in Assam under National Afforestation Programme with over 700 J.F.M.Cs at present functioning under them. Out of these J.F.M.Cs, 90 are in forest villages and remaining 460 are in revenue villages. Till now more than 3, 21,103 population and 57,341 households have been economically benefitted through the constitution of the JFMCs and a total plantation area of more than 30030 ha has already been achieved (SFR Assam, 2007).

While the forest fringe villagers have heartily welcomed the paradigm shift in management policy and the inclusion of community participation in the management of forests, there is a wide gap between the current supply and demand needs for timber and fuelwood needs that need to be bridged urgently to prevent any further degradation. The plantation taken up through JFMC has ensured any further encroachment of forest land however, the quality of plantation and survival percentage is definitely a cause of concern. Bamboo with its fast growing ability and multiple use characteristics can therefore help in mitigating this gap to a large extent.

Advantages of bamboo over tree plantation in Assam

- Bamboo is a fast growing, sturdy and versatile species that can be harvested between 4-5 years whereas tree species such as Teak (*Tectona grandis*) and Gamari (*Gmelina arborea*) take atleast 30 years before they can be harvested. The JFM schemes are normally funded for 3-4 years and therefore do not assist in management of tree species till their maturity. The loss of economic incentive and a long gestation period for harvesting of produce can therefore result in loss of interest and negligence in the part of JFMC members. Bamboo on the other hand is harvestable during the project period and therefore continues to give the economic impetus for community management of forests.

- There are more than 42 species of bamboo that are recorded from Assam and each has their known economic uses with a market readily available at village level for primary processing. Bamboo is also socially more accepted and preferred by villagers as they are well aware about the multiple use of each.

- JFM was initially started with the concept of 'Janata Fencing' which means that the plantation will not be provided with any permanent fencing; instead the JFMC members shall be protecting the plantation on their own. However, it has been observed that grazing is one of the serious causes of concern for plantation and therefore fencing of semi-permanent nature is a must in the initial three years. The bamboo mission guidelines provide for three strand barbed wire fencing and this has helped the JFMC members to prevent any grazing in the plantation site.

Conclusion

Bamboo can be the best solution for implementing participatory schemes and also for targeting degraded forest areas. It acts as a barrier to prevent any further land encroachment and also provides quick economic incentives that convince the local people to be involved and participate in government funded schemes. It is therefore best suited for augmenting the forest revenue and implementing community forestry and JFM in the state.

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Fig 1: Percentage outturn of different forest produce including bamboo from Reserved Forest Areas of Assam (2005-06) (Source: Assam Forest Department Annual Report)

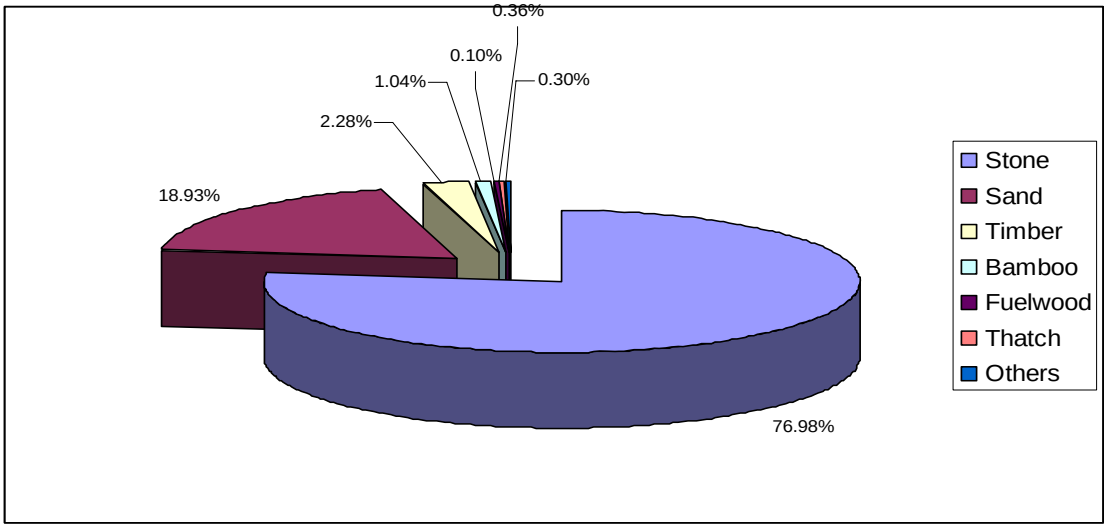
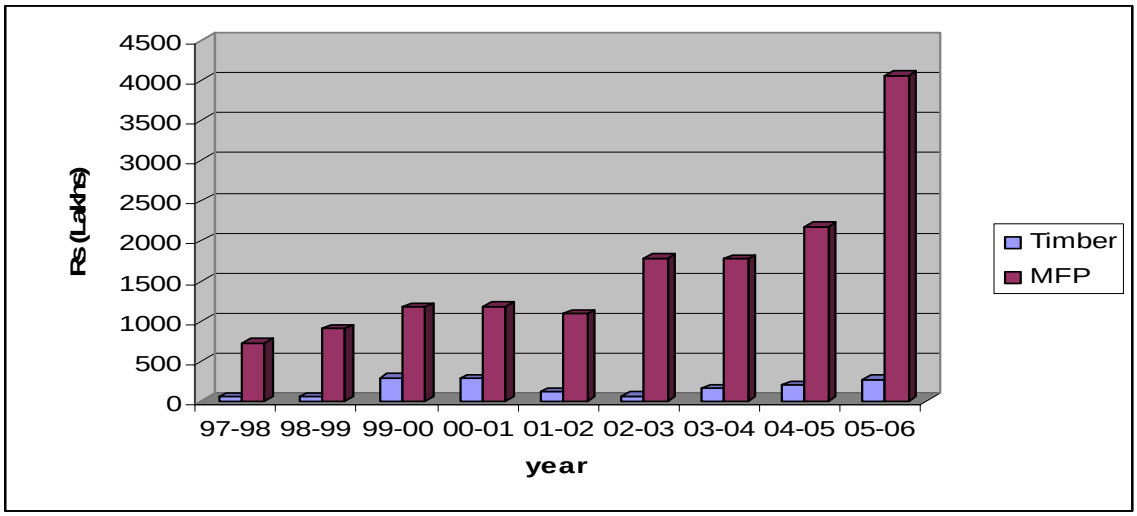


Fig 2: Comparative chart of Revenue generated from Timber and Minor forest produce (including bamboo) in Assam since 1997-2006 (Source: Assam Forest Department Annual Report)



Vanishing Trade of Bamboo: A Case study of Traditional Artisans of Uttarakhand

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Abstract

Indian state Uttarakhand has a long tradition of using bamboo for making diverse utility items that are traded in villages. There are 5 genera and 8 species of bamboo in the state. *Arundinaria falcata* and *Thamnocalamus spathiflora, T. falconeri* and *Chemnobambusa jaunsarensis* are popularly called as 'Ringal' which are thin reed like bamboo that grow in mid and high hill areas, while four are of thick bamboo species (viz. *Dendrocalamus strictus, D. somdeviii, Dendrocalamus patellaris* and *Bambusa bamboos).* A total of 62 bamboo and ringal items have been identified that are made from different bamboo species, which comprise large variety of baskets, mats, toys instruments, and other utility items for daily household needs. Socio-economically bamboo artisans are poor and they come from lower strata of the society, and lack land and other resources. The indigenous knowledge about the use of bamboo species is disappearing from younger generation due to low profit and lack of marketing avenues. Moreover because there was high exploitation of bamboo in past, the natural resource status is dwindling fast. Considering the regional and global markets of bamboo and the indigenous knowledge of local community, it is emphasized that value addition in products, a market oriented approach and capacity building of the craftsmen will help in improving the socioeconomic status of the community along with conservation of bamboo species.

Introduction

Bamboo is the fastest growing plant on the earth and characterized by woody, mostly hollow culms with internodes and branches at the culms nodes. India is the second richest country in terms of Bamboo genetic diversity with a total of 136 species under 75 genera (Rai et al. 1998, Biswas 2004)**.** The country has over 8.96 million hectares area underneath bamboo that forms 12.8% of the total forest cover (Anonymous 2005a). Bamboo plays an important role in the livelihood of rural and tribal people and has been intimately associated with mankind since ancient time (Ram and Tondon 1997). However, the social situation of bamboo workers is quite bad as they are at the bottom of social hierarchy. The total number of cane, bamboo and basket weavers in 1981 was 8.2 lakhs, out of which 6.9 are in the rural areas (Saxena 2004). These families have the expertise and skills of processing bamboo, and make hats, baskets, and other utility items, however they are not able to get the full price for their labour because of various reasons (Sundriyal et al. 2002).

The Planning Commission has launched a National Mission on Bamboo Technology and Trade Development (NMBTTD) with a focus to adopt a holistic and integrated approach for using bamboo as an important vehicle for development of the country. It is, therefore strongly desirable to generate baseline data on resource status and socio-economic condition of bamboo artisans so that suitable strategies are developed for resource management and conservation as well as uplifting the status of bamboo-artisans. This study focuses on assuring bamboo based trade in the state and its role in the household subsistence economy, traditional uses, knowledge and management of bamboo and major trade challenges that the trade is facing.

Materials and methods

Uttarakhand is a newly formed state of India which is predominantly a hilly region with 53,483 sq km land area with an elevation between 300 to 7800 m asl. Administratively the state is divisible in 13 districts. The individual land holdings in the state is generally small (<1 ha), and such farmers need income diversification. Bamboo is found in Siwalik forests at low hill areas. At mid-hills, bamboo species are found in wastelands under individual ownership is small patches comprising 2-5 clumps. At high hills, only ringal-bamboo species are found that grow as middle forest strata in reserve or van-panchayat forests. Based on the large number of bamboo artisans, four districts of Uttarakhand (viz. Almora, Nainital, Bageshwar and Uttarkashi) were identified for the purpose of this investigation. Documentation of the community indigenous knowledge system (IKS) on bamboo artifact was done through standard questionnaire surveys and formal-informal interviews with the local people. Selection of the districts and villages were made with the help of discussion with the experts, NGOs, BFDB and other resource persons. Detailed information were gathered with reference to species used, areas and mode of collection, quantity of raw material used for different products, design used and finishing of the product, and mode of selling of the product. The cost-benefit analysis was done using all cost involved in material purchage, labour in collection, processing and product making and net sold prices for different items. The species used by the communities were collected and a herbarium was made. These species were subsequently identified with the help of experts and flora available with the Botanical Survey of India and Forest Research Institute, Dehradun. Value addition of the products and capacity building of the artisans was done by organizing two training programmes. Data on bamboo harvest and revenue generated was collected from Forest Corporation, Dehradun.

Results

1. Bamboo uses, trade and consumption

The bamboo is used in all 13 districts of Uttarakhand state. The gross commercial bamboo standing stock is estimated at 45,000 m^3 from the total growing area of 1394 km^2 for the state of Uttarakhand. Bamboo in the state is categorized into two groups, the bamboo and the ringal-bamboo The four ringal species are *Drepanostachyum falcatum*, *Himalayacalamus falconeri, Thamnocalamus spathiflorus,* and *Thamnocalamus jaunsarensis.* Ringal species grow at mid and high hills mainly in temperate areas between 1500-3500 m elevations in Uttarakhand. Mostly ringal is used in making baskets, mats, toys, umbrella, agricultural tools and fish rod. Leaves of ringal and bamboo are considered good fodder as well.

Bamboo is thick, long and slender like plant. The most bamboo species are D*endrocalamus strictus, D. somdeviii, Dendrocalamus patellaris* and *Bambusa bambos* that grows between 300-1500 m elevation above sea level and cover 15,620 ha area. These species are mainly used for making diverse household items though in recent times also used in paper industry. In recent times, a large number of species are also planted in Civil Soyam and Van-panchayat forests for meeting pulp and other commercial needs. The bamboo-artisans are called 'baruries' while ringal-artisans as 'rudias'. Based on the survey of traditional bamboo artisans/craftsman in 20 villages revealed that communities make a total of 62 items which comprised large variety of baskets, mats, toys, instruments, and other utility items. Most of these items are used for daily household needs. Selected families are totally dependent on selling of bamboo items. Despite of a huge knowledge base on making articles, only 14 items were recorded sold to the villages (Table 1).

Table 1. Major bamboo items sold in the villages by the bamboo-artisans and their utility in Uttarakhand, India

Items	Local name	Market cost	Local use
Big basket	Tokri (Big)	45-50	Used for collection of fodder (grass, leaves) and for carrying manure in agricultural field
Winnowing tray	Supa	30.0	For winnowing food grains
Small basket	Dalia (small)	40-45	Childrens use for carrying Chirpine leaves, woods and manure
Big bassket with handle	Kandi (Big)	40-50	For storage of vegetables
Small basket with handle	Kandi (small)	25-30	Used in marriage ceremony for puri and curd
Round basket	Chapri	25-30	For chapatti and for selling Butter and Khoya
Small round basket	Chapri ((small)	20-25	For sowing harela
Food grain storage basket	Topra	130-150	For storage of food grains
Round basket for sleeping small baby	Choura (Jhuger)	160-175	For sleeping of newly born baby
Carrying basket	Doka	125	For carrying grass and fodder
Carrying basket	Solta	100.0	,,
Mat	Moste or Bishal	700-800	For drying and cleaning of rice
Hat	Topi	100.0	To cover head
Round umbrella	Chatura	200.0	Used in god pray and offer to god.

Most of the artisans live at mid and high hills, however bamboo is harvested from community land and ringal from forest areas. Local artisans travel long distances in search of harvesting adequate quantities of ringal. The entire trade is labour intensive from material procurement to processing to marketing. High labour requirement and dwindling raw material status are causing much pressure on the artisans to switch over to other seasonal labor for immediate cash. The bamboo is available in plenty in low hill forests that are under the control of Forest Department, who collects and auction it through selected depots. Unfortunately such material is not accessible and procured by artisans because of poor socioeconomic condition. The artisan required low volume of raw material in the form of green bamboo, which comes from a few bamboo growers in the villages. The artisans procure clumps from owners on a fixed price. Of late the artisans/craftsmen are facing the problem of availability of raw material; therefore prices of bamboo culms have registered substantial increase. The conservation status of most bamboo species was also discouraging, which indicates likely vulnerable trade. An analysis of total village level consumption of bamboo articles revealed that nearly 600-3000 bamboo/ringal articles are used per village depending upon the size of the village (Fig. 1).

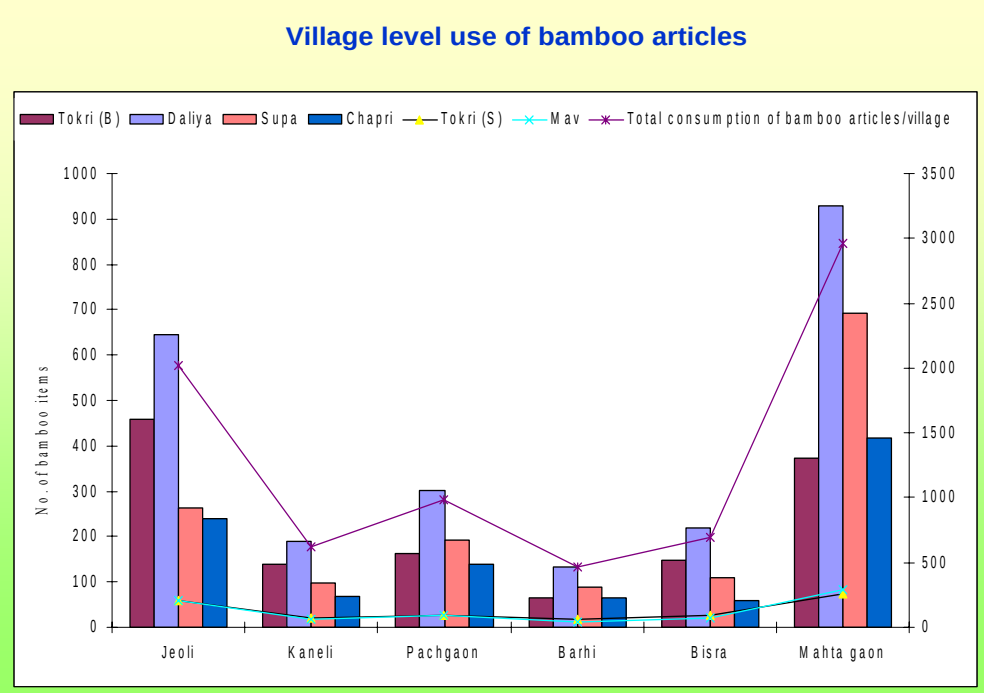

Fig. 1. Village level use of bamboo articles for selected items in Uttarakhand state, India

Dalia (basket for carrying leaves, grain, and fodder) is used in maximum quantity (150-950/annum) followed by *Supa (*Winnowing tray for grains) (150-750/annum), *Tokri* (80-450/annum) *(*basket for carrying manure and grass*)*, and *Chapri (*basket for keeping chapati) (80-450/annum).

2. Socio-economic status of artisans

An analysis of net income of bamboo artisans reveals that the overall socio-economic status is very poor, which mostly comprised highly marginalized families. *Baruries* live at low and mid hills whereas *Rudias* live at high hill areas. These communities sell bamboo-articles to villagers to earn their livelihoods. Such communities lack land and other resources for their livelihood, therefore dependent on this trade for centuries, which is run at subsistence level. A large number of such traders live in remote villages, unfortunately most of them are not in position to take the benefit of the government run schemes. In a study of 20 villages in present investigation the status of all the bamboo-artisans families (100%) was recorded as below poverty line schedule caste (BPL-SC). In case of ringal, however, 75% families were BPL (SC) while remaining 15% were APL families. Most articles are made for domestic use they are big in size and do not carry commercial values. The articles are sold either direct to rural folks either in cash or on bartered or made on order. Sometimes the items are sold in small towns but purchased by rural people only. Most artisans had >50 years of age and only few from younger generation, which showed that the later category is not interested in this tradition.

3. Management of bamboo resource

The major constraints of the bamboo-trade are that it is now restricted to remote village areas and highly marginalized communities of *barurees* and *rudias* are practicing it that have low socio-economic profile in the society. Despite of good skill for processing of bamboo, these communities do not own the resource and therefore dependent on others for raw materials. The artisans were not skilled for plantation of bamboo and they generally purchase the raw material from private growers. Ringal artisans collect the raw material from forests. Management of bamboo is also poor in villages. Usually bamboo clumps are found in open and wastelands areas, where they are not protected from grazing which affects growth of new shoots.

The study clearly depicts that the bamboo-trade is labour intensive and products are made in low volume that are sold in low prices, thus the trade is highly subsistence. As the cost of raw material is increasing day by day the communities are looking for the alternate source of income. Such a situation asks for more concerted efforts for survival of these communities. The traditional enterprise is home-based and consumption of the product occurs within village or walking distances or to a town that is just a bus ride away or in festivals in nearby areas. The benefit of government run schemes often do not yield positive results because of various reasons including lack of awareness, and organizational and risk taking capacities.

4. Value addition of the local products

In view of the depleting status of the bamboo in the state, it was utmost importance to use other materials with bamboo and ringal so that the quantity of raw material could be saved during product making. Therefore, an approach that promotes conservation of bamboo resource and increase income of artisans was adopted. A market survey was made to select products of common requirement, e.g. baskets (of different shapes & sizes),

flower pot, lamp shade, dust bin, hand bag, foot mat and other utility items were selected. Capacity of the artisans was developed through trainings for making such products and use other materials such as rope, fiber and cloth with bamboo and ringal. The trainings demonstrated that the approach significantly reduced use of raw materials and its cost, and also give better appearance and finishing to the products. The items were small in sizes, comprised local designs and cost-effective (Table 2). The trainings effectively demonstrated that the raw material could be saved by 40-60%, while income can be increased by 75-150%.

Table 2. Quantity of ringal-bamboo used for making articles, preparation time and selling cost of traditional and new products made in the training

Traditional products				New products			
Products	Quantity of ringal (culms)	Preparation time	Selling cost (Rs)	Products	Quantity of ringal (culms)	Preparation time	Selling cost (Rs)
Big basket	50	4-6 hrs	60-70	Prashad-basket	5	2 hrs	35
Dala	30	3-5 hrs	50	Flower Pot	2	1 hrs	30
Supa	10	2-3 hrs	35-40	Lamp Shade	6	2 hrs	50-60
Chatai (mat)	80	15-25 hrs	300-400	Dust bin	4	1½ hrs	25-30

5. Bamboo harvest and revenue in the state

It is also worthwhile to have an assessment of the commercial bamboo harvesting in the state of Uttarakhand. The bamboo rich forests are located in the low-hills only. The State Forest Corporation is responsible for quantum of bamboo harvests and its auction. The commercial felling was started in 1987-88 in the region. Maximum felling and revenue was generated in 1987-90, the bamboo harvest declined subsequently that clearly shows lack of proper felling cycle and reduced the culms density of bamboos (Fig. 2).

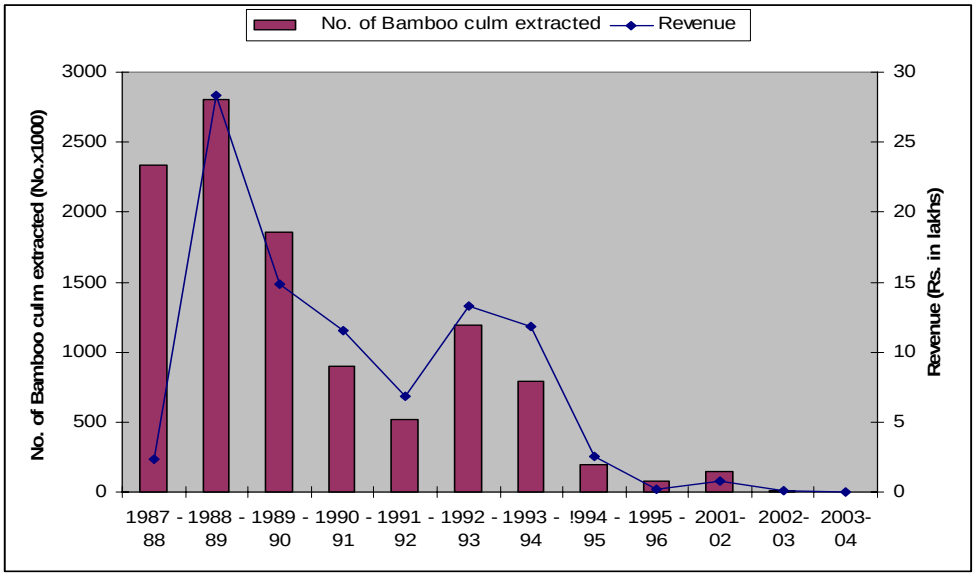

Fig. 2. Quantum of bamboo harvest and revenue generated during 1987-2004 (data collected for Lansdowne Forest Division, Uttarakhand, India).

Discussion

A detailed investigation of the resource status and socio-economic conditions of the artisans clearly showed that the bamboo trade is highly subsistence in the state that desired immediate attention. There is need to save this trade through proper strategies by the Govt. by which coming time would be more useful.

The product range is limited to various types of baskets for storing and carrying household items, and some other utility items. These articles are big in size with rough finish and sharp edges, poor in strength, non-uniform in texture and shape, and low in durability. A discussion with the *baruree* and *rudia* communities reveled that they demand for some advocacy for the trade along with building their skills for new products. Besides ensuring resource availability to the artisans, another major problem of the trade is increasing community linkages with the market. An important challenge is to mainstreaming the remotely located artisans who have resource but they are not aware of market demands, therefore trade is done in villages only. Value addition and resource conservation are required at equal footing for the bamboo-sector development. Market linkages, credits and transportation of finished goods are need to be planned and demonstrated to the craftsmen. There should be a common facility centre where artisan could sell there products. If artisans' knowledge and experience could be upgraded for making new products, they are linked with markets and organized to form cooperatives, and benefit of government run schemes are extended to them, perhaps the low-status of these highly marginalized communities could be improved substantially. Artisans in remote areas cannot be left merely on training basis. They should get appropriate helps through NGO and SHG, and cooperative networks who can take responsibilities of marketing of their products. At present all artisans are above 50 years, which highlights the

need to motivate younger generations by associating them with appropriate schemes. If vast bamboo resource of the region could be developed scientifically, it would generate enough employment opportunities for the artisans, entrepreneurs and farmers of the state, which can revolutionize the socio- economic status of the rural people of Uttarakhand state.

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Bamboo Development in the Philippines: BambooPhil Strategies

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Abstract

The paper discusses the different strategies that the Bamboo Network of the Philippines is employing to promote the widespread planting of bamboo and to strengthen the country's bamboo industries. Presented in the paper are the following programs/projects: (1) Bamboo for People and the Environment, (2) Multipurpose Training Lab, (3) Bamboo Techno-Digest, (4) Adopt-A-Bamboo Project, (5) In-house newsletter, (6) Coffee Table Book on Philippine Bamboos, and (7) Database Development.

Introduction

The Bamboo Network of the Philippines, or BambooPhil, for short, was born in April, 2008 when a small group of bamboo scientists and advocates got together and decided to form an NGO that will work for the widespread planting of bamboo and the development of the country's bamboo industries. The group felt strongly that a nationwide campaign for the planting of bamboo has to be undertaken for a number of important reasons:

- The current bamboo resource base of the Philippines is very small. It is only 53,000 hectares which accounts for only 0.18% of the country's total land area.
- The natural stands of bamboo in the Philippines (34,000 out of the 53,000 hectares) no longer serve as sources of raw materials for manufacturers of different kinds of products because most of them are poorly stocked because of unabated illegal cutting.
- Existing bamboo plantations (about 19,000 hectares), are grossly inadequate to provide the raw material requirements of the country's bamboo industries, which in 2003 was estimated to be around 50 million poles per year. Broadening the country's bamboo resource base would ensure the industries of sustained raw material supply. The development of the industries would result in expanded employment and increased export of bamboo products.
- Deforestation has devastated the country's forest resources, resulting in the acute shortage of wood for many types of wood products. Because bamboo can be used as a substitute raw material for many wood products and because bamboo is fast growing, its widespread planting can help alleviate the shortage while also reducing population pressure on the residual forest stands.

- It would greatly help reduce erosion, landslides and flooding and at the same time help in sequestering carbon dioxide from the air.

In a recent paper, Lantican and Perreras (2008) estimated that (1) at least 167,000 hectares of bamboo plantations would be needed to meet the country's annual demand for poles for furniture and handicrafts, construction and fishpens, propping for fruit trees and others and (2) at least 5% of the country's degraded forest lands (or about 400,000 hectares) should be planted to bamboo for environmental purposes, i.e. reforestation of poorly stocked watersheds, erosion- and landslide-prone mountainsides, riverbanks and grassland areas that are difficult to reforest with trees. The figures for future needed plantings concur with those mentioned in a recent publication by Midmore (2009).

During the organizational meeting, the group agreed that forming a national network on bamboo would help:

- Promote the complementation of activities among various groups rather than competition to avoid costly duplication of efforts and minimizing wastage of scarce resources.
- Facilitate the exchange of information, knowledge, materials and experiences for the mutual advantage of all concerned.
- Enhance the packaging and dissemination of technologies to intended beneficiaries.
- Facilitate the development of an effective training program to enhance manpower capacity in the production and utilization of bamboo
- Hasten the development of bamboo plantations and industries in the country.

Objectives of BambooPhil

Adopting the dictum of "harnessing the best of bamboo science and technology for people and the environment", BambooPhil is committed to pursue several objectives:

1. Carry out a nationwide advocacy program promoting the use of bamboo for reforestation, plantation development and environmental protection.
2. Develop a database system which shall serve as an electronic repository of all known information about bamboo in the Philippines and other tropical countries.
3. Package and disseminate bamboo technologies generated by research agencies/institutions in the Philippines and other countries.
4. Design, develop and organize training courses to improve the skills of bamboo growers and processors in the Philippines.
5. Provide expert services to local government units (LGUs), peoples' organizations (POs), NGOs and entrepreneurs requiring technical assistance on bamboo production and utilization.

The Bamboo for People and the Environment (BPE) Program

The BPE program is the current flagship program of BambooPhil. It was conceived to achieve three principal objectives:

1. Promote the planting of bamboo in idle, unproductive, understocked and erosion and landslide prone lands in all provinces of the country.
2. Build the capacity of local government units (provincial and municipal) to raise bamboo sustainably within their respective areas of jurisdiction.
3. Improve the skills of technicians and workers involved in bamboo processing.

Implementation Strategy

BambooPhil's implementation strategy for the BPE program is to follow a province by province or cluster of provinces approach, enjoining as many municipal governments in each province or cluster of provinces to participate in the program (please see conceptual framework shown in Figure 1).

There are several reasons why BambooPhil is focusing on LGUs in the implementation of the program. Apart from the fact that every Filipino citizen resides in a place that is within the political jurisdiction of a local government unit, LGUs:

- Have the authority to decide whether planting bamboo would be in the best interest of their constituents.
- Have direct access and contacts with village leaders and owners of lands that can be developed into bamboo farms and plantations
- Have agriculture and environment officers who, given the proper training, can actively participate in the execution of some project activities, particularly the training of constituents in the establishment and management of bamboo farms and plantations.

Moreover, it is generally easier for farmers to approach LGUs for help than government departments or bureaus.

For every province, BambooPhil plans to designate a partner to help coordinate the program activities within the province. The partner could be another NGO, an institution or an agency involved in bamboo development activities.

Although the program is only a few months old several provincial governments have already signified their interest to participate in the program.

Bamboo Planting Promotion

The BPE program promotes the planting of bamboo in provinces and municipalities in a number of ways:

1. Holding informal meetings with governors, mayors and other LGU officials.

2. Producing posters, stickers and brochures featuring the many benefits that can be derived from bamboo.
3. Establishing at least one nursery per province to supply the bamboo planting needs of different municipalities.
4. Putting up two or more bamboo demonstration farms in each province
5. Establishing linkages with the print and broadcast media and other NGOS
6. Organizing provincial bamboo expositions
7. Creating a website on bamboo
8. Encouraging governors to organize provincial bamboo development councils.

Capacity Building

One very important component of the BPE program is the capacity building component, which aims to improve the knowledge and skills of:

- Agriculture and environment officers of each municipality in bamboo propagation, plantation development, harvesting, marketing and bambusetum development.
- Technicians and workers of enterprises engaged in the manufacture of different kinds of bamboo products in primary processing, seasoning, preservation, gluing and machine care and maintenance.

Other Components

In addition to bamboo promotion and capacity building, BPE has 3 other important components:

- Establishment of at least one nursery in each province which shall serve as the province's source of planting materials for its various municipalities.
- Setting up of two or more demonstration farms within each province. Such demonstration farms are expected to help increase people's interest in planting bamboo.
- Development of a bambusetum in each province that wants to have one. The purpose of the bambusetum component is to educate the general public about different species of bamboo. The bambusetum would be an object of educational trips because people would be able to learn many things about bamboo identification, propagation and uses. Many Mayors in the province of Iloilo signified their interest in putting up a bambusetum in their municipalities because they realize that this could help enhance ecotourism which would provide their municipalities additional income.

Funding scheme

BambooPhil doesn't have funds to implement the BPE program on its own. Some governors of provinces who have been approached, however, have indicated their willingness to raise the funds for specific components of BPE that they would like to implement in their respective provinces. The Governor of the province of Pampanga, for example, has secured the approval of the Provincial Board to earmark several million pesos for the implementation of the program in the province. BambooPhil anticipates that governors of other provinces would follow the Pampanga governor's example.

Multipurpose Training Lab

Because BambooPhil foresees that it will be heavily involved in training, it has started to establish a training lab in a 1-hectare piece of land owned by its president. The lab, when completed, will consist of a nursery, a small bambusetum or orchard and a processing mill.

The nursery will serve as a facility for (1) demonstrating various techniques of vegetative propagation and (2) showcasing structures, equipment, tools and supplies and materials needed for the care and management of a nursery.

The small bambusetum, which shall be made up of different species of bamboo being grown in the Philippines, will be used to train participants in bamboo identification and silvicultural practices such as weeding, fertilization, branch clearing and culm harvesting. At present, BambooPhil has more than 20 species planted in the orchard.

The purpose of the processing mill is to train participants in primary processing, seasoning, preservation, gluing and finishing, etc. Because BambooPhil is still raising funds for the mill, it is temporarily using a privately-owned mill for the purpose.

Bamboo Techno-Digest Project

The Bamboo Techno-Digest (BTD) is a quarterly publication being put up by BambooPhil as a vehicle to disseminate technologies generated by researchers in the Philippines and abroad. As the name implies, the publication would contain digests of research outputs that are usually highly technical in content and difficult for laymen to understand. Articles in the Digest shall be written in popular style so that they will be easy to read and understand.

The first issue of BTD is expected to come out at the end of the second quarter of 2009. If BambooPhil succeeds in obtaining sufficient funds, the BTD will be printed on folded 8.5 x 17-inch sheets; if it fails the initial issue shall be in electronic form.

“Adopt-A-Bamboo” Project (ABP)

BambooPhil recently came up with a strategy that will lead to the establishment of bamboo groves in different municipalities with the support of people and organizations who wish to help improve the environment in the countryside. The strategy involves soliciting financial contributions from individuals, commercial establishments and NGOs to support the planting of bamboo in different localities. For every donation of 100 pesos (or US2.00), BambooPhil shall plant 1 propagule in the name of the donor in designated areas for planting.

To make sure that the idea will work, BambooPhil members have been going around talking to municipal mayors to designate specific areas in their respective municipalities that can be used for planting. One mayor has responded very enthusiastically to the ABP and has in fact verbally committed a 10-hectare area in his municipality for the project.

Other Noteworthy Projects of BambooPhil

In-House Newsletter

Called BambooPhil UPDATE, the newsletter which comes out on a quarterly basis is BamboPhil’s way of keeping its members informed about what’s happening at the network headquarters and what its Board and Officers are doing. The 4-page newsletter written in PDF format is sent out to all members by email.

Coffee Table Book on Philippine Bamboos

This project is still waiting for somebody to fund. The idea is to prepare a pictorial cyclopedia of Philippine bamboos, highlighting their botanical characteristics, properties and uses. The project was actually prepared in response to a call for proposals from an NGO but the NGO has not taken action on it yet.

Database Development

The design of the database has been completed and data entry began when BambooPhil received a donation of a desktop computer from a businessman who is a bamboo advocate.

Concluding Statements

Although BambooPhil is just a year old, it has succeeded in formulating projects that have aroused the interest of government officials, businessmen and environmentalists in bamboo development. Businessmen in particular, because they believe in the cause being espoused by BambooPhil, have wholeheartedly donated many kinds of equipment to the network. We’re greatly inspired by the support we’re getting and we promise we’ll continue working hard to achieve the network objectives.

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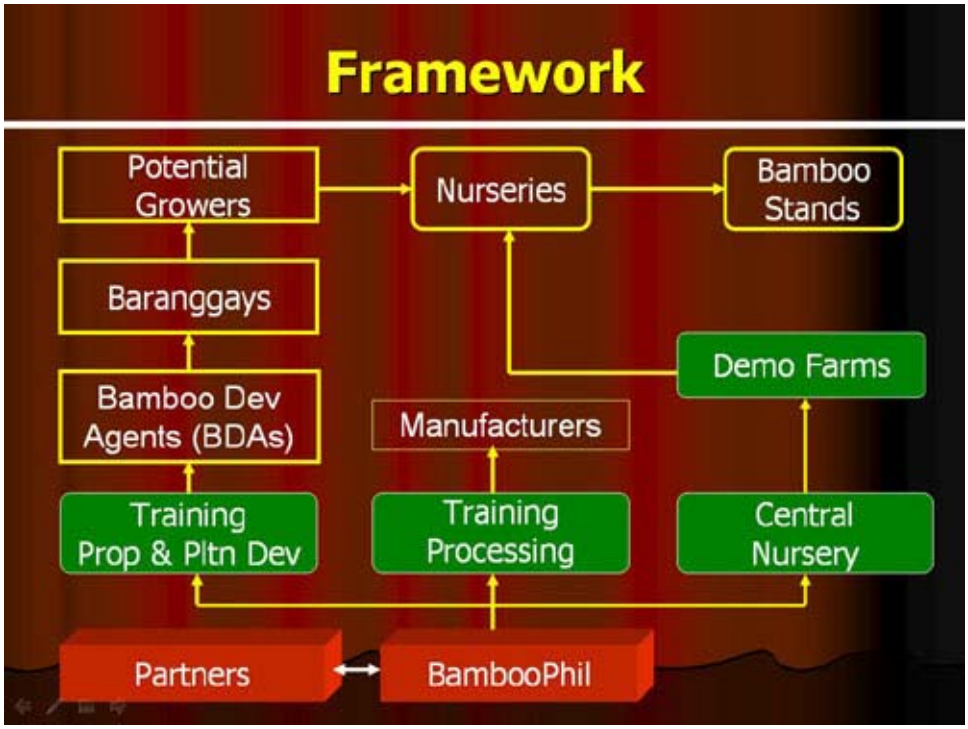
Figure 1. Conceptual framework of the BPE program.



ITC Limited
Incense Business

V.M.Rajasekharan

About ITC Ltd (www.itcpotal.com)

ITC Ltd is one of India's foremost private sector companies with a market capitalisation of nearly US $ 19 billion* and a turnover of over US $ 5.1 Billion. ITC is rated among the World's Best Big Companies, Asia's 'Fab 50' and the World's Most Reputable Companies by Forbes magazine, among India's Most Respected Companies by BusinessWorld and among India's Most Valuable Companies by Business Today. ITC ranks among India's `10 Most Valuable (Company) Brands', in a study conducted by Brand Finance and published by the Economic Times. ITC also ranks among Asia's 50 best performing companies compiled by Business Week.

ITC has a diversified presence in Cigarettes, Hotels, Paperboards & Specialty Papers, Packaging, Agri-Business, Packaged Foods & Confectionery, Information Technology, Branded Apparel, Personal Care, Stationery, Safety Matches, Incense sticks and other FMCG products. While ITC is an outstanding market leader in its traditional businesses of Cigarettes, Hotels, Paperboards, Packaging and Agri-Exports, it is rapidly gaining market share even in its nascent businesses of Packaged Foods & Confectionery, Branded Apparel, Personal Care, Incense and Stationery.

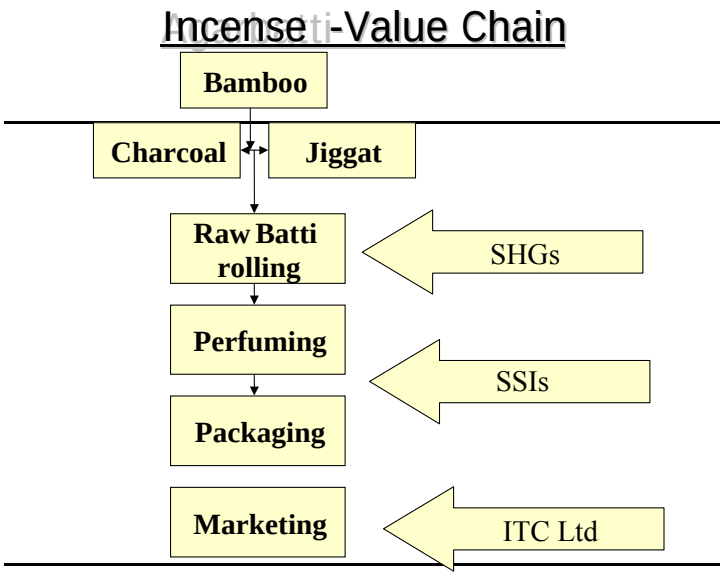
About ITC's Incense Business

Manufacturing of incense sticks is done by hand rolling Process process. The size of the industry is about Rs.1800 crore (USD 360 mn) per annum. There are various brands and labels available in the highly fragmented industry in India. Incense sticks are manufactured in several parts of India and distributed thro the wholesale channel. Brand Building activities are seldom carried out There are no BIS Standards for quality in this category.

ITC Ltd commenced marketing Mangaldeep Incense sticks in 2005 . Mangaldeep today is the second largest National Incense Brand in India, over 225 million sticks are sold every month

Periodic Brand building activities like mass media advertising , product sampling, Trade promotions are done.

Before commencing the manufacturing , the usage and attitude study along with complete analysis of best selling competitive brands was done. Post this exercise, set of specifications for Incense as well as packing was evolved by the Business. In addition to this, fragrance was selected based on Consumer Panel Tests



Mangaldeep Incense sticks are sourced currently from Ten Small Scale/Cottage vendors across the Country

In the last two years, Seven vendors out of the total Ten have received ISO 9001 – 2000 Certification. This achievement is for the first time in India.

One Vendor has also received the ISO 14001-2004 certification

The above exercise was initiated by ITC and was enthusiastically followed up by the Vendors. This initiative has helped in standardizing the systems and procedures across Vendors.

Cottage industries , Unit of Sri Aurobindo Ashram ,Pondicherry, India ,our vendor for Mangaldeep Incense sticks has been accredited with IFAT certification (Fair trade organization) .

The Business conducts quaterly quality audits across all Vendor points and presents the comparative scores to the vendors announcing the "Quality Champion". This has proved to be a good motivation point. The SBU has also introduced an in-process quality monitoring software which enables timely feedback and helps in quick corrective action.

As a part of helping the Small Scale Industries to follow the best practices in terms of safety and other statutory requirements, continuous feedback is given to the vendors.

Raw Incense (unperfumed) is a principle raw material for the process. ITC Managers impart training to NGOs and SHGs like Seva Munger, N-Logue Mayiladuthurai, etc.. They continuously supply raw Incense sticks to our vendors. This programe is called **"ASHA" (A**ssistance in **S**ocial **H**abilitation thro **A**garbattis)

The business works with the rural artisans in Andhra Pradesh and Tripura to help produce good quality bamboo sticks,which is used for Incense sticks.

MOU with EXIM Bank of India signed in 2006 to help in exports of ITC's incense sticks manufactured by Small Scale Indutries.

This Unique model of Marketing Incense sticks manufactured by Small Scale Industries has benefited the Bamboo stick and Incense producers focus on their core competencies (manufacturing) and insulating them from varying and tough market conditions .

ITC's Incense business is providing livelihood for over 8000 people in India through its association with the small scale and cottage sector

Bamboo Handicraft Industry in Kerala State of India: Problems and Prospects

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Abstract

Bamboo-based handicraft production in Kerala state of India is carried out both in the traditional and non-traditional sectors. In the traditional sector, production of mats and baskets is the major activity undertaken by traditional workers. The non-traditional sector mainly involves the production of other handicraft products which are produced by traditional and non-traditional workers. The bamboo handicraft industry in both the sectors is faced with a number of problems. Due to a variety of reasons traditional sources of supply of raw materials are declining. Institutional support for its development is inadequate. The potential of bamboo handicrafts has not been properly tapped; for instance export of some of these items to other countries and proper marketing within the country have not received adequate attention. Intermediaries still play an important role in the industry which often hinders its progress. Profitability in the manufacturing of handicraft products is very low due to a variety of reasons like low production rate and high cost of manufacturing. Technological progress is inadequate because of structural and financial constraints. The technical and financial capabilities of the new generation artisans to meet challenges in the industry in the context of globalization are limited. Unemployment and exploitation of labour in the industry are rampant. All these affect the livelihood of the bamboo workers. However, the improvement of their livelihood depends upon the development of this industry which calls for actions from government or appropriate agencies. The paper attempts to highlight some of the problems and prospects of the bamboo handicraft industry in Kerala.

Introduction

The co-existence of modern and traditional handcrafted production is one of the major features of Indian industrial scene. According to International Trade Centre (1999) handcrafted items are artisans' products which are produced by artisans, either completely by hand or with the help of tools or even by mechanical means. However, the most substantial component of the finished products is the direct manual contribution of the artisans. The special nature of artisans' products is attributable to their distinctive features which make them '*utilitarian, aesthetic, artistic, creative, culturally attached, decorative, functional, traditional, religiously and socially symbolic and significant'*. Most of the above features can be applied to bamboo handicraft production in Kerala State of India.

Kerala is wedged between the Arabian Sea and the Western Ghats. Lying between north latitudes 8°18' and 12°48' and east longitudes 74°52' and 72°22', it constitutes an area of 38863 sq. km, spreading over 14 districts

with a population of 31.83 million. Kerala is one of the major diversity centres of bamboo in the country, where bamboo is available both from forests and homesteads (Muraleedharan et al. 2008). Viewed in a historical perspective, Kerala has remained as a land of crafts and rich craft heritage. Among different crafts, bamboo based handicraft production is one of the oldest. It plays an important role in the state's economic development because of its labour intensive technology and employment potential. For instance, in Kerala, it is estimated that about 300,000 people, most of whom belonging to socially and economically weaker sections of the society, depend on bamboo for their livelihood (Nair and Muraleedharan, 1983). Interestingly, the majority of them are engaged in the handicraft production.

Bamboo-based handicraft production in Kerala is carried out both in the traditional and non-traditional sectors. In the traditional sector, production of mats and baskets is the major activity undertaken by traditional artisans/workers (*Kavaras*). Further, it largely remains a household industry. The non-traditional sector involves mainly the production of other handicraft products which are produced by traditional and non-traditional artisans/workers (members of all castes). In general the handicraft industry produces both premium as well as household utility products. One important feature of bamboo handicraft industry is that it employs a large number of people particularly women belonging to socially and economically weaker sections of the society. At present, the potential of bamboo handicraft sector is not adequately tapped because of a number of problems. The traditional sources of raw materials are dwindling due to shrinkage of forest areas and lack of cultivation of bamboo in homestead. The intermediaries play an important role in marketing and poor management makes the problem worse. The artisans lack capability to face new challenges of producing new products with new designs with low cost. The future of the handicraft industry depends on the resolution of these problems which requires policy and intuitional interventions among others. The paper attempts to delineate the major problems of bamboo handicraft industry, policy changes and the type and nature of intervention required for its development.

Methodology

The artisans of the traditional bamboo based production are workers of the Kerala State Bamboo Corporation Ltd., a government organization, which was established in 1971. Its main objectives are, to develop and promote industries based on bamboo, reed, cane and rattan, to undertake manufacture and trading of those products, and provide financial, technical, marketing or any other assistance and guidance among others. Traditional bamboo based production is largely spread over central Kerala. In order to study the problems of this sector, data were collected from 100 randomly selected households located in central Kerala.

The non-traditional bamboo handicraft sector in Kerala produces products such as table mats, bamboo curtain, flower baskets, bottle cover, furniture, notepads, among others. Survey method was used to collect data. The survey was conducted during 2005-06. There were 39 non-traditional bamboo handicraft units in Kerala and socioeconomic data covering profitability, cost of production, marketing and livelihood conditions of the workers were collected from all the units.

Bamboo Based Production in Traditional Sector

The traditional weaving community rely on their manual labour for all bamboo related activities. The traditional weavers have their own products such as *Kotta* (basket), *Muram (*Sifts*) and Panambu* (large mats), among others. Production is a time consuming laborious activity needing a lot of physical strength. Production is also a seasonal activity in the rural areas when there is a high seasonal demand for bamboo baskets and the like (mats, baskets). But due to the high cost of production and low price of the products the community remains backward and underpaid even during the peak period. The marketing condition of the workers of Bamboo Corporation is slightly better as they are able to sell their products to the Corporation. In the case of other workers in the traditional sector, once the products are ready they are usually stacked up for sale. These finished products cater to only local demand and are carried by head loads to distant markets (local) or to individual households for sale. A market analysis of the bamboo products highlights that the opportunity cost is greater than the earned benefit and the community is underpaid even during the peak period of sales (Table 1).

Table 1. Opportunity cost / forgone benefit of bamboo workers

Production stages	Earned benefit	Required labour days	Foregone benefit (in Rs.)
Collection	2-3 poles (30-35 slices)	5.5	275
Processing	390-396 slivers	12	600
Production	40 small baskets	4	200
Marketing	40 small baskets	1	50
Total	Rs. 736	22.5	1125

Primary data estimates

Size and Ownership Pattern of Units in Non-traditional Sector

According to National Council of Applied Economic Research Surveys (NCAER) (1999; 2002), average number of artisans per production unit (average size of unit) was 2.37 in the rattan and bamboo sector. However, our survey indicated the average number to be 5 in bamboo handicraft units, excluding trainees and other part-time workers (the low size of the unit in NCAER surveys is due to the inclusion of rattan units as they generally fewer workers compared to bamboo units). If we include the latter categories of workers also, the average size of unit in handicraft sector increases to 15.65 (since many units employed trainees who constituted cheap labour, a means of increasing profit). About 80 per cent of the units were owned by individual proprietors and the rest were partnership units.

About 80 per cent units had their own land and building. A few units had machinery also. Fixed and working capital, two constituents of productive capital, employed per unit amounted to Rs 200,000 and 75,000 (1 USD = Rs. 45) respectively. The stock of raw material was found to be very low, amounting to Rs. 20,000. Cost of land accounted for 60 per cent of the fixed capital and building and machinery shared the rest. It was reported that borrowing both from the organized and unorganized sectors, was the major source of investment, accounting for 65 per cent of the productive capital. The investment-employment ratio was estimated as Rs 17,187, indicating that with low investment, this sector could generate more employment.

Profitability of Selected Bamboo Handicraft Items

The non-traditional sector produced a number of products at varying quantity based on demand and marketability. The profitability of four handicraft items, *viz*., bamboo curtain, table mat, lamp shade and oval basket is given in Table 2.

Table 2. Estimation of cost of production of selected handicraft products

	Bamboo curtain		*Table mat*		*Lamp shade*		*Oval basket*	
	Amount (Rs)	Total	Amount (Rs)	Total	Amount (Rs)	Total	Amount (Rs)	Total
	Per sq.ft	Amount (Rs)	Per sq.ft	Amount (Rs)	Per unit	Amount (Rs)	Per unit	Amount (Rs)
Direct cost								
Raw material (bamboo)	11.00 (36.70)	82500.00	3.00 (56.60)	52500.00	15.00 (18.75)	1500.00	5.00 (18.52)	2000.00
Chemicals	1.00 (3.34)	7500.00	0.25 (4.72)	4375.00	2.00 (2.50)	200.00	2.00 (7.40)	800.00
Dyes	2.16 (7.20)	16200.00	0.50 (9.43)	8750.00	3.00 (3.75)	300.00	0.00 (0.00)	0.00
Wages	13.00 (43.38)	97500.00	1.30 (24.53)	22750.00	50.00 (62.50)	5000.00	18.00 (66.68)	7200.00
Direct consumables used in the production process	2.50 (8.34)	18750.00	0.25 (4.72)	4375.00	10.00 (12.50)	1000.00	2.00 (7.40)	800.00
Rentals	0.23 (0.77)	1725	0	0	0			
Indirect costs (allocated costs)								
Utilities (electricity, water, etc.)	0.08 (0.27)	600	0	0	0	0	0	0
Cost of production	29.97 (100)	224775.00	5.3 (100)	92750.00	80.00 (100)	8000.00	27.00 (100)	10800.00
Gross profit margin	5.03	37725.00	1.70	29750.00	10.00	1000.00	3.00	1200.00
Selling cost	35.00	262500.00	7.00	122500.00	90.00	9000.00	30.00	12000.00

USD1=Rs. 45

Values in parentheses are percentages

The cost of production of 0.09 m^2 (1 ft^2) of bamboo curtain worked out to be Rs. 30 and selling price was Rs. 35. In the case of table mat, lamp shade and oval basket, the cost of production per unit worked out to Rs.5.3, Rs. 80 and Rs.27 and the selling prices to Rs. 7, Rs. 90 and Rs.30 respectively. This indicates that production of handicraft items is profitable and the profit varies from product to product; for instance, the profit margin of bamboo curtain is 14 per cent, table mat 24 per cent, lamp shade 11 per cent and oval basket 10 per cent. Among the four items, table mat earned more profit mainly because the production units got orders both from within and outside the State. On the contrary, the bamboo curtain was less profitable as most of the production units were located along the National Highway and thus faced severe competition. Further, wages paid in the production of curtain were also very high; on an average, a worker got Rs.325 per day and 15-20 days work per month (Table 2). There was only limited demand for lamp shade and oval basket that restricted earning higher profit.

The raw material cost and wages are the two major items of cost, accounting for 80 per cent. It was reported that there had been cost escalation during the last five years in the sector, accounting for 60 per cent. But the selling price increased by only 35 per cent during this period, resulting in low surplus generation. Further, payment of interest on borrowed capital also made the investment in this sector less attractive.

Cost and Value Addition Ratios

The value addition (value of production-cost of materials), cost ratio (cost of production as per cent of value of production) and value addition ratio (value added as per cent of value of production) for the handicraft sector are worked out (Table 3). The cost and value addition ratios of bamboo handicraft amounted to 84 and 16 per cent respectively. The cost ratio worked out for the handicraft sector was found to be very high probably due to higher paid-out cost for raw materials, interest, among others. Further, the value addition ratio estimated for the sector constituted only 16 per cent which is unfavourable for the growth of the industry. In other words, the value addition or surplus generation by manufacturing of bamboo handicrafts was very low in Kerala. This conclusion coincides with that of NCAER surveys carried out during 1999 and 2002 (Subrhamanian, 2004).

Table 3. Production, cost and returns of selected handicraft products

	Bamboo curtain	Table mat	Lamp shade	Oval basket
Sq.ft (0.09 m^2) produced per day	375	875	5	20
Monthly production quantity	7500	17500	100	400
Cost of production/unit	29.97	5.30	80	27
Cost of production/month	224775	92750	8000	10800
Profit margin/product	5.03	1.70	10	3
Selling rate (at the first point of sale at the production unit)	35	7	90	30
Total sales value	262500	122500	9000	12000
Gross profit	37725	29750	1000	1200
Wages earned/person/day	325	45.50	25	36
Wages earned/month/ person	6500	910	500	720

Production technology

Primitive technology developed locally was used for the production of mats. Processing involved cutting of bamboo culms into short lengths, splitting, slivering, and weaving. The traditional tools used for these processes were bill hook and knives. In the handicraft sector also, the production was mostly labour intensive using primitive technology. There are several reasons for poor development of technology in this sector; the most important being scarcity of capital as this is carried out by socially and economically weaker sectors in the society.

Since the mid-1990's, some bamboo handicraft units in the State have started using modern technology such as circular saw, planer, sanding machine, drilling machine, hacksaw, knife, hand drill and file. Handicrafts, over the last few years, have transformed their utility from mere decorative items to articles of daily use. It is thus the primary need of any seller to constantly update, develop and add his product profile (Anonymous, 2006). One of the problems in the production of bamboo products in Kerala is the lack of quality and homogeneity due to low mechanization. Keeping this in view, the Industrial Design Centre of Indian Institute of Technology, Bombay designed about 30 tools, aiming to produce 'new generation craft products' which could compete with plastic products (IDC, 2001). There is potential to use more machines in bamboo handicraft units to produce new generation products to meet the growing demand of modern societies.

One of the arguments against mechanization is that it is not acceptable from an employment point of view as this industry is considered as an avenue for providing employment in labour surplus economy (Jayasankar, 2004). This may be true in the case of mat and basket production in the traditional sector, but not in the case of handicraft production in the non-traditional sector. In the context of globalization, demand for products, to a

great extent, depends on their quality which can be achieved only through use of appropriate technology. This will not only reduce the cost of production but also boost up the demand and consequently, the profit.

The details on average product-wise cost of production, sale value, production time per unit, number of labour involved and tools used are presented in Table 4.

Table 4. Product range, cost of production, time, labour and tools used in a bamboo handicrafts unit

Type of product	Cost of production and sale value(in Rs)		Production time/per unit	Labour involved		Tools used
	Cost	Sales		Male	Female	
Pen	27	35	90 min		1	Knife, drill, file
Lamp shade	180	250	8-10 h		1	Knife, drill
Pen cup	6	15	25 min		1	Knife, drill, file
Puttu maker	25	40-50	30 min	1	1	Knife, drill, file
Flower vase	20	28-30	1 h		1	File, knife
Hair clip	6	10	30 min		1	File, knife
Whistle	3.50	5-10	20 min	1	1	File, knife, Hacksaw
Wall hangings	70	100	90 min	1		File, knife, Hacksaw
Note pad	80	100-120	4 h	1	1	Knife, drill, cutter
Bottles	120	180-200	8 h		1	Knife, drill, cutter
Measures	10	15-20	90 min	1	1	Knife, drill, cutter
Curtains	20	25-30	30 min (per 0.09 m^2)	1	1	Knife, file, Hand drill, cutter

It is to be noted that most of the items shown in Table 4 can be made with the help of tools/machines. In other words, there should be proper mixing of labour and appropriate technology to produce quality handicraft products. An attempt was made to compare the number of workers and profit margins in units which use modern tools as against units which use traditional technology. For instance, it is reported that units which used looms in curtain making received about 30 per cent more profit than that of non-users, mainly due to improved quality of the products. At the same time, average number of workers employed by both the units was found to be more or less the same, indicating that use of appropriate tools does not replace labour in handicraft sector.

Market Imperfection and Consumer's Surplus

The bamboo products of the bamboo artisans are yet to reach the larger markets and attract national as well global attention. The market features of these products (Box 1) made by artisans are not so encouraging and this calls for strategic initiatives for their improvement. Although bamboo is a natural, strong fibre, having aesthetic looks and the products are environment-friendly, the production rate is low and the cost of manufacturing is high. Competition with products such as plastics and other substitutes pose a severe threat. The utility of bamboo and plastic products are identical but there exists price difference between the two (Table 5).

Box 1. Market features of bamboo products of traditional bamboo artisans

- Seasonal demand
- Availability of large number of substitutes
- Small number of buyers & large number of producers
- High market price volatility among the sellers and markets
- Competitive market with buyers dominance
- Direct marketing with no advertisement
- Poor bargaining power
- Lower price elasticity of demand
- High transaction cost

Table. 5. Bamboo products and their substitutes

Market name	Plastic / Rubber		Bamboo		
	Price[1] (P_p)	Duration[2] (D_p)	Price (P_b)	Duration (D_b)	Relative price[3] (R_p)
Sift	65	2	35	1	70
Basket	40	2	35	0.5	140

[1]Price in rupees, [2]duration in years, and [3]Relative Price (R_P)=P_b [D_p / D_b]

The market price and durability of a single unit of plastic product is higher than that of a single unit of bamboo product. However, the relative price reveals that the total economic cost over bamboo product is higher than that of plastic product for the same utility. In other words, the consumer surplus in case of the plastic product is higher than that of bamboo products, thus people prefer plastic products to bamboo without considering the social and environmental cost.

The demand curve of two bamboo products and their corresponding plastic substitute products is derived from the primary data collected from the sellers and the consumers of these products. The price elasticity of bamboo basket is equal to that of plastic basket (Table 6) while for sift, the price elasticity of bamboo sift is higher than that of plastic sift. People prefer plastic to bamboo products because the consumer surplus of plastic product is higher than that of bamboo. Imposing a green tax equivalent to the difference in the consumer surplus of these

products will help to induce the substitution of environmental hazardous plastic products by the environment-friendly bamboo products to some extent. Since the price elasticity of the bamboo products is higher than one, the demand for the product is elastic in nature, thus the price is an important determinant factor in the market demand of these products. Thus, for making the sector more competitive adequate attention should be given to reduce the price and increase the quality of the products.

Table 6. Price elasticity of bamboo/plastic products

Products	*Consumer Surplus*	*Price Elasticity*
Bamboo basket	4.7	2.35
Plastic basket	5.7	2.35
Bamboo sift	3.3	2.95
Plastic sift	10	2.53

Towards an action plan

In spite of the immense opportunities and strengths, their inherent weaknesses and apparent threats do not permit adequate development of this sector. There are ample opportunities and with immense potential for product and technology diversity, and it is a good and cheaper substitute for wood. The strategy should be long-term market development process. Product-education and market development are essential to enhance the image of bamboo products as well as bringing a change in the mindset of the end-users. Technological, pricing, marketing and institutional constraints of the industry must be mitigated/minimised through some conventional actions. In addition, the implementation of the following non-conventional actions may also help to improve the condition of the industry.

i) Developing a Sustainable Livelihoods Framework for Bamboo Workers through Organization and Training

The livelihood security of the bamboo workers can be enhanced and improved through increased accessibility to raw material and market, employment opportunity, skill development and adequate sustainable institutional support. In order to ensure sustainable livelihood to bamboo workers, we have to break the diminishing circular flow of development by organizing the sector and production activities. The people may be organised through Self Help Groups (SHG), Non-Governmental Organization (NGOs), private sector and local bodies and provided wth training and credit. The training imparted should be on the use of capital-intensive techniques of production which will bring about product diversification, division of labour and large-scale production. They can then enjoy various types of economies of scale like reduced raw material cost and increased efficiency. Thereby they can expand their market beyond the local level and generate higher income.

The livelihood potential of this sector will automatically increase, leading to further improvement in the quality and the market for the products. The government should ensure training, raw materials and marketing facilities

and encourage the financial institutions to provide credit to the sector. This organizational setup can ensure an expanding circular flow of development as a result of which livelihood strategies (Table 7) will facilitate the realization of sustainable livelihood outcomes.

Table 7. Strategies for social and economic development of the bamboo workers

Short-term	Long-term
Improve social conditions (community infrastructure, human development index)	Long term market development programme (product education)
Increase income security through bamboo-based and other alternative employment opportunities	Impose Green Tax on environmentally hazardous product
Provide raw materials at low price	Publicize the long term benefits of environmentally friendly products
Provide training in the value addition process	Promote cluster development based on sustainable livelihood principles
Efficient use of available resources	Document and promote Indigenous Technology Knowledge (ITK) and identify which can be financially exploited
Life insurance of bamboo workers	Organize production & encourage division of labour
Provide market information, marketing tools & market support	R&D for improving the quality of the product
Discourage child labour	Expand market size in national and international level
Encourage savings through SHGs	
Encourage education among the children	
Promote gender-based activities like tailoring, food processing, handicrafts, etc	

ii) Environmental Tax for Ensuring Sustainability of Nature and Humanity

Plastic and its products occupy importance in the day-to-day life of the people and these products pose great threats to the sustainability of the environment. Even though we cannot reject the sector altogether, we can encourage its substitution as far as possible by environment-friendly products. As all plastic products do not have perfect substitutes, the plastic industry should devote its resources for the production of those products, which have no environment-friendly substitutes. One of the benefits offered by the bamboo sector is its environment-friendly products but the market forces do not take into consideration this benefit in fixing the price. The relative difference in the market scenario of the two products highlights the high environment cost on the part of the plastic product. The market forces determine the price only by taking into account the private cost and benefit and not the social cost. The proposed green tax is a tax proposed to be imposed on the environmentally hazardous products for reducing their unnecessary consumption and encouraging the use of environment-friendly products. In order to encourage the substitution the governmental intervention may impose a tax on the plastic products equivalent to the total consumer surplus gained by these consumers. In other words, let the plastic consumers pay the maximum what they are actually willing to pay.

Conclusion

The bamboo handicraft industry of the State has immense economic potential. The investment in this sector is less attractive due to its small size, low surplus generation, cost escalation, low technological development, and payment of interest on borrowed capital. With these inherent weaknesses, this sector still supports a good fraction of the rural economy. Mechanisation will reduce the cost of production and improve the quality of the products, leading to boosting up the demand and consequently the profit. The livelihood security of the bamboo workers can be enhanced and improved through increased accessibility to raw material and market, employment opportunity, skill development and adequate sustainable institutional support.

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Scouting, Documentation and Standardization of use of Bamboo in Livestock and Poultry with Special Reference to Northeast India

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Abstract

People of NE India are using bamboo in their day to day life traditionally since time immemorial. Small holder livestock and poultry farmers use bamboo in husbandry practice extensively to reduce cost on fixed expenditure on their farm operations. It has also stimulated innovative use of bamboo in livestock and poultry husbandry in different rural areas. Many rural innovations on bamboo use in husbandry practice vanish with time due to lack of organized effort to document and promote such innovations. There also exists a gap in information and technology updates amongst the rural people on the use of bamboo in livestock farming. The paper explains in detail the process undertaken in a project in this regard.

Varied use of bamboo in Northeast India, grass root innovations, challenges on durability, cost benefit, acceptability, adoption of modern technology in rural set up, skill up gradation, and scopes for alternative bamboo enterprise development etc are recorded through scouting in different parts of the region. A list of feasible ideas was prepared through a number of consultations and e-discussion. A total of six selected prototypes were developed through Participatory Technology Development where farmers, bamboo craftsmen, grass root innovator, design experts, market intermediaries, experts in livestock and poultry husbandry participated.

Final designs of selected items, standardization of developed designs, entrepreneurship development, cluster development, creation of wider market of the developed products are the ways to be explored under the project. The whole process prospects for new ideas continuously and the steps are linked and dependent on each other.

It is envisioned that enhanced use of bamboo items shall augment small holder livestock and poultry farming. This will also create alternative bamboo enterprise amongst the rural masses. Wider market of bamboo made animal husbandry items will encourage more bamboo plantations by farmers and craftsmen for environment friendly growth.

Introduction

Bamboo is used traditionally in many countries in construction of houses, household appliances, storage structures, livestock and poultry sheds and in various other forms in rural areas, since time immemorial. There is ample scope to popularize bamboo use in smallholder livestock / poultry farming, as these are locally available, durable and economical. Use of bamboo will not only reduce fixed capital cost but also permit smallholder farmers to expand / reduce the farm size / shift operations with limited investment. Use of modular bamboo items in husbandry practice will make small scale commercial farming e.g. layer farming with improved bird possible for both urban and rural poor, thus enhancing livelihood opportunity and quality nutrition. The designs, durability, mass production and market appeal of bamboo structures and items can also be improved to a great extent with modern scientific treatment, use of equipments and processing.

A model project was initiated in the later part of the year 2008 covering few North Eastern states of India for continuous scouting, documentation and standardization of innovative uses of bamboo in smallholder livestock and poultry farming.

Project conceptualization

The initial conceptualization of the project was made during a regular field visit of FARMER team to an egg production cluster in Assam (India). The trip report of the visit, clubbed with desktop research and in- house consultation was the basis for finalization of the following objectives of the project.

A. To scout and document use of bamboo in livestock and poultry farming in N.E. India.
B. To standardize selected developed items in the context of animal husbandry practices.
C. To augment enterprise / cluster development.

Linking with three broad segments of a typical technological innovation system[1], the entire project is divided into three major steps viz. Birth Phase, Survival phase and Growth phase (figure 1). A number of sub steps are undertaken under each major step towards achievement of the ultimate objectives of the project. These steps are interlinked, open for new ideas and continuous.

[1] Gupta Ashwini, Dutta P K Indian Innovation System – Perspective and Challenges : Technology Exports Vol-VII No.4 , April-June (2005) URL: http://www.dsir.gov.in/pubs/te/te200502.pdf

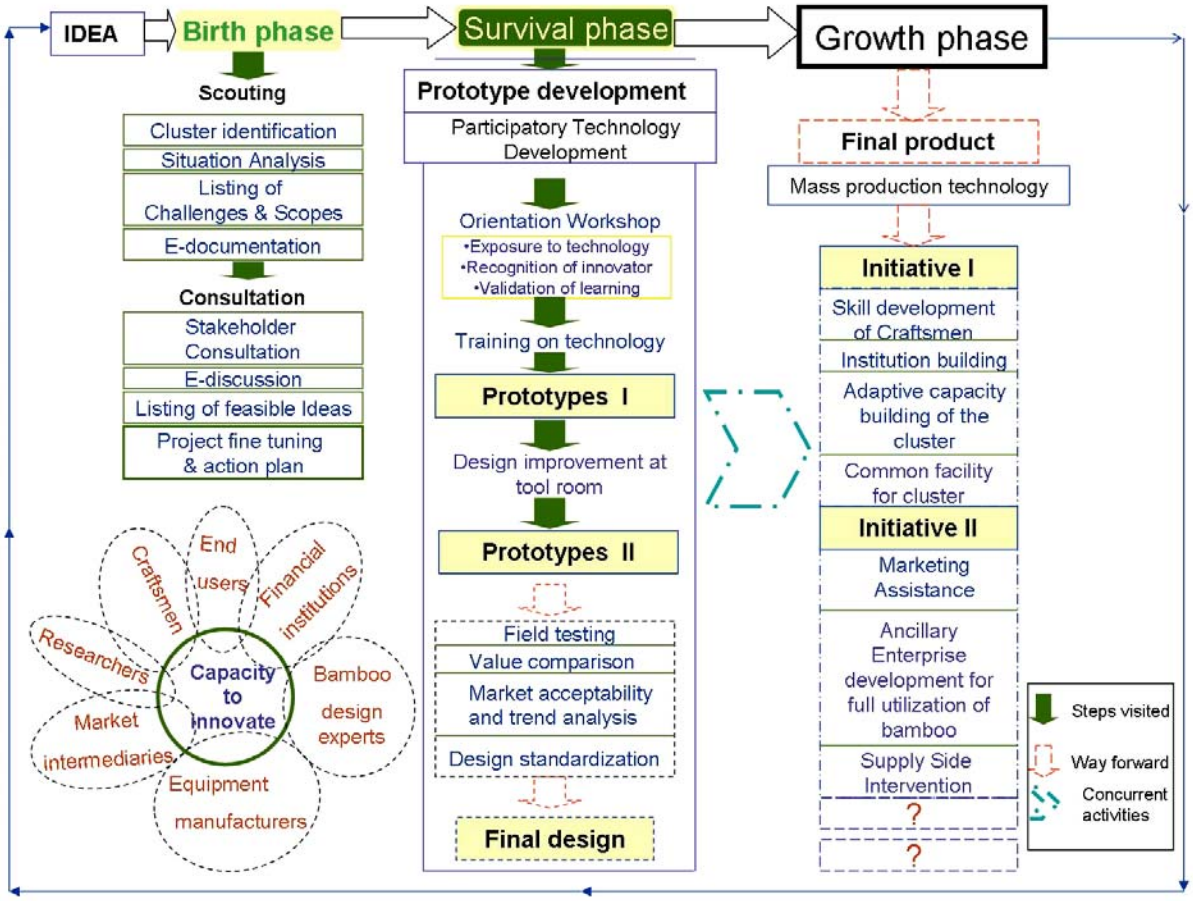

Figure 1: Project process flow diagram developed in-house during the inception meeting and updated at regular interval incorporating critical learning.

During the project conceptualization, much importance was also accorded to sincere approaches related to participatory learning on challenges and scopes, Participatory Technology Development process and enhanced interaction amongst different stakeholders. This approach was in-built in the project so that same can strengthen innovation and adaptive capabilities of identified clusters.

The Birth Phase

Scouting

Cluster identification:

As decided during project inception discussion, two clusters were identified in the state of Assam, North east India viz.

(1) Small holder layer / broiler farming cluster in a place called Golaghat and

(2) Day-old-Chick carrying bamboo basket making cluster at a place called Bezera.

Situation analysis: To record different use of bamboo, extent of use, processes adopted, uniqueness of grass root innovation, technology adoption etc. a situational study was undertaken under the project using participatory technique. The study covered a total of 50 numbers of livestock and poultry farmers, five grass root level innovators and more than 20 bamboo craftsmen. Number of innovative uses of bamboo was recorded during the situation analysis. Most prominent amongst them were bamboo layer cage (figure 2) for layer farming and raised bamboo floor (figure 3) for broiler bird rearing. Current challenges faced by users and scope for further improvement was identified during the situational analysis process.

Figure 2: Bamboo layer

Figure 3: Raised bamboo floor for rearing broiler chicken

Major challenges identified from the point of view of farmers in use of bamboo made items are (1) Convenience – for use by the livestock and poultry farmers, for example easy cleaning and handling, meeting the standard husbandry norms etc. (2) Availability – on the nearest accessible source and / or cheapest source. (3) Cost – on purchase or cost- benefit. (4) Durability – in comparison to items made of other materials like plastic, etc. Other challenges were technology adoption in local context, skill up-gradation of local bamboo craftsmen and to identify cluster where prototypes could be developed.

Consultation

A number of brainstorming sessions with different stakeholders including an e-discussion at UNSE-FNS community (http://www.solutionexchange-un.net.in/en/Food-&-Nutirion-Security/introduction.html) were organized to list out feasible ideas for improvement and to up scale the grass root level innovation. The e-discussion conducted highlighted other uses of bamboo e.g. as fodder besides number of challenges including that of the challenge of cleaning and disinfection of bamboo structures. Subsequently an action plan was drawn to further proceed towards remaining steps of the project.

The Survival phase: Prototype Development – Participatory Technology Development

Orientation workshop:

One cluster at Golaghat district of Assam was selected for first prototype (Prototype-I) development. Exposure to modern bamboo technology, validation of learning of situational analysis and consultation and introduction of grass root innovator was done in the orientation workshop. Grass root innovators shared ideas and processes undertaken during development of design with the participants. Grass root innovators, bamboo design experts, experts in animal husbandry practices and farmers interacted to evolve solutions in designing and adapting the bamboo items in husbandry practice (figure 4 and 5).

Fig 4: Innovator explaining his innovation

Fig 5: Design expert explaining the designs

Training on technology:

Hands on training on technology on bamboo treatment, joinery methods, use of tools was given to the participants (figure 6) and they could develop few selected prototypes using the knowledge gained.

Figure 6: Hands on training to the participants

After completion of the process of prototype-I development number of new challenges, like use of appropriate method for joineries, making the modular prototypes, treatment methods, use of right type of bamboo, requirement of skill up gradation, etc. emerged.

After completion of prototype-I, list of designs were selected for prototype-II development that were not included in the process of prototype-I development. These were

1. Layer cage
2. Brooder
3. Chick guard
4. Egg laying nest
5. Live bird carrying cage
6. Modular bamboo net for side walls of livestock and poultry shed.
7. Table egg carrying basket
8. Egg collecting basket
9. Egg carrying tray

Amongst these, prototypes of Layer cage, Bamboo brooder, chick guard, egg laying nest, live bird carrying cage and modular bamboo net were developed at cluster-II at Bezera, Kamrup District (fig 7).

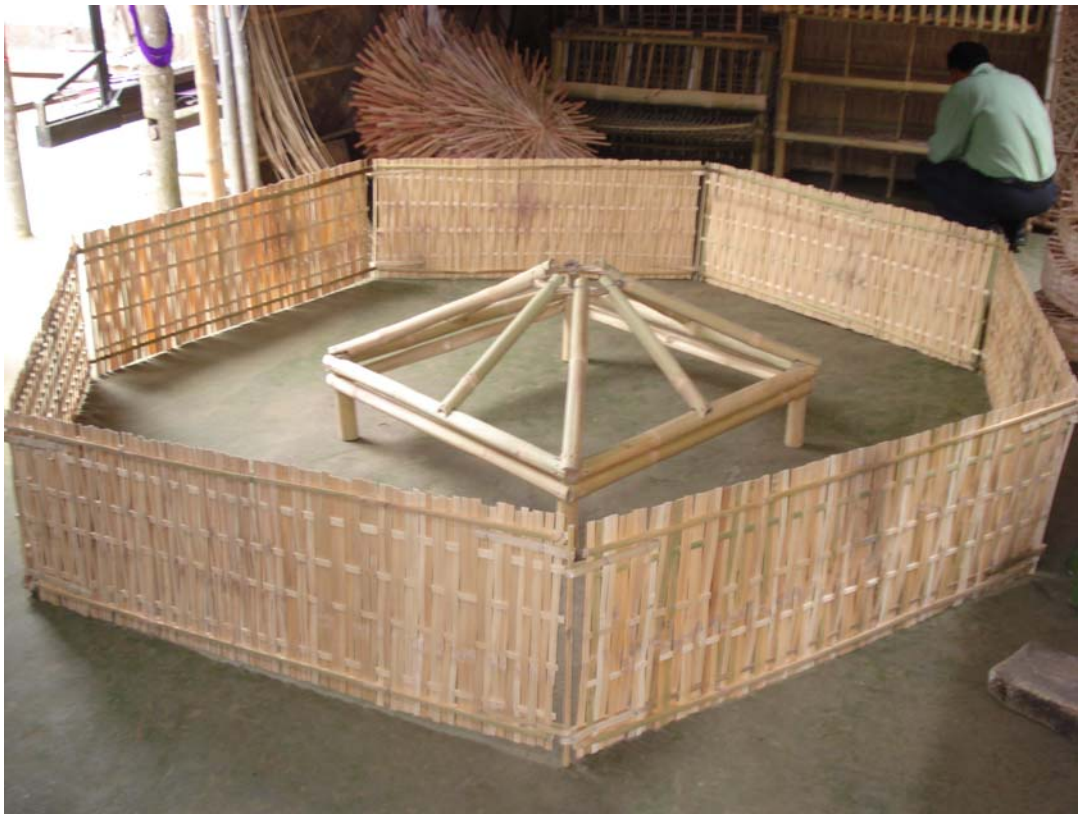

Figure 7: Developed prototypes at cluster –II

After completion of the prototype development a number of product wise challenges are identified which are to be addressed during development of the final designs at Cane and Bamboo Technology Center (CBTC), Guwahati tool room.

Meanwhile during the process of prototype development skill up-gradation need of the craftsmen, need of institution building, adaptive capacity building of the cluster and listing of infrastructure / input requirement for adaptive capacity of the cluster are initiated (figure 8). Dialogue with the clusters for institution building has also been initiated and few craftsmen are already selected for handhold training at the workshop of Cane and Bamboo Technology Centre (CBTC), Guwahati. It is also proposed to develop final design at the workshop of CBTC with participation of the innovators and craftsmen involved in the process. After skill up-gradation of selected participants, attempts will be undertaken to provide common facility for the cluster.

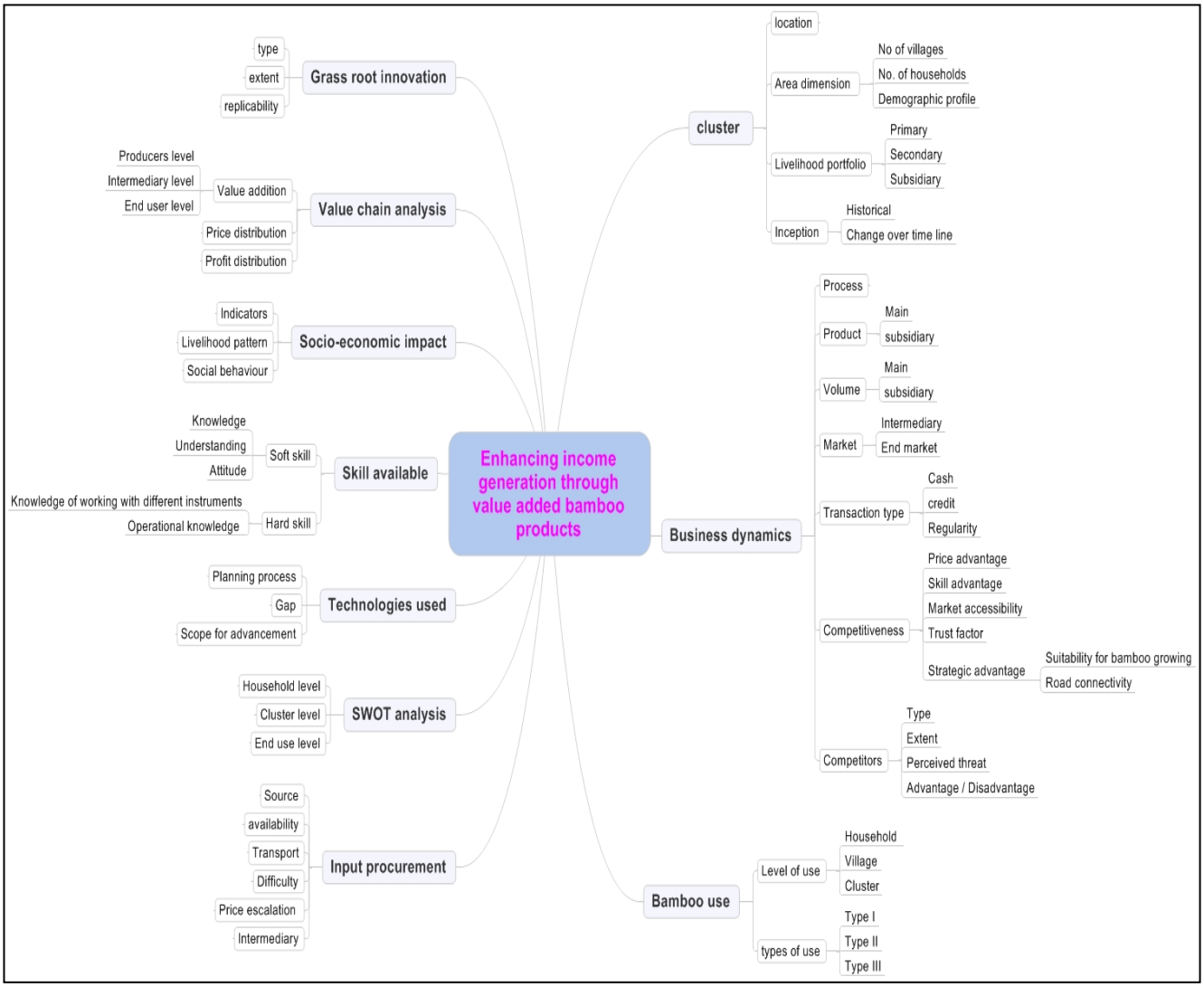

Figure 8. Plan map for cluster analysis developed by the project team.

Way forward under the survival phase

Field testing:

After development of the final design, field testing will be conducted on parameters of husbandry practices, suitability and acceptability etc.

Value comparison:

Value comparison of the developed design with that of conventional types shall be done in different levels where equipment manufacturers and large commercial farm holders will be involved.

Market acceptability and trend analysis:

Acceptability of the developed designs in the market and changing market scenario shall be examined and re modeling of the prototypes and plans shall be undertaken continuously.

Standardization

Based on the input of the above steps, design standardization shall be done to make it ready for mass production and commercialization.

Growth phase: Final product – Mass production technology:

After standardization of the products number of initiatives shall be undertaken for commercialization of the products. These initiatives include skill up-gradation of craftsmen, institution building in the cluster, adaptive capacity building of the cluster and providing common facility for the cluster.

Upon successful completion of these initiatives, marketing assistance to the cluster, ancillary enterprise development for full utilization of bamboo and supply side intervention to ensure uninterrupted supply of bamboo in the cluster shall be undertaken under Initiative-II.

Conclusion

The project is augmenting economic and community development within two identified clusters primarily by building capacity of the beneficiaries to face challenges listed below.

For Cluster-I Parts of Golaghat & Sibsagar District of Assam

Key Challenge that is being addressed:

- Effective Management of small scale layer farms raising genetically improved birds
  ----- Cage Vis a Vis Deep litter Method of rearing.
- Absence of appropriate farm equipment suppliers tailored to need of small layer / broiler farming units.
- Low Cash flow and market risk related challenges limiting investment on fixed assets.

For Cluster-II Village: Singimari, Bejera, Kamrup District Assam

Key Challenge that is being addressed:

- Quality improvement & Product line diversification for:
  ----Addressing competition from printed paper boxes for carrying day-old-chick.
  -----Full utilization of bamboo
  -- --Risk mitigation and increased revenue
- Capacity to handle large demand (enhancing capacity for design, quality improvement and technology adoption for mass production)

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Consolidated reply of e-discussion on 'Bamboo Usage in Livestock and Poultry – Experiences; referrals' at FAO UNSE- Food and Nutrition Security Community http://www.solutionexchange-un.net.in/food/cr/cr-se-food-15010901.pdf

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Experience with Livelihood Development Projects – A Case Study of Chhattisgarh, India

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Abstract

Bamboos are one of the versatile plant groups, offering great opportunities for meeting livelihood need of the people and increasing rural incomes. Bamboo artisans are very poor. The paper elucidates the potential of value addition of Bamboo in ensuring sustained employment and in providing an additional income. The paper also dwells upon the skill upgradation use of machines, preparation and marketing of quality value added Bamboo articles. More than fifty percent of the artisans are women and the additional income is used for welfare of family. With further training skill upgradation and marketing the increased income shall be used for providing better education, health care resulting in improved life style.

Bamboo is an enduring, versatile and highly renewable resource in the Indian socio-economic-cultural-ecological-climatic-functional context with 1,500 recorded uses. It has been estimated that in the world market of bamboo, the combined value of internal and commercial consumption of bamboo is to the tune of US $ 10 billion. The total revenue from bamboo and bamboo based products is estimated as Rs. 25,000 crores. Of this bamboo shoot accounts for Rs. 7,500 crores while other bamboo based products account for Rs. 17,500 crores (Anon, 2003)

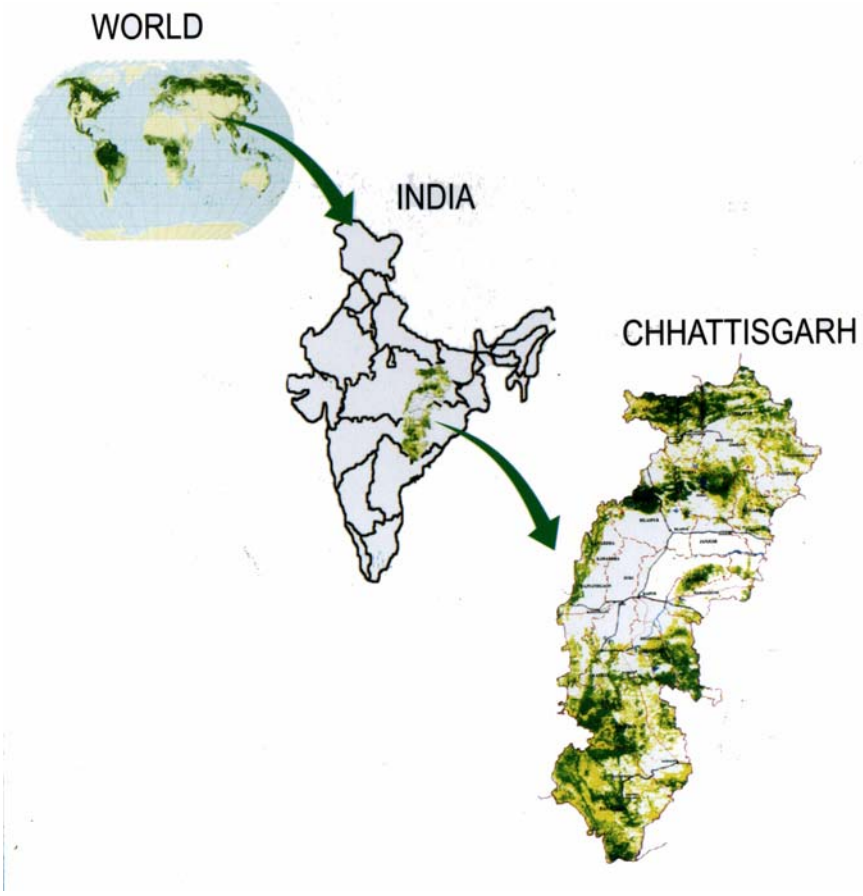
Bamboo as a natural resource offers great opportunities for meeting livelihood needs of our people, increasing rural incomes and for development of eco-friendly technology.It also has religious sanctity because of its use in various customs.. Value addition of Bamboo in Bamboo processing centres can be a effective tool in poverty reduction and providing additional income to bamboo artisans in remote areas of Chhattisgarh.

Introduction

The State of Chhattisgarh came into existence on 1st November, 2000 by separation of 16 (now 18) Districts of Chhattisgarh region from Madhya Pradesh. Chhattisgarh is situated between 170 46' N to 240 6' latitude and 800 15' E to 840 51' E longitude in Central Eastern part of India. The total geographical area of the State is 136.03 thousand sq. km and it is larger than 16 other Indian States.

Demographic Characteristics:

Total population of the State is about 20.79 million with 16.62 million people residing in rural area constituting more than 75% of the total population. The Scheduled Castes and Scheduled Tribe population constitutes more than 45% population of the State.

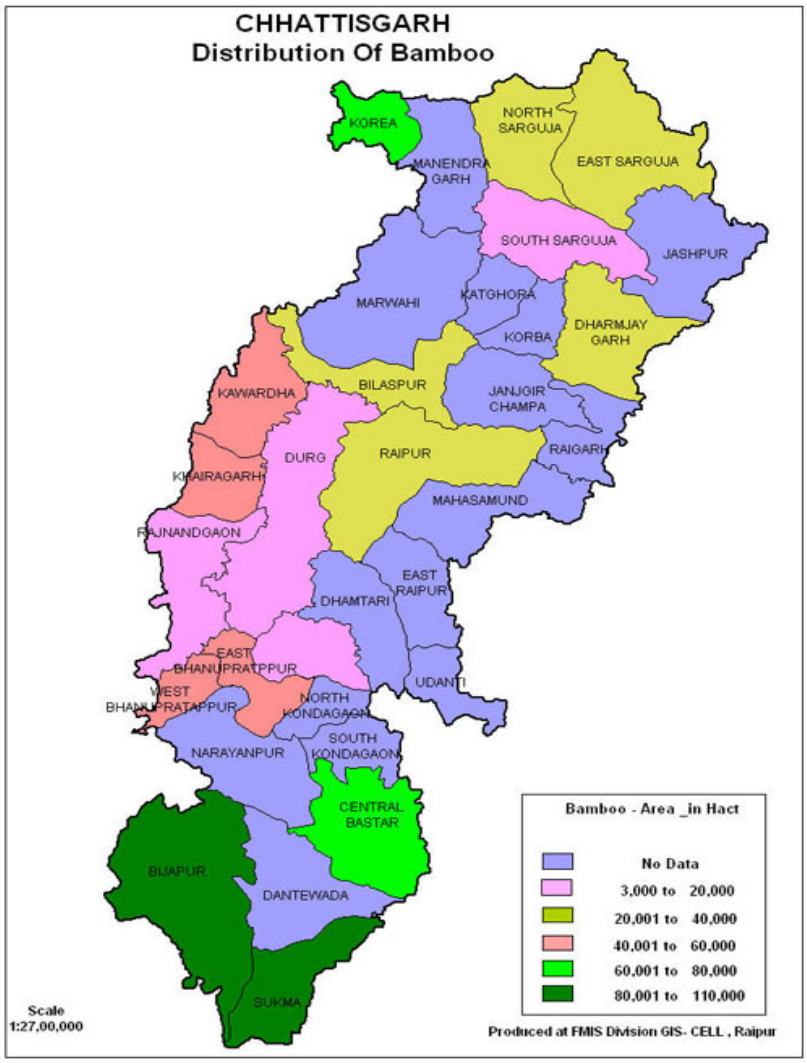


Bamboo Forests

In Chhattisgarh, Dendrocalamus strictus is the major species. Bamboos are found in Kanker, Jagdalpur, Raipur, Mahasamund, Dantewara, Bilaspur, Korba, Raigarh, Surguja, Koriya, Durg, Rajnandgaon and Kawardha Districts. In Bastar two species of Dendrocalamus (D. Strictus and D. longisphathus) are found naturally. In some areas of Bastar Oxytenanthera nigrocialata (Pani Bans), Cephalostachyum pergracile (balan Bans), Bambusa arundianacea (Kanta Bans) and Bambusa tulda area also found. The villagers, especially in Bastar and other areas have planted Bambusa vulgaris (Sunder Konya) and Bambusa polymorpha (Barha Bans) in their homestead and on field bunds. According to the available estimates, the area under Bamboo forests it about 6.56 lakh hectare. About 40% of this area is under Rehabilitation of Degraded Bamboo Forest Working Circle.

"Basods" And Rural Artisans

The Bamboo artisans, commonly known as "Basods" and "Kamars" have been recognized as a separate caste in the State and have been included in the list of scheduled castes. They prepare various Bamboo articles such as Dala, Soopa, Dalia, Jhal, Chick, Chatia (Local names) from Bamboo, and sell them in local markets in various parts of the State. Some of them also produce fancy items like lamp shades, furniture, wall panels etc. Thus the economic well being of the Basods is entirely dependent upon the availability of Bamboo. Besides Basods. Other primitive tribal groups like Birhor, Pahari Korva, Baiga, Pando, Kamars are also traditionally engaged in Bamboo crafts. Their socioeconomic condition is very poor. To improve their socioeconomic condition and provide sustained employment Bamboo Processing Centres are being established in the State.



Methodology

Bamboo forest of Chhattisgarh are located mostly in the southern part. Cluster based approach has been adopted for the establishment of Bamboo Processing Centres (BPC). These clusters are as under :-

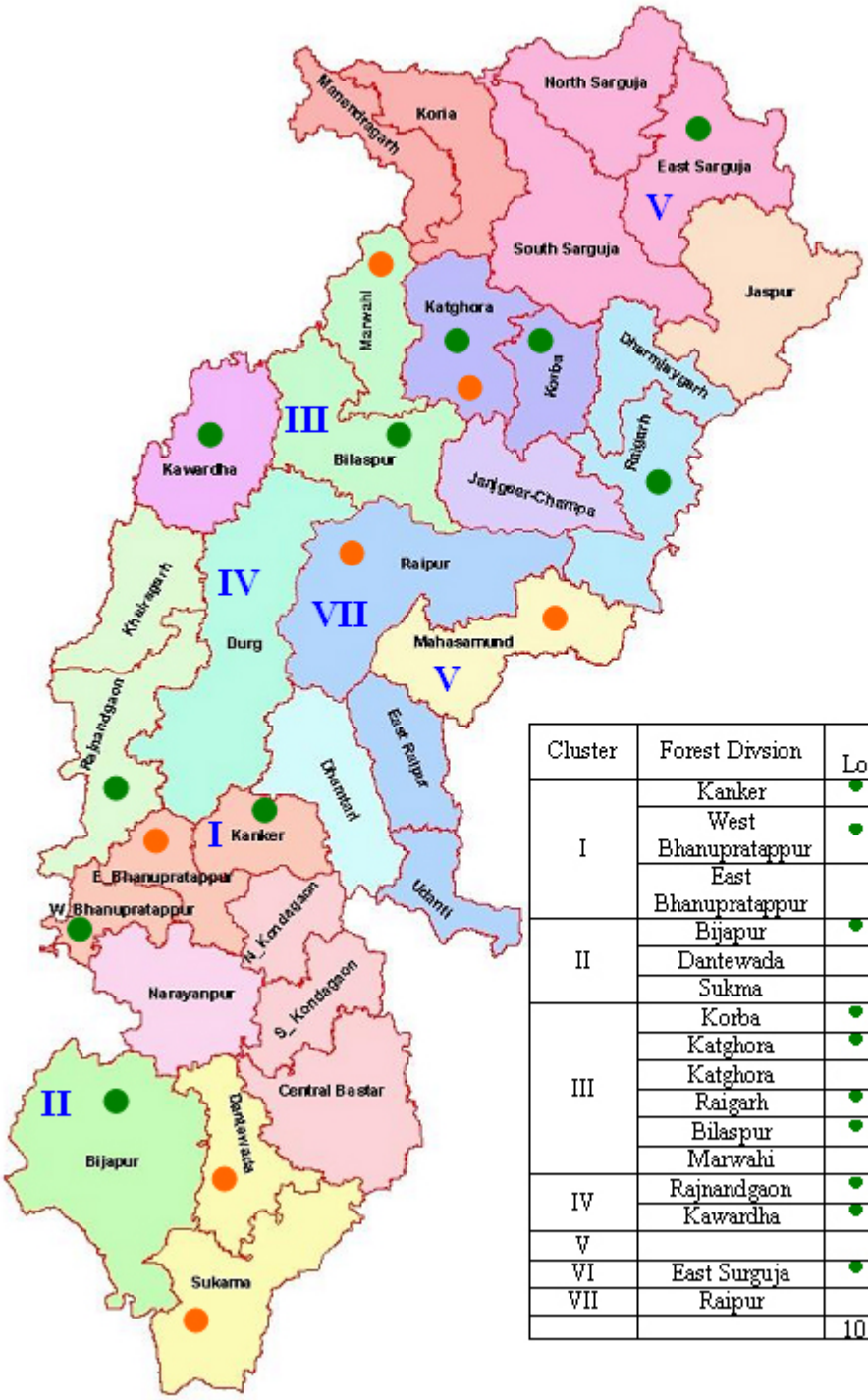
Cluster	District	Forest Division	S. No.	BPC Location Existing	S. No.	Under Establishment	Number of Beneficiaries
	1	2	3		4		5
I	Kanker	Kanker	1	Charama			20
	-"-	West Bhanupratappur	2	Bande			15
	-"-	East Bhanupratappur			1	Antagarh	
II	Bijapur	Bijapur	3	Bijapur			42
	Dantewada	Dantewada			2	Kasoli	
	-"-	Sukma			3	Dornapal	
III	Korba	Korba	4	Nonbirra			50
	-"-	Katghora	5	Donganala			67
	-"-	Katghora			4	Iraf	
	Raigarh	Raigarh	6	Kosamnara			50
	Bilaspur	Bilaspur	7	Ratanpur			20
	-"-	Marwahi			5	Danikundi	
IV	Rajnandgaon	Rajnandgaon	8	Dongargaon			22
	Kawardha	Kawardha	9	Lalpur			13
V	Mahasamund				6	Bagbahara	
VI	Surguja	East Surguja	10	Aamgaon			25
VII	Raipur	Raipur			7	Amuruba	
	Total		10		7		329

The methodology involves the following steps -

(i) Establishment of self help groups (SHGS). Bamboo artisans have formed SHG'S consisting of 10-12 members. These members work together as a team in BPC'S. More than 50% of the members are women.

(ii) Training - Traditionally these artisans were preparing local bamboo articles like Jhaua, Tokna, Supa, Broom and other articles. For preparation of value added Bamboo furniture and other decorative articles the .expertise of skilled artisans from Narayanpur centre under Industries Department and Tripura Bamboo Mission are utilized Local artisans have been trained for varying duration from two to six months. This has improved their skills and the journey con tines.

Location of BPC in Chhattisgarh State



Cluster	Forest Divsion	BPC Location Existing		Under Establishment	
I	Kanker	●	Charama		
	West Bhanupratappur	●	Bande		
	East Bhanupratappur			●	Antagarh
II	Bijapur	●	Bijapur		
	Dantewada			●	Kasoli
	Sukma			●	Dornapal
III	Korba	●	Nonbirra		
	Katghora	●	Donganala		
	Katghora			●	Iraf
	Raigarh	●	Kosamnara		
	Bilaspur	●	Ratanpur		
	Marwahi			●	Danikundi
IV	Rajnandgaon	●	Dongargaon		
	Kawardha	●	Lalpur		
V				●	Bagbahara
VI	East Surguja	●	Aamgaon		
VII	Raipur			●	Amuruba
		10		7	

(iii) Establishment of machines - following machines have been set up at the BPC'S. Crosscut, Auto splitter, Bamboo Slicing and inside knot remover, Bamboo polishing, Bamboo square stick, outer knot removal. Some other machines have been set up in a few BPC'S. The artisans were given a hands on training in the use of these machines.

SHG member Bande using machine

(iv) Operation of the BPC'S - SHG'S work as a team and produce Bamboo articles. For purchase of material like fevicol, Varnish, nails, etc Rolling fund of about Rs. 20 to 50,000 has been deposited in each BPC. On request from the SHG'S the Range officer takes consent of the Divisional Forest Officer and with draws the amount from the bank and gives an advance to SHG'S. SHG'S get the amount for the articles prepared by them as per price fixed. Marketing of these products is done by a separate SHG. The advance taken for purchase of the material is re-deposited in the rolling fund.

(v) Participation in Fairs:- Six Bamboo artisans from the State participated in National Malabar Craft Mela held at Mallapuram, Kerala from 16.12.2008 to 30.12.2008. The Bamboo articles prepared by them were appreciated very much and Chhattisgarh State was awarded the second prize.

(vi) Marketing - Value added Bamboo articles have been prepared and marketed in various BPC'S. The details are as under -

						(Amount in lakh)
Name of BPC		Bamboo Articles prepared	Marketed	Balance	Articles	Duration
1.	Bijapur	.70	.42	.26	Book rack, T.V. Stand, Stool	30.09.08
2.	Charama (Kanker)	.10	.05	.05	Stool, Easy chair	From Jan. to April, 09
3.	Bande (West Bhanupratappur	.75	.45	.30	Sofa set, Tea table, Stool, Decorative article	Feb. to April, 09
4.	Nonbirra (Korba)	2.50	1.6	.90	Easy chair, Stool, corner rack, Sofa set	2007
5.	Kosamnara (Raigarh)	2.54	1.74	.80	Sofa set, Centre table, Decorative articles	April 2008
6.	Dongargaon (Rajnandgaon)	1.5	.10	1.40	Decorative utility articles	April 2008
7.	Lalpur (Kawardha)	.40	.23	.17	Sofa set, Tea table, Stool, Decorative article	December, 2008
8.	Ratanpur (Bilaspur)	.83	.63	.20	Decorative utility articles	December, 2008
9.	Aamgaon (East Surguja)	.05	.01	.04	Decorative article	April, 2009
	Total	**9.37**	**5.23**	**4.12**		

It is proposed to set up separate retail outlet for these articles, when the volume increases. Presently these articles are sold from the BPC's and Sanjeevani-an outlet of Minor Forest Produce Federation Chhattisgarh, set up in all the forest Divisions.


01/01/2006

Photographs of some of the articles produced in BPC's of Chhattisgarh,

Goal - It is proposed to set up 55 BPC'S in Chhattisgarh in 8 clusters. Each cluster will have a Common Facility Centre (CFC) to look after forward and backward linkages.25 Bamboo artisans will get sustainable additional income of Rs. 60-70per day from each BPCS from 2010-11.

Preservative and seasoning plants shall be established in each CFC.

New innovative designs and articles shall be prepared. Quality shall be given at most attention. While traditional products with modern design for use in villages and cities shall continue to be encouraged ,focussed attention on making modern, utility products with innovative designs to cater to niche market. Awareness campaigns shall be undertaken in big way to popularize the products and to ensure that Bamboo becomes the real "Green Gold" for the Bamboo artisans of Chhattisgarh.

BPC'S of Bijapur, Bande and proposed BPC'S of Dornapal, Kasoli are in extremist affected area. It has been a challenge to form SHG'S and provide sustained employment in these BPCS BPC of Bijapur and Bande are functioning quite effectively with 42 and 15 beneficiaries.

Foresters of Chhattisgarh are working closely with the Bamboo artisans community to improve their socioeconomic condition.

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Marketing and Supply Chain Analysis of Bamboo Products from Northeastern India in Major Consumption Markets of India

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Abstract

In a developing country like India there is a continuous search for sectors which can generate income and employment in an equitable way for people of all socio-economic strata. Besides, such sectors should also enable upliftment of backward regions which have been left behind in the development story of the country for various reasons. One such region is the Northeastern region (NER) with an abundance of natural resources, one of which is bamboo.

This study is a unique attempt to analyze the existing marketing scenario of bamboo products manufactured in the NER to identify the constraints and gaps present in the supply chain which would assist in designing an effective strategy for sustainable growth of the bamboo industry.

An indepth study of the major market functionaries consisting of traders, retailers and consumers was undertaken through a detailed primary survey in major consumption markets of Kolkata, New Delhi, Chandigarh, Mumbai and Pune. The study analyzes the existing market channel dynamics through a detailed value chain and product analysis along with consumer behaviour analysis. The survey reveals the channel dynamics through a detailed value chain and product analysis. The survey also brings out the existing consumer preferences through the consumer buying behaviour for bamboo products.

It also identifies a set of potential products and gaps in the existing supply chain network. In the current situation, the artisans and small and medium manufacturers are experiencing increasing difficulty to maintain financial viability of the bamboo business with the competing products occupying increasing market share with changing consumer perception.

The final part of the study focuses on charting out a strategy for developing an operational framework for improving the channel, market and product efficiency for specific bamboo products manufactured in North East India.

Introduction

Bamboo is quickly changing its image from the "poor man's timber" to a more commercially viable product. Bamboo cultivation is becoming an increasingly important economic activity which has the potential to accentuate poverty eradication and economic and environmental development. The global bamboo market is estimated to be about USD 12 billion and is expected to grow to about USD 20 billion by 2015. This can mainly be attributed to the growing consumer awareness and acceptance of bamboo products as an eco-friendly and unique product differentiating itself from its major competing and substitute product categories.

India has the largest area and the second largest reserve of bamboo in the world. The NER (North Eastern Region) of India has the largest bamboo stock in the country and accounts for 54 per cent of the bamboo resources in India. The other most abundant bamboo growing areas are the Andaman and Nicobar Islands, the Himalayan foothills, Madhya Pradesh and Western Ghats. On the demand side, the domestic bamboo market size is estimated to be about USD 400 million[2] and is estimated to be growing at an annual rate of 15 per cent.

However, despite huge potential the sector lacks competitiveness and focus mainly due to the absence of a well organised production, marketing and supply chain network. The supply chain is highly scattered both at the production and marketing ends giving rise to supply chain related issues such as demand-supply mismatch on one end and low market penetration on the other. Lack of proper marketing and promotion efforts contribute to a very low awareness of bamboo product among consumers.

The entry of the highly organised and competitive Chinese bamboo products also pose a major threat to the immature Indian industry both as a direct competitor and also through adversely affecting market perception of bamboo products in some categories such as home furniture due to poor quality of the Chinese products.

In view of the above, an attempt has been made to study the marketing and supply chain of bamboo products from Northeast India in major consumption markets of India with the following specific objectives:

1. To analyse the existing market channel dynamics through value chain and product analysis
2. To understand consumer buying behavior for the bamboo products
3. To identify gaps existing in the existing supply chain network and to understand critical factors for the success of bamboo products
4. To identify a list of potential products best suited to the current market requirement and consumer preference for immediate focus
5. To chart out strategy for developing operational framework for improving the channel, market and product efficiency for specific bamboo products manufactured in North East India

[2] Planning commission estimates

Research Methodology and Approach

The research methodology consisted of both primary and secondary research. A brief description of both methods is provided below:

Primary Research:

The primary research was undertaken by drawing representative samples of respondents from major consumption markets in North, West, East and North East India. Personalized opinion surveys were administered to these respondents consisting of 480 respondents including 250 customers, 130 retailers' and 100 traders. The key objective of the primary research was to provide an insight into the consumer buying behaviour, market trends, trade practices, functioning and preference of channel members and supply chain dynamics of the Bamboo products, .

Secondary Research:

The secondary research primarily focused on obtaining relevant information pertaining to demographic, socio-economical set up of the areas surveyed and to understand the historical data related to major consumption markets. The secondary research also focused on identifying successful marketing models for bamboo marketing and analyzing the relevant best practices suiting the requirements of North East Indian bamboo industry.

The overall approach of the research focused on identifying and developing sustainable institutional framework for popularization and promotion of North East Bamboo products in the major consumption market.

Results and Analysis

I. Channel characteristic and behavior

A conventional channel of bamboo products, which links the consumers to the manufacturer through traders and retailers, is the most commonly used by the organized bamboo market. Apart from this, distributors, fairs & exhibitions and agencies such as NGO's are the other trade channels used for marketing of Bamboo products. During the study, each trade channel was analyzed with respect to its structure, merits & demerits, scalability potential, trade margins offered etc. to ascertain its suitability for different product types and changing market scenario. The analysis of trade channel reveals the following general characteristics:

- 75% of the traders surveyed have a turn over of greater than INR 5 lacs while only 25% of the traders surveyed have a turnover of less than INR 5 lacs
- Bamboo business contributes between 30-60% of the total annual turnover for 62 % of the traders surveyed in Western India
- Bamboo business contributes more than 75% of the total annual turnover for 60% of the traders surveyed in North and North East India

- The traders/wholesalers typically work on a margin of 25-40% of the end consumer price
- The retailers earn a better margins of around 35-40% of the end consumer price
- 60-80% of the retailers surveyed in North and West India stated high demand and profitability as the key reasons for taking up bamboo business
- Although there is strong recognition for bamboo of North East origin, there is no Geographical Indicators (GI) for the finished products
- 82% of the retailers from West India and 66% of retailers from North India rely on traders (wholesalers) as the key source for supply of bamboo products

The bamboo trade is mostly cash based business and takes place through personal network of the channel members. The current demand scenario is changing with customer gaining more purchase power and demanding more reliable and value added products. The study focuses on the need of having customized channel solutions based on the market, consumer and trade requirements. The following are some of the facts to be considered while developing channel strategy for North East based bamboo products:

- Identification of market segments such as school children, tourists, business organization and institutes etc. having low penetration of bamboo products
- Selection of right product mix for each target segment identified. For e.g. toys, gift items for children and customized order processing for institutional buyers etc.
- Identification of existing/alternate channel for each target segment
- Introduction of channel incentives for products having high growth potential
- Introduction and awareness of geographical indicator concept to popularize the bamboo products manufactured in the North East

Apart from the conventional channel, there are available alternate channels which can be adopted for different bamboo products. Some of the available alternate channel for different products are mentioned in Table 1.

Table 1: List of available alternate channels

S.No	Product	Alternate Channel
1	Utility Products (mats, blinds)	▪ Khadigram Udyog Outlets ▪ Postal and railway department ▪ Rural retail outlets ▪ Gram Panchayat ▪ Urban and farmers cooperative
2	Furniture	▪ Shopping malls ▪ Lifestyle/ gift shops chains such as Fab India, Archies Gallery etc ▪ Existing traders dealing in wooden furniture
3	Handicraft	▪ Hotels and Resorts at major tourist destination ▪ Khadigram Udyog Outlets ▪ IRCTC, PSU's and other institutes

Keeping in view the increasing popularity of Business to Consumer (B2C) solutions, online web portals can be an effective tool in linking up the consumers to the manufacturers. However, such measures should be initiated with the following adequate support in systems:

- Logistic
- Distribution System
- Inventory management system
- Customer care service
- Consignment tracking
- Payment solutions
- Marketing team support

II. Consumer Behaviour Analysis

Consumer Behavior Analysis constituted an important aspect of the study which focused on having a better understanding of the consumers' perception towards various bamboo product categories. This analysis would assist in designing an effective strategy for capturing the target consumers.

1. Consumer Buying Behavior

Consumer behavior is the total of consumers' decisions with respect to the acquisition, consumption, and disposition of goods, services, time, and ideas by (human) decision-making units. In other words, consumer behavior involves the thoughts and feeling people experience and their actions. Moreover, it includes all the things in the environment that influence thoughts, feeling, and actions. The key components of consumer buying behaviour analyzed in the study are discussed below:

a. Nature of buying decision

The key observations made under this heading are as follows:

i. The bargaining power of the customer is high
ii. The demand for most of the bamboo products is cyclical and seasonal. The demand for the bamboo based product (especially the handicraft category) depends upon the different fairs and exhibitions that are arranged during the winter and post monsoon season
iii. Increasing consumer awareness and demand for the natural product has gathered momentum and is increasingly affecting buying decision especially among the upper middle class consumers
iv. Consumers now increasingly prefer handmade and ethnic products. The trend seen in the revival of khadi products into a fashionable novelty product can also be clearly seen among bamboo product especially in the handicraft and utility segment
v. Rising purchasing power of people with higher propensity to consume with preference for unique products is providing constant impetus to growth

b. Consumer perception analysis

The key observations made under this heading are:

i. Price: The consumers were found to be highly price sensitive in buying the bamboo products. The utility and furniture segment was perceived to be particularly high priced in comparison to the other available substitutes. In contrast the handicraft and utility products category were perceived as being priced in the reasonable and lower price category respectively. However, under the existing marketing situation more than 75 per cent of the consumers are not willing to pay a premium for the bamboo based products and hence the need for a different branding and marketing strategy.
ii. Availability: The availability of bamboo products was found to be highly limited by the consumers. Most of the consumers can access bamboo products only in the seasonal fairs/exhibitions and haats due to negligible penetration of other channels like organised retail outlets. In fact, 74 per cent of the respondents become aware of various bamboo product categories only through the fairs/haats/exhibitions. For certain high value products like home furniture the consumers preferred to buy from organised outlets but due to non-availability of such outlets or due to lack of wide range of choice they easily switch to other competing products.
iii. Expected features: The perceived notion about the low durability of bamboo products was the main concern voiced by the consumers. Even non-users of bamboo products perceived bamboo as non-durable and only fit for petty handicrafts items and not fit for utility items or furniture meant for rigorous use. This perception was also seen among some of the channel members, particularly the out of state wholesalers/retailers with smaller contribution of bamboo products to total sales. The three most preferred attributes of consumers regarding bamboo products are design and uniqueness, low maintenance and cost effectiveness. On an average more than 90 per cent of surveyed consumers preferred bamboo products due to their design and uniqueness as compared to other competing products. The key expected features of the consumers for buying the bamboo products are superior finishing, low maintenance and warranty services for the high value products. The consumers were also of the opinion that greater availability and wide range of choice will also facilitate usage to a large extent.

c. Average purchase time and distance traveled

The key observations made under this heading are:

i. On an average 49 per cent of the respondents used less than 30 minutes to make a purchase decision
ii. Impulse buying is observed in case of handicrafts, decorative items and other lower and mid range products
iii. In case of high value products like furniture a prolonged pre-purchase evaluation is observed along with on store decision making period of about 1 to 2 hours
iv. Most of the consumers traveled a distance of 2-5 km for assessing bamboo products

To gauge the need gap between consumer awareness, preferences & usage/availability of bamboo products a study was undertaken and the summary of the same is enumerated below:

2. Consumer Awareness Study

This section of the study captured the awareness of consumer for various products and media used for product promotion. The key observations made during the study are enumerated below:

i. In Mumbai/Pune, Delhi/Chandigarh and Kolkata the products having maximum awareness among consumers are table mats, baskets for various purposes, construction material, flower sticks, trays, wall hangings, toys, decorative items, handicraft items, window blinds, furniture, utility products and flower packing
ii. In addition the Delhi/Chandigarh region has a large demand for window blinds
iii. Awareness about bamboo products through promotional campaigns or mass media was lacking in all the survey locations unlike other natural products like coir, coconut, etc. Hence, the consumers become aware of various bamboo products only through word of mouth, self use, fairs/exhibitions/haats, traditional retail shops or through mass media to a limited extent
iv. In Mumbai/Pune 92 per cent and 88 per cent of the surveyed consumers became aware of the various bamboo products through self-use and word of mouth respectively
v. In Delhi/Chandigarh 74 per cent of the consumers become aware of the various bamboo products through the fairs/exhibitions and haats which are frequent in the region
vi. In Kolkata the usage of bamboo products was found to be higher in comparison to the other surveyed locations and 97 per cent, 91 per cent and 82 per cent of the consumers become aware of various bamboo products through self use, word of mouth and traditional retail shops respectively
vii. The heightened consumer environmental awareness has given a boost to the sales of bamboo product

3. Consumer Preference Study

This section identified and analyzed the taste and preferences of the consumers for different products and channel.

a. Overall product preference

The key observations made under this heading are:

i. In Mumbai/Pune the highest preferred products are baskets and wall hangings with 67 per cent and 63 per cent respectively. Other products preferred by the consumers are table mats, flower sticks and handicraft products in order of preference
ii. In Delhi/Chandigarh the highest preferred products are decorative items, handicraft products and flower Sticks with the consumer preference of 82 per cent, 80 per cent and 76 per cent respectively. Of the other products that are preferred by the consumers are wall hangings, window blinds and toys
iii. In Kolkata furniture and handicraft products are highly preferred. Of the other products that are preferred are baskets, lamp shades and gift items
iv. In all the survey locations a *latent demand for bamboo furniture was observed*. Both the traditional and modern designs are being preferred by the consumers to provide a unique appearance to home decoration. A growth of the bamboo furniture sector towards mass market segment (in contrast to the present build to order status, low and erratic availability) in laminated, moulded and detachable segment will greatly increase its market penetration. The growth can be similar to the success of bamboo flooring sector through adoption of innovative and modern designs

b. Product preference based on usage

The key observations made under this heading are:

i. In Mumbai/Pune the preference in terms of usage are place mats, baskets and flower sticks
ii. In Delhi the preference in terms of usage are flower stick, window blinds, wall hangings and handicraft products
iii. In Kolkata the preference in terms of usage are baskets, decorative items, utility products and handicraft products

c. Channel preference

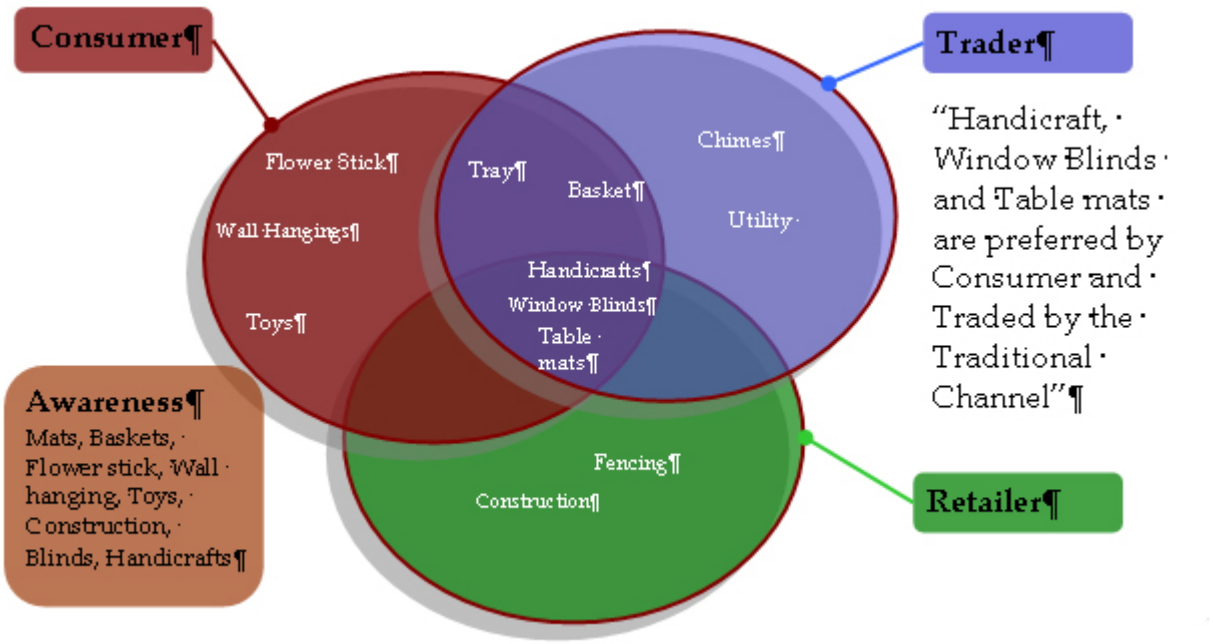
The key observations made under this heading are:

i. Of the surveyed consumers 92 per cent gave the preference to purchase products from a traditional shop. The main reason behind this can be attributed to the comfort of consumers in buying products from an identified supplier in absence of any formal warranty even in high value products
ii. Haats, fairs and exhibitions come as the next preferred channel for the consumers with 72 per cent of the respondents giving the choice for the same. This observation can also be attributed due to the relative lack of other channels in contrast to other competing and substitute products

Even though organised retail outlets for bamboo products are fairly low in penetration, 47 per cent of the consumers preferred the organized channel. *Given a better value proposition the consumers of traditional shops and fairs/haats and exhibitions can easily migrate to the organized channel*

Based on the survey of the traders, retailers and consumers a product matrix of the most potential products based on cross-matching of channel and consumer dynamics was prepared (Figure 1). *These products can be taken up*

on a priority basis for undertaking research and development and appropriate marketing activities. Later on other products can be brought into the product mix based on market response.



Source: YES BANK analysis

Figure 1: Identified potential product analysis

Apart from handicrafts, window blinds and table mats the other potential segments observed with latent demand are furniture and toys.

Road Ahead

The future of the North East Bamboo Industry hinges upon strengthening of the supply chain through establishment of active linkages of manufactures with the end consumers. Also, there is a requirement of developing robust business model to consolidate the manufacturers and develop interface with consumers through coordinated effort among various market functionaries.

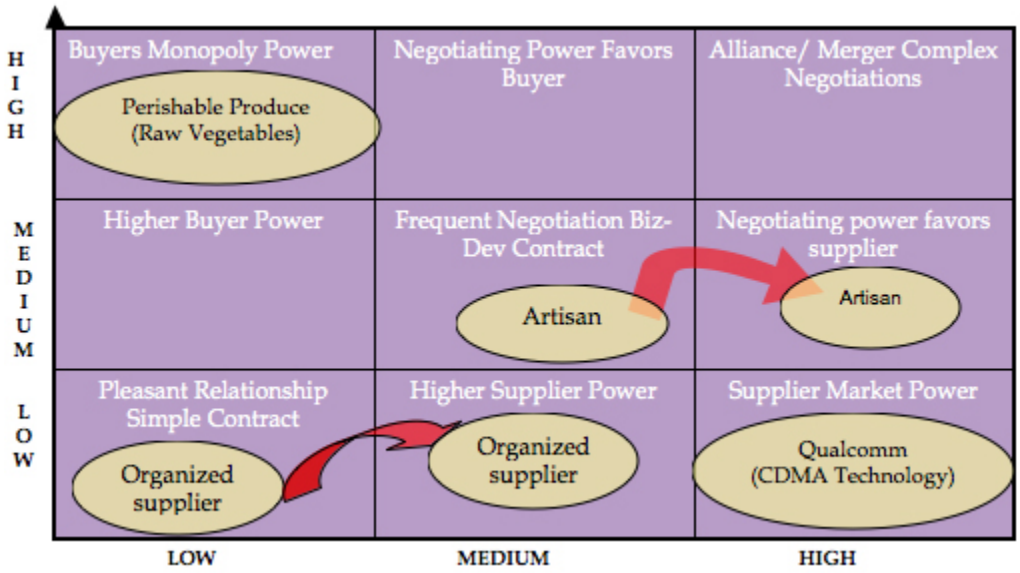
Introduction of such measures will be a dynamic market driven process and will require a separate organization or a Nodal Agency with adequate funding, systems and support structure in place. The Nodal Agency will be based in North East India and will act as a service provider to facilitate direct trade between manufacturers of bamboo products and traders and retailers. The Nodal Agency will operate on a B2C (Business to Consumer) model through a dedicated web portal. The same shall be supported by business development units which will have dedicated marketing staff in the major consumption markets. The nodal agency in effect will act as a bridge between the buyers and sellers of bamboo products thereby eliminating tiers of intermediaries. Further,

the nodal agency will work on a service based revenue model. Based on the supply chain requirements the following services are identified:

- Free online registration for buyers and sellers
- Providing samples for order booking
- Physical order booking from buyers
- Booking orders on behalf of traders who pays in cash
- Online Product Catalogue and Price List
- Online payment gateways
- Online Trading
- Home deliveries for retail buyers
- Stock verification upon delivery of consignment
- Toll free customer care
- New Product Information
- Information about bamboo events such as fairs/exhibition
- Tracking of consignment
- Online product rating survey
- Warehousing

There has to be an active role of the government to establish the nodal agency in its initial phase. The support can come in the form of grant to enable the nodal agency to deploy the necessary system and infrastructure in place. Further, soft support in form of providing manpower or existing infrastructure such as office space/ godown space at various locations can greatly reduce the overall implementation cost.

Clearly the role of the nodal agency will be to aid in eliminating the extra tiers of intermediaries present in the existing trade channel. At the back end it will help in consolidating the unorganized artisans and small traders. Considering the existing situation, the organized suppliers have low importance in the buyers supply chain. The suppliers have low to negligible bargaining power. On the other hand the artisans, despite of contributing to maximum value addition in the bamboo products are not having the terms of trade I their favor. The figure below depicts the current situation of the artisans and organized suppliers in the Buyer-Supplier Matrix (Figure 2).



Source: YES BANK analysis

Figure 2: Buyer Supplier Matrix

The current position of suppliers and artisans in the buyer supplier matrix is likely to change through interventions brought by introduction of Nodal Agency. The efforts to bridge the gap between suppliers and the consumers through interventions such as geographical indication, branding etc. is going to increase the supply strength of the organized suppliers. Further, organizing the artisans through medium of Nodal Agency is going to boost the negotiating power of the artisans in the buyers supply chain.

It is estimated that the cost benefit of the operations of the nodal agency will increase the price realized by the suppliers and will also be able to post a competitive pricing in the market. The real time information flow of demand, customer preferences and changing market dynamics will help narrow down the information gap between the manufacturers and the market. Further introduction of value added services such as product branding, product warranty and Geographical Indicator at a later stage is going to boost the perception of bamboo products among consumers.

Conclusion

The Indian Bamboo Industry is rapidly orienting itself towards the tastes and preferences of the consumers. The bamboo industry of the North East India needs to develop a strong market driven approach to remain abreast with the ever changing market situation. Establishing market linkages to bridge the gap between manufacturers and consumers will play an important role in the revamping the image of North East Bamboo Industry on a pan India basis. Further, adequate support from relevant government agencies and a dedicated nodal agency on a structural level will be required to ensure sustained and inclusive growth of the North East Bamboo Industry.

Income from Bamboo and Cane Handicrafts, cases from Bjoka, Silambi, Gongdue and Kangpara in Bhutan

Dorji Wangdi and Marianne Meijboom

Abstract

Handicrafts made of a climbing bamboo locally called Yula (*Neomicrocalamus andropogonifolius*) and cane (*Calamus spp*.) form the major source of cash income in selected pockets in the country of Bhutan. The bamboo and cane resources are derived from the wild. This paper shares the experiences from the management, production and commercialization of handicrafts in the remote areas of Bjoka, Silambi, Gongdue and Kangpara in Bhutan. The paper stresses the importance of working along the entire value chain including sustainable management of the resources through community based management, product development and establishing proper marketing linkages.

Introduction

Bhutan lies in the Eastern Himalayas in between China and India. The total land area is about 38,394 km^2 of which 72.5 % is classified as Forest land. Bhutan has a population of 635,000 people of which 69% live in rural areas (National Statistics Bureau, 2005). According to the poverty analysis carried out in 2007, about 32% of the population live under the national poverty line (Nu 740.36 which is equivalent to about 15 USD) per month per capita. There is a higher incidence of poverty in the rural areas (National Statistics Bureau, 2007).

Rural areas in Bhutan are often located far from market centres or even road heads[3]. People living in these areas depend on forest resources to a large extent for their livelihood as agriculture production is low due to crop raiding by wild animals. This paper addresses the experiences from Bjoka (Zhemgang district), Silambi (Mongar district) and Kangpara (Trashigang district). See the map in figure1. In these geogs people intensively use bamboo (*Neomicrocalamus andropogonifolius*) and cane (*Calamus spp*.) for handicraft production. Bamboo and cane handicraft production is one of the 13 traditional crafts in Bhutan and is known as Tshazo (cane & bamboo work).

Neomicrocalamus andropogonifolius, locally known as Yula and Ringshoo (respectively in Kengka and Sharchopa language[4]) is one of the about 30 species of bamboos found in Bhutan (Stapleton, 1994). This

[3] The road head refers to the nearest road accessible by car
[4] The official language in Bhutan is Dzongkha while Sharchopa is spoken in large parts of Eastern Bhutan and Khengka in the Keng areas in Zhemgang and Mongar districts.

climbing bamboo species has very smooth and flexible culms of less than two cm in diameter with long shiny internodes. The culms can reach a length of up to twelve meters long (see figure 2). Yula is found in warm broadleaf forests at an altitude range of 300 to 1800 meters above sea level and needs tree branches or bushes for support and shade (Stapleton, 1994; Noltie, 2000; Department of Forests, 2008). In Bhutan it is mainly found in the wetter sub-tropical forests in the East in Zhemgang, Mongar, Samdrup Jongkhar and Sarpang Districts. Farmers prefer the use of elastic, one or two year-old shoots of Yula, which are easy to use for weaving. Older culms loose their elasticity.

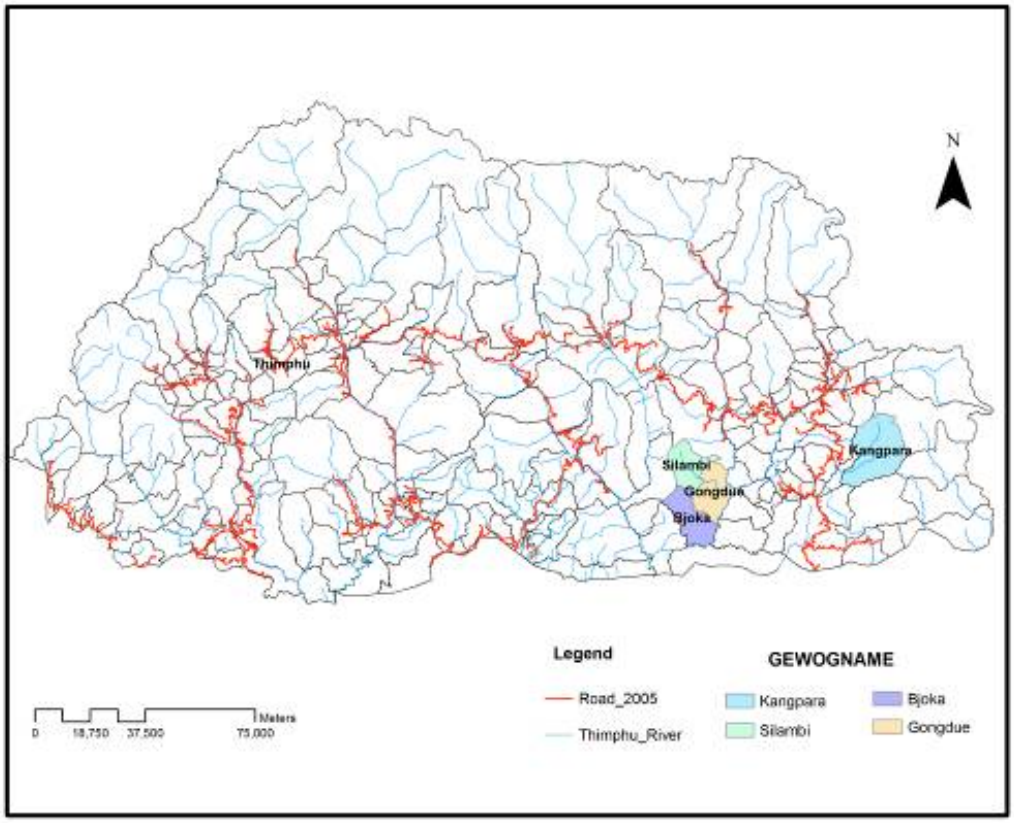


Figure1: Location of Bjoka, Silambi, Gongdue and Kangpara

Figure 2: Yula culms

Bamboo management under Community Forestry

According to the Forest and Nature Conservation Rules, 2006 a management plan should be in place prior to the extraction of natural resources on Government Land for commercial purposes. For the management of the bamboo and cane resources management plans have been developed according to the rules for Community Forestry. A Community Forestry Management Plan consists of two parts: the first part describes the resource management, which includes the socio-economic background of the village, traditional management systems, the planning process, product prioritization and demand/ need assessment, goals and objectives, location and boundaries including resource maps, resource inventory- including data on methodology used, analysis of data, information on annual harvesting limits, sustainable management and harvesting prescriptions- annual plan of operation and a chapter on monitoring and evaluation. The second part includes the by-laws. By-laws refer to good governance of the group and stipulate the institutional arrangements for the group including: the membership arrangements (including fee), the roles and responsibilities of the management committee (e.g. chairperson, vice-chair, secretary and treasurer), roles and responsibilities of group members, benefit sharing procedures (including provisions for the poorest group members), fees, offences & penalties, community fund mobilization, record keeping, conflict resolution, provisions for amendment and support required from service providers. The management plan needs to be approved by the Department of Forest (DoF). After approval the area is officially handed over to the community for management, providing the community legal access to the resources. The management plan is valid for a time span of 10 years.

DoF furthermore published guidelines for resource assessment and management of Yula (2008). In these guidelines rules for harvesting are described to ensure the sustainable management of the species (see box 1). These guidelines are based on local knowledge and combined with the more technical knowledge of the foresters.

Box 1: Harvesting guidelines to sustain the Yula resource base

- Harvesting should be limited to one, two year-old or older culms (when culms produce second shoot (branch) at the top);
- Harvest culms only from clumps that have more than five culms;
- Two to three young (one to two-year old) culms should be maintained in each clump to favour more shoot regeneration in the following season;
- Culms should be harvested between November and May (the growth of Yula shoots is hampered if younger culms are damaged. Therefore, the Yula area should not be visited during the rest of the year).
- Livestock should be kept out of the growing areas of Yula especially during the period from May to November; presence of cattle will stunt the growth of young shoots.

(DoF, 2008)

Product development

The production process starts with the collection of Yula and cane from the natural forests. The cane and bamboo is cut into bundles to ease transportation to the village. In the village the cane and bamboo is further peeled and cut into strips usually of about 40 cm long and a few mm wide. These strips are dried in the sun for up to three hours and afterwards dyed. The coloured strips are then used to make the different products. For the processing no sandpaper, glue or varnish is used. According to the traders and buyers, customers in Bhutan prefer the natural rustic look.

The main handicraft products made out of bamboo and cane are the traditional baskets "Bangchungs" of various sizes and other baskets (see Figure 3). The handicraft skills and patterns are handed over from one generation to the next. Bangchungs are used as plates, lunch boxes or bowls to keep certain food products in the local villages while in urban areas they are mostly used for decoration. The Bangchungs are made in several pockets of the country, of which the most famous for commercial purposes are Kangpara and Bjoka. The materials needed for making Bangchungs are Yula, cane (*Calamus spp.*) and chemical dyes. Natural dyes were used in the past (about 50 years ago) but not at present anymore because chemical dyes are more easy to use and stick better to the bamboo strips. Chemical dyes are used to get the four basic colours of blue, red, green and yellow. The difficulty in the weaving designs depends on the number of colours used. The most difficult patterns include 4 colours while the easiest designs are plain of one colour (Yangzom, 2002). The price for Bangchungs is about Nu 100-450 (USD 2-9) per set depending on its size and place of selling.

Figure 3: Bangchungs of various sizes

The Rural Enterprise Development Programme[5] (REDP) provided support in product development, marketing and business planning. Trainings were provided for villagers mainly from the target area of Bjoka in 2005 on new product design, and technologies for processing and seasoning by the Cane and Bamboo Technology Centre (CBTC) in Guwahati, Assam, India. The trainees were provided a new toolkit with 21 different tools developed by the Indian Institute in Mumbai. In total 225 toolkits were distributed in 2005 and 2006 (REDP, 2009). In order to replicate the successes from Bjoka to other areas in the country, including Silambi, Gongdue and Kangpara, UNDP further supported the "Skills Development Project" which is focused on product diversification, processing, quality control, and product costing . As part of this project another 178 artisans were trained in January and February 2009.

On 27 and 28th of June, 2009, a two days handicraft exhibition was held in Thimphu to test and market the new handicraft products developed by the communities of Bjoka, Silambi, Gongdue and Kangpara. The exhibition was attended by three Ministers, including the Minister of Economic Affairs as the Chief Guest, the Minister of Agriculture and the Minister of Labour and Employment as the event was considered very auspicious for promotion of rural handicrafts aimed at addressing the rural poverty in remote areas in Eastern Bhutan.

Seven participants represented the three communities and brought 40 different kinds of products for sale during the exhibition. The exhibition attracted many people on both days which indicated a strong interest in the new products. People showed great interest in about 30 out of the 40 products, especially in those new products that have traditional elements (see figure 4). Some of the products were developed in joint collaboration with

[5] The RED programme (2002-2007) was implemented by the Ministry of Economic Affairs (MoEA) with financial support from UNDP and technical assistance from the Netherlands Development Organisation (SNV)

Tarayana Foundation with communities providing bamboo mats with traditional designs and Tarayana Foundation doing the stitching. A number of hoteliers and international tourists, handicraft shops? placed orders as the exhibition had only limited number of products and some direct market linkages were established between interested buyers and the communities. During the two days exhibition, the three communities sold their entire stock worth Nu.200,000 (about 2100 $). For the exhibition some leaflets were developed showing different designs and describing the origin of the products.

The exhibition was considered very successful as it gave insights in product demands, and helped to establish direct marketing linkages. Representatives of the involved communities expressed their appreciation and gratitude to the government - MoEA, UNDP and SNV for organizing the exhibition and made requests for similar arrangements in the future.

Figure 4: New product designs

Handicraft production in Bjoka

Bjoka lies about 3 days walk from the road head and two days drive from the capital Thimphu. Handicraft production has been a traditional activity of the local villagers for over a number of generations. Nowadays almost all 150 households of the geog are involved in this craft and make all sorts of colourful baskets in Bhutan known as “bangchungs, baykor and lakchungs”. A study in 2004 revealed (Moktan et al, 2004) that 66% of the monetary income is derived from bamboo and cane handicraft production.

Bjoka was one of the pilot sites of the second phase of the Community-based Natural Resource Management (CBNRM) Project6 (2005-2008), and received support in the establishment of a Community Forestry

[6] The CBNRM project was executed by the Council for Renewable Resources Research of Bhutan (CoRRB) with financial support from the International Development Research Centre (IDRC) and technical assistance from SNV

management plan in order to ensure the sustainable supply of the resources as resources were getting depleted in the vicinity of the villages. This management plan has been approved by the Department of Forests (DoF) and ensures the legal access to the resources for a period of 10 years (2007-2017). Almost all villagers are part of the Community Forestry Management Group. The by-laws of the management plan of Bjoka include the set up of a Community Development fund (raised through sale profits, membership fee, and fines) which will be used for the operation of the community forestry group, community works such as the repairs of Lhakangs, drinking water supply and construction of an office, provision of loans to its members and for sending orphans to school.

The CBNRM project has supported the villagers with the establishment of weaving centres, where farmers can jointly gather and craft their products, learn from each other and monitor each other's techniques and products. The weaving centres are equipped with solar panels so that farmers can work on handicraft production in the evenings and complete their farm work during the day.

As part of the RED programme, villagers in Bjoka were trained in product diversification and as a result villagers make currently 12 different main products, including the Bangchungs of different sizes. However, according to the business plan, the Bangchungs form still the major products and provide the major income to the villagers.

In late 2008, a handicraft sales centre was established in Zhemgang town with the objective of becoming a major outlet for the handicrafts, and a business plan has been developed in order to optimize marketing. At present the group sells about 60% of the products to local middlemen, 30% at exhibition, fairs and middlemen in Thimphu and 10 % at the road head.

Because of the group formation, product diversification, and quality control, the direct income for the farmers in Bjoka is about Nu. 347,500 per year. On average this means Nu 2,635 per household which is about twice as much what they were earning before the group formation (Meijboom et al, 2008).

Handicraft production in Silambi and Gongdue

Silambi lies about 2 days walk from the road head and two day drive from Thimphu. It is one day walk from Silambi to the neighboring village called Dali in Bjoka Geog. With support of DoF and technical assistance of SNV, Community Forest management plans (describing the management of the bamboo and cane resources as well the by-laws) have been developed for Nagor (129 households) and Gyelgong (20 households) located in Silambi geog. Both groups have created a Community Development fund raised from membership fees, fines, sale profits, and donations. In Nagor, the group intends to use this fund for the provision of loans, as a commission to the committee members, maintenance of the community Lhakhangs and water supply schemes, and the maintenance of the community weaving shed. The Community Forest Management Group of Gyelgong plans to use the raised funds for the construction of community weaving shed, to purchase facilities for the shed such as solar lights and buying of improved varieties of agricultural seeds.

Tarayana Foundation supports the villagers in this area and has established a weaving centre in Nagor village in Silambi Geog. They carry out quality control and buy Bangchungs which meet the quality standards from the villagers for a set price and sell the products mainly in Thimphu.

Villagers in Silambi and Gongdue only produce the traditional "Bangchungs" in various sizes. Recently under the Skills Development Project training on product development was organized by the Skills Development Project and during the training four potential products for commercial purposes were identified apart from the bangchungs as the traditional products have a limited market demand. The products have been labelled and tested during an exhibition in Thimphu held in June 2009. (See the chapter on product development above).

Handicraft production in Kangpara

Kangpara has a total of 388 households spread over 13 villages and lies in Eastern Bhutan (with the centre half a day walk from the road head) and about 3 days drive from Thimphu. In this Geog, two villages Passaphu and Maduwa are well-known for their fine handicraft production skills especially of the traditional baskets. It is said that the best handicrafts of Bhutan come from this area.

Villagers have been able to keep up the tradition and passed the crafting skills over from one to the next generation, despite the fact that resources have been completely degraded for decades due to increasing demands, unsustainable harvesting techniques, forest fire and deforestation. Now, farmers travel to Serchem and Martang in Samdrup Jongkhar to get the raw materials. A round trip from Kangpara to Samdrup-Jongkhar and collect the bamboo takes 7 to 8 days. Because of the long travel distances, artisans make only one to two trips per year and can only take two backloads per trip which severely reduces the quantity of handicrafts from this area. Also the bamboo resources in Sechem and Martang dwindle rapidly because of the unsustainable techniques (collection of all young culms which severely hampers the shooting of new culms). The guidelines from DoF are not implemented nor enforced. Although a Ringshoo management group was formed in 2005, there is no management plan in place to ensure the sustainable management of the resources in Kangpara, Serchem and Martang. Plans are that next year a Community Forests will be formed for managing the resources in Kangpara (Trinh et al, 2009).

Because of the depletion of the resources, the villagers have set up a nursery and a plantation of 30 acres with wildlings from Samdrup Jongkhar in 2005. However the plantation was not very successful and many plants did not survive because of poor site selection, poor plantation techniques, poor quality of wild lings (too old) and lack of maintenance (Trinh et al, 2009). As requested by the community and recommended by the Dungkhag (local administration), UNDP provided funds for another 30 acres of plantation and fencing during 2009 while RSPN provided technical training in proper nursery and plantation set up.

Kangpara is also one of the selected sites for the "Skills Development Project" and 70 artisans from Passaphu and Maduwa took part in a training carried out with resource persons from the Cane and Bamboo Technology Centre. Apart from the bangchungs and other traditional products, six other designs were selected for product diversification as traditional products have limited market demand. Like Bjoka and Silambi, the selected products have traditional aspects (see chapter above on product development).

As of now, artisans sell their products to middlemen who are living in the same village. The middlemen take the products to major towns such as Thimphu, Trashigang, and Mongar.

Community and economic development

The three communities depend for a large extent on bamboo handicraft production for their livelihood. At present the traditional bangchungs form the major part of the business as these baskets are used in almost every household in Bhutan. As the tourism market is increasing, other designs are introduced by projects in order to diversify for attracting new market outlets, including tourists, hotels, handicraft shops, etc. Designs that are most successful include traditional Bhutanese elements.

Apart from the direct monetary income derived from the handicrafts production, the communities also profit through the Community Development Fund as established in Bjoka, Nagor and Gyelgong which is used for the economic development of the entire community.

Challenges

The areas of Bjoka, Silambi & Gongdue and Kangpara face similar problems in marketing their products. As the areas are very isolated, transport costs are very high which result in relative expensive products. Furthermore, because of the isolated location and the dispersed location of the households in the mountainous terrain, it takes time to communicate the requests of the buyers and traders to the producers. Therefore at present villagers just produce and try to sell their products instead of producing the handicrafts based on market demands.

The isolated location furthermore makes it difficult for villagers to have access to new information, techniques and materials. For example chemicals for processing the raw bamboo and sandpaper, wood glue, varnish and chemical dyes are only available in India. Also villagers are less aware of the new market developments related to colours, patterns and product designs. This does not constitute a major problem as long as there is a large market demand for the traditional baskets in its current form. However, it will become a problem if the market shifts and demands more sophisticated products.

There is a risk that alternatives such as plastic baskets will dominate the market and replace the traditional bamboo baskets. Plastic products are weather resistant and therefore more durable and also very cheap. People might prefer these and the demands for the traditional bamboo baskets might drastically decline as a result. However the Government of Bhutan discourages the use of plastics.

Yula can be cultivated but needs moist conditions and grows best under a forest canopy cover. This makes that almost all Yula is derived from the wild. In Bjoka and Silambi, villagers carried out some successful enrichment planting in designated areas in the forest in a small scale. In Kangpara a plantation has been established successfully established. Because of the high demand for the resources there is a potential risk that the resources are over-exploited and entirely get depleted or become locally extinct as in the case in Kangpara. If resources get depleted, it will take more time to collect the raw materials for producing the crafts which will lead to higher prices of the products and/or less income for the villagers.

Yula grows only in some selected pockets of the country in warm broad leaf forest. Because of this, there is limited scope for up-scaling handicraft production from this species and as a consequence production quantities will remain relatively low, while prices are relatively high.

Because of the above reasons, the possibilities for villagers living in these areas are limited to produce handicrafts in sufficient quantities of international standards which can compete on international markets. Therefore the Bhutanese handicrafts target the national market rather than the export market at present.

Lessons learnt

It is essential to have a management plan in place in order to ensure the sustainable supply of the raw materials. The depletion of the resources is one of the major constraints in all production areas. This management plan should be developed in a participatory manner and clearly describe the boundaries of the area, management prescriptions, harvesting rules, zoning, etc. It is important to carry out inventory exercises with local people as they will have then a better understanding and respect for the outcomes. Also the management prescriptions are best defined by combining traditional knowledge of farmers with technical and scientific knowledge of foresters. The community's interest to adhere to the management plan depends on a feeling of ownership of the plan and the resources to be managed. Apart from the description on natural resource management in the management plan, the by-laws are at least as important. Good leadership from the committee is crucial for the functioning of the group. Also Community Forest Management Groups that are homogenous and of a controllable size and have a strong cohesion are more likely to be successful in achieving their objectives.

Apart from the formation of a management group ensuring the sustainable supply of the resources, it is essential to have a marketing group. This group could be the same as the management committee or could be different based on the interest of the villagers. The objective of the marketing group is simply put to minimize the marketing costs and increase the benefits for the farmers. Even villages in one geog are often located a days walking distance from the collection centre. Therefore, the task of the marketing group is to coordinate the marketing activities, including communicating quantity and quality requirements from buyers to the villagers, minimizing transportation costs, agreeing upon place and time for selling the products, setting and monitoring quality requirements & standards and determining standard prices for the different products. These tasks should be formally agreed upon by all villagers and written down as a specific Terms of Reference for the marketing group. As these activities are time consuming, the people assigned to the marketing group should get a commission / percentage of the total value sold as agreed upon by the villagers. A commission will help to stimulate the marketing group to carry out their tasks properly and also stimulate them to look for wider markets. Of course it is essential that the marketing group keeps detailed records of the sold products, prices, outlets where the products were sold, etc. Clear terms of reference, the provision of a financial incentive and records will help the villagers in keeping the marketing group accountable. In Bjoka, a separate marketing group has been formed, whereas in Silambi the tasks of the marketing group are mainly carried out by the Tarayana Foundation.

Although training has been provided in a number of designs, the most popular products are the traditional bangchungs in various sizes and products with traditional elements. Some designs turned out to be too complicated, not suitable for the Bhutanese market or too bulky, such as chairs, lampshades and tables, in order to make a profit.

The construction of weaving centres equipped with solar panels, are not only instrumental to increase productivity (because farmers can work on handicraft production in the evening), but are also instrumental as meeting places to share ideas and experiences.

Conclusions

Bamboo & cane handicrafts play a crucial role in the livelihoods of poor communities in Bjoka, Silambi, Gongdue and Kangpara as their cash income is mostly derived from these products. In order to increase the economic benefits for the local villagers, it is important to work along the entire value chain including resource management, product development and marketing. Related to resource management it is important to formally form a Community Forest management group in order to have legal access to the resources and to ensure the sustainable supply of the raw materials. Related to product development, products should be within the skills of the artisans, have a market demand and be suitable to the local circumstances e.g. products should not be bulky if there is no road access. Furthermore labelling helps to show the origin and distinctiveness of the product while the marketing of the products should be well coordinated in order to increase the bargaining power of the villagers as well as to minimize the transportation costs which always form a substantial part of the production costs in the mountainous terrain of Bhutan.

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Production, Design and Industrial Aspects

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Preface

Juergen Hierold
UNIDO

The development of industries to provide employment and income for people in developing countries is one of UNIDO's highest priorities. These have to be in line with strategies to ensure environmental sustainability with the specific targets to integrate the principles of sustainable development into country policies and programs and reverse the loss of environmental resources. UNIDO has, since 1999, appreciated the enormous potential of bamboo to satisfy industrial processing raw material needs and has made a point of compiling databases on processes, specialized equipment and machinery and on investigating economic feasibility of industrial enterprises.

Bamboo technologies are a feasible way to achieve these sometimes conflicting goals, industrialization and environmental preservation. The tremendous potential of bamboo technologies in terms of

- wood substitution to fight deforestation,
- employment generation,
- locally added value to raw materials or
- environmentally sound development

is the reason for UNIDO's ongoing support for bamboo projects and the World Bamboo Conference.

This panel's contributions focus mainly on the vital advantages bamboo usage can have on the development and production of building materials and pulp & paper. The potential of bamboo for UNIDO's overarching goal of poverty reduction through productive activities is clearly reflected in the contributions to this session.

UNIDO has been recognized as one of the leading International Agencies worldwide in bamboo processing technologies and industrialization with very specific know-how in the sector and is promoting bamboo industrialization process worldwide with great success during the last 10 years. UNIDO is also very much aware of the importance of Research & Development efforts to improve the effectiveness of bamboo technologies. We therefore look forward to the fruitful discussions and the inspiring input stemming from the World Bamboo Conference 2009.

The Gluability and Bonding Strength of *Dendrocalamus asper* Backer for Exterior Structural Applications

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Abstract

This study evaluated the effect of culm location in an Asian bamboo, *Dendrocalamus asper* Backer, on the pH and acid-buffer capacity and glueline bonding strength of strands using different types of adhesive. These properties were analyzed in order to prove its suitability to be promoted as a raw material for the manufacture of structural composite products like Oriented Strand Board (OSB), Oriented Strand Lumber (OSL) etc.

The pH and acid-buffering capacity were investigated in three locations, which composed of bottom, middle and top parts, along the culm length. The obtained results from this study indicate that the average pH value and acid-buffer capacity of *Dendrocalamus asper* is 5.4 and 0.53 milliequivalents, respectively The different culm location of a 3 years old has no effect on this value. The bonding strength development of bamboo strands bonded with some exterior used type adhesives was investigated by using a special testing device called an Automated Bonding Evaluation System (ABES). This experiment proposed three parameters, i.e., three types of glues; Melamine Formaldehyde (MF), Melamine Urea Phenol Formaldehyde (MUPF), and Phenol Formaldehyde (PF), and four pressing temperatures (130, 150, 170 and 190°C) and different pressing time (20 to 200 seconds). It was found that bonding strength was improved by increasing the hot pressing time and temperature. All adhesives showed satisfactory bond quality for the gluelines in the bonding of the bamboo strands. The best adhesive to bond bamboo strands following the ABES was found to be MF.

Introduction

The available high quality wood from natural forest in the world has declined. Then, structural composite products (e.g., Waferboard, Oriented Strand Board and Structural Composite Lumber) for construction building has been taken placed of massive wood lumber and increase their global market share every year. In the past few decades, wood composite industry has used the forest plantation and saw mill residues as the raw material for engineered product manufacturing. At the same time, the strength harvesting regulation and pressure from environmental policy have created decreasing high quality wood supply and an increasing cost. Consequently, the search for alternative resources of fiber instead of the traditional use of wood has been focused. Non-wood or agricultural-material has been received considerable attention as an alternative raw material for structural composite products.

Bamboo is a non-wood lignocellulosic material which has been widely used since thousands of years in tropical countries as a material for construction, furniture manufacture and daily household. Recently, it has been widely used as a raw material for wood composite manufactures, such as for Medium Density Fiberboard (MDF), Particleboard (PB) and Oriented Strand Board (OSB), owing to its high strength and properties. It is known that the chemical composition of bamboo culms is similar to that of wood with cellulose, hemicellulose and lignin accounting for over 90% of the total mass. From the study of Kamthai (2003), the average chemical composition of a three-year old *Dendrocalamus asper* consists of α-cellulose (68%) and lignin (29%). It contains about 1.5% of ash, 6% of alcohol-benzene soluble, 8% of hot-water soluble, 7% of cold-water soluble and 25% of 1% NaOH soluble materials. However, a change in raw material may affect on product properties and requires additional adjustment of some processing manufacture, such as the adhesive system. Since the adhesive is a significant cost factor in board production (about 20% of total production cost), future development of bamboo-based composites will require an analysis of bamboo gluability and the bonding strength of its strands.

The cross-linking rate of most thermosetting adhesives used in wood composite manufacturing depends on the pH levels. Thence, the acidity of raw material and the catalyst which is added into the adhesive play a very important role in providing the optimum condition during resin curing. The buffer capacity is the resistance of wood to change in its pH level by acid additional. Maloney (1993) suggested that the wood which requires a larger amount of acid catalyst to decrease its pH to a level required for optimum adhesive cure is considered as a high buffering capacity species. Many previous researchers (Freeman 1959; Johns and Niazi 1980; Van Niekerk and Pizzi 1994; Zanetti and Pizzi 2003) studied the influence of pH and buffer capacity of wood on curing time of some resins and product properties. According of these studies, the adhesive curing time and its bond strength decreased with the wood increasing pH and buffer capacity. Moreover, catalyst buffering action has strong effects on curing time and the degree of networks formed of MUF, PF and tannin based adhesives. Thus, the pH and buffering capacity measurement of raw materials is fundamental to determine the optimum of pressing parameters (i.e., time and temperature) for wood-based composite manufacturing. Understanding these properties is important when discussing the suitability of bamboo as a potential raw material for structural composite products.

Therefore, the objectives of this paper are to measure and compare the mean pH value and buffer capacity in each culm location of *Dendrocalamus asper* and investigate application by using the ABES equipment the strength development characteristics and bonding quality between bamboo strands using different adhesives for exterior.

Materials and Methods

Materials

In this study, the 3 years old of *Dendrocalamus asper* culms were collected from plantations located in Nakorn Sri Thammarat, South of Thailand. The three culms were harvested and immediately transported to Wood Science and Engineering Research Unit, Walailak University in Thailand. These bamboos had an average culm length of 18 m. The culm diameter at the bottom was about 11.5 cm, while the top culm was about 2 cm. The average culm wall thickness was 1.6 cm. The average specific gravity at 12% MC was 0.75. Each culm was

divided into three parts each of 6 m lengths. Specimens were obtained from three locations which were related to the height position in the culm following the scheme in Figure 1.

Bamboo chips from each part were cut into fine particles by a Wiley machine. The samples were then put into a shaken screener to pass through a $40^{\#}$ mesh screen and retained on a $60^{\#}$ mesh screen. The particle remaining on the mesh screen was used for the measurement of pH value and buffer capacity.

The bamboo strands with a size of 120 mm by 20 mm and a thickness of 0.7 mm were used to prepare the two-layer lap-shear specimens for the ABES bond quality testing. All strands had been dried a final MC of 12% before gluing.

Three commercial exterior adhesives were used in this research: Melamine formaldehyde (MF), Melamine urea phenol formaldehyde (MUPF) and Phenol formaldehyde (PF). The MF resin (Prefere13H560) was supplied by Dynea. The MUPF resin (KML 534) was supplied from BASF. The PF resin (Bakelite 1279 HW) was supplied by Hexion. All adhesive mixtures were prepared following the supplier's suggestion. Their properties are presented in Table 1.

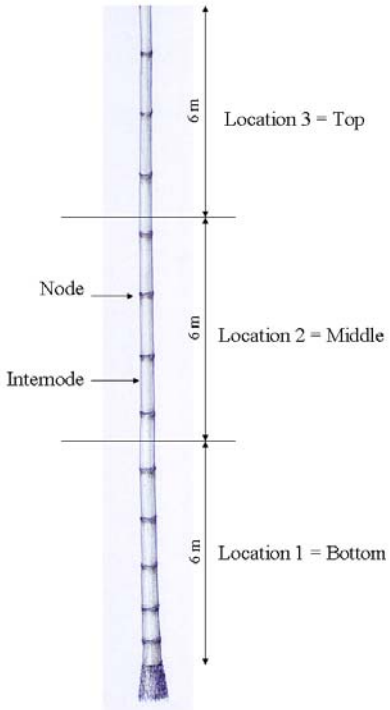


Figure 1 Sampling technique from *Dendrocalamus asper* culm for pH and buffer capacity analysis

Table 1 Characteristic property of the used glues

Properties	Glue types		
	MF	MUPF	PF
Appearance	Pale liquid	Pale brown liquid	Red brown liquid
Solids content (%)	62.5	64±1	48
pH at 20^0C	9.73	9.3-9.8	8.5-10.5
Viscosity at 20^0C (mPa*s)	100-150	150-400	650-700

pH Value and Buffer Capacity Measurement

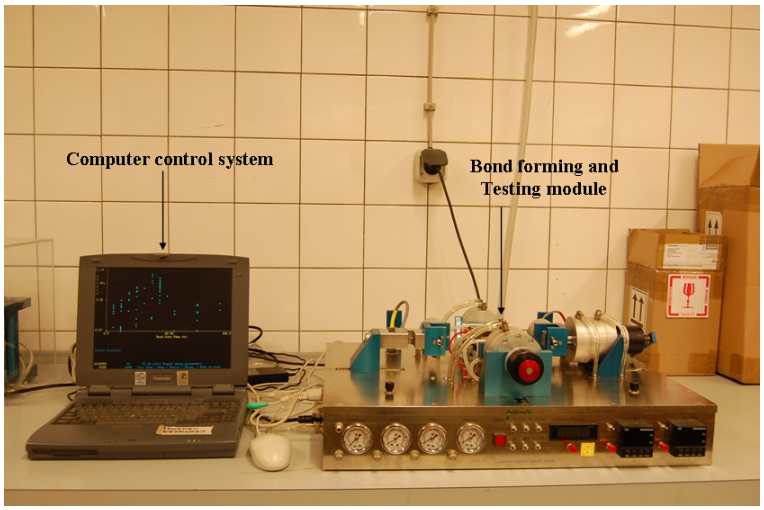
Most of pH value reports have been analyze by hot water extracts, obtained by refluxing for short periods (Johns and Niazi 1980; Xing et al. 2004). However, cold water extracts for a longer period is also presented and accepted in laboratory scale (Hague et al. 1998). The cold extract pH was measured according to TAPPI T 509 om-83. 1 g of specimen was put into a 100 ml beaker and distilled water was added to bring the total volume to 70 ml. The mixture was stirred and allowed to soak for one hour at room temperature (20^0C). A pH meter (Type WTW pH 330i) was used for the measurement.

The buffer capacity measurement procedure was adapted from the method suggested by Maloney (1993). 30 g of dry specimen were soaked and stirred in 400 g of distilled water at 20 ± 1^0C for 30 minutes. The liquid was then poured into a Buchner (Coors) filter no.2 containing a Whatman filter paper no.4. The liquid was drawn through the filter paper with the aid of a vacuum and 150 g of the liquid was transferred in a 400 ml beaker. The same pH meter was used for determining the pH value. The solution was then titrated to a pH of 3.5 with nominal 0.01N Sulfuric acid solution. The liquid was mixed by a magnetic stirrer. The pH and milliequivalents (N×ml) of acid needed to change the pH to 3.5 were calculated as the buffer capacity

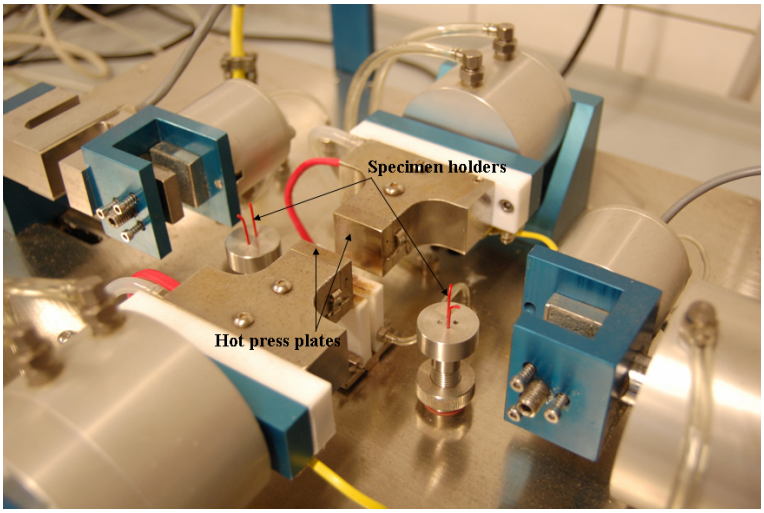
Each specimen was conducted using three replications. Analysis of the variance was performed and Duncan's Multiple Range Test was used for the comparison procedure.

Bonding Quality

The development of bonding strength was investigated with the Automated Bonding Evaluation System (ABES). The ABES is designed to determine the development of adhesive bonding strength between two pieces of strands. The bonding is affected by temperature, curing time or the pressure that is applied to lab-shear samples (Humphrey 1993). This device is composed of a bond-forming and test module, which are present in Figure 2, and a computer control system with testing-software program.



(a)



(b)

Figure 2 Details of Automated Bonding Evaluation System device, (a) ABES overview, which is composed of the bond-forming with testing module and computer control system (b) A close-up of the bond forming zone, which is composed of the hot press plates and specimen holders.

The adhesive was spread onto one side (5x10 mm^2 of overlapping area) of the bamboo strand with a hand brush at an application rate of 200 g/m². As suggested by hypothesis and literature review (Lee et al. 1996), the outer layer of bamboo culm is difficult to glue than the inner layer, because of the specific gravity variation. Hence,

two strands were placed in the bond pressing zone of ABES with both grains parallel to each other in an outer-layer-to-inner-layer configuration.

After lay up, the strands were then hot-pressed under controlled parameters of temperature, time and pressure which are given in Table 2. After each bond was cured to the required time and temperature, the pressure was released from the specimen, which was then immediately pulled in a shear mode according to the ASTM D-3165-07. Tensile load and gripping head movement (sample elongation) were PC-monitored during strands pulling, and load at failure was recorded by a computer like for the determining the shear strength of the adhesive bond. At least three replications were performed for each of the condition. The operation manner of equipment experiment is described in Figure 3.

Table 2 Design parameters for the experiments

Sample parameters	Data
Resin types	• MF (Prefere 13H560) + 3% NH_4NO_3 • MUPF (KML 534) + 3% NH_4NO_3 • PF (Bakelite 1279 HW) + 6% K_2CO_3
Resin spread rate	200 g/m^2
Sample moisture content	12%
Pressing parameters	
Pressing temperatures	130, 150, 170 and 190^{0}C
Pressing times	20 to 200 seconds
Pressure	4 N/mm^2 (constant)

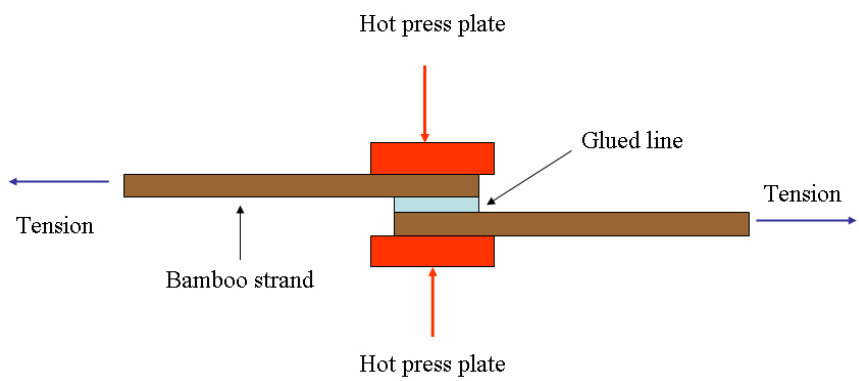


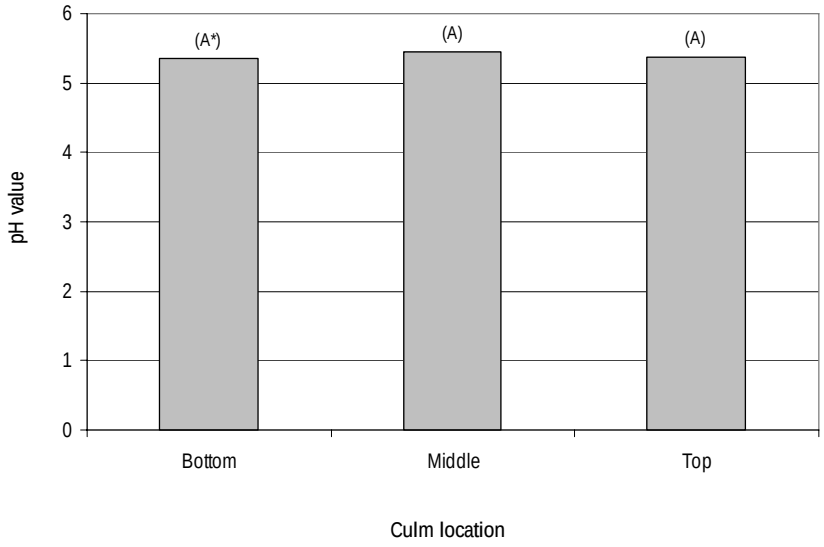
Figure 3 Schematic description of shear test by Automated Bonding Evaluation System (ABES)

Results and Discussion

pH and Effect of Culm Location on Value

Figure 4 presents the pH value data, obtained for the measurement from three locations of three bamboo culms. The pH value of *Dendrocalamus asper* ranges in the acid region from 5.36 – 5.45. The highest value occurs in bottom part, while the lowest value occurs in top part of the culm. The differences of pH value between each location is not significant (F-value = 0.23). Compared to wood species, the pH value of *Dendrocalamus asper* is quite similar to some softwood and hardwood species, which have value in the range of 4-6 (Fengel and Wegener 1984).

It is desirable that the pH value of *Dendrocalamus asper* is quite similar to common wood species. Moreover, the different culm location has no sever effect on pH value. The same technology and practices might be applied to this bamboo specie when being used as raw material in wood composites manufacturing.



Note: * Means with the same letter for the location are not significantly different at p<0.05 by Duncan's Multiple Range Test

Figure 4 pH value of *Dendrocalamus asper* at different locations

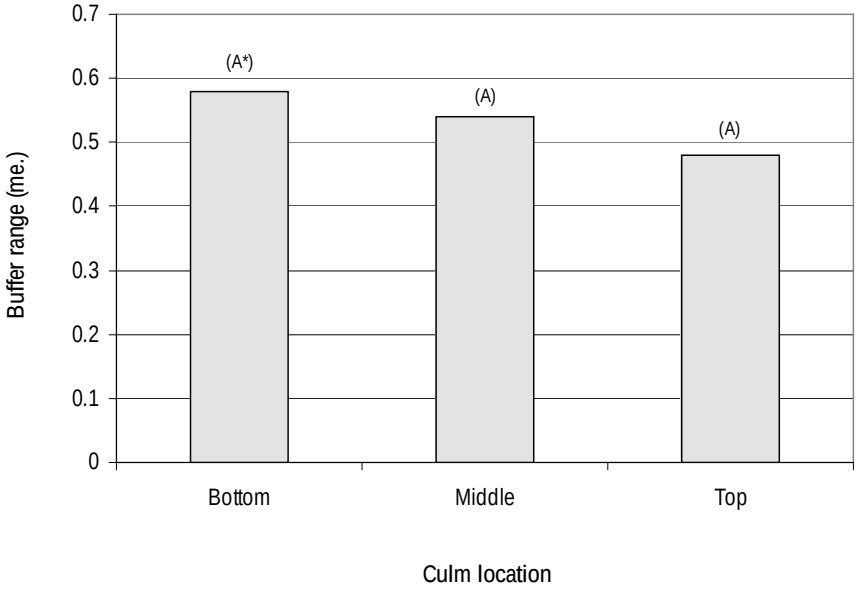
Buffer Capacity and the Effect of Culm Location on Value

The acid-buffering capacity of *Dendrocalamus asper* at three different locations in the culm is illustrated in Figure 5. The average value of bottom, middle and top parts of the culm are 0.58, 0.54 and 0.48 milliequivalents, respectively. Although there are not significant differences between the location (F-value = 0.27), the value gradually decrease from bottom to the top of the culm. The bottom part of culm shows highest

acid-buffering capacity compared to the top. It is known that bamboo extractives have some variation in their vertical location. The bottom part of the culm has significantly higher extractive contents, particularly with hot-water extracts, alcohol-benzene extracts, 1%NaOH extracts and ash, than the other parts (Kamthai 2003). It is reasonable to hypothesize that the chemical composition of bamboo, especially water extracts and inorganic matters, has effect on its buffer capacity. This hypothesis can be confirmed by study of Passialis et al (2008). They found out that hot-water extracts and inorganic elements, which evidently present in bark of wood, have significantly effect on buffer capacity of raw material.

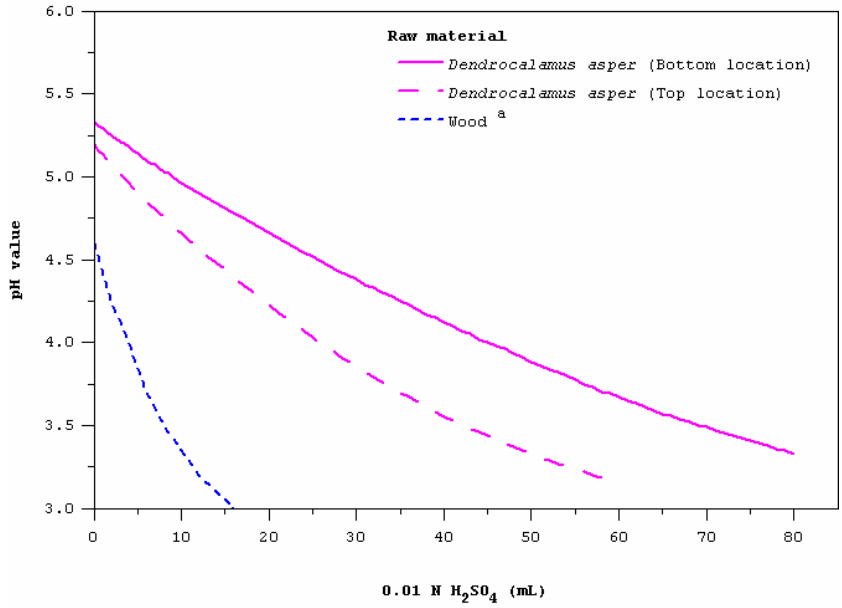
The pH value changes for bottom and top parts of *Dendrocalamus asper* on the acid addition is presented in Figure 6. It is clear that *Dendrocalamus asper* has extremely high resistance to pH changes and weakly responds to the acid addition when compared to normal wood, as also shown in Figure 6. *Dendrocalamus asper* needs 5 to 6 times the amount of acid which is required for wood to achieve a pH of 3.5. It would be considered that *Dendrocalamus asper* is a high buffer capacity specie. It requires a huge amount of acid catalyst to reduce the pH to the optimum level which is required for a resin cure. This may cause problems to use it as raw material in wood composite with conventional gluing technology. Some strategies, such as the use of special glue to produce boards or adjusted hot-pressing parameters, might be applied to improve resin curing and therefore improve product properties too.

As the result of this research, the buffer capacity would be mentioned as a key factor for consideration *Dendrocalamus asper* as the raw material in all wood composite manufacturing processes. It is also a noteworthy issue that its buffer capacity varies along the culm location, although the differences seem small until the statistical analysis cannot find. Thus, it should require some special consideration in regard to catalyst addition and resin cure.



Note: * Means with the same letter for the location are not significantly different at p<0.05 by Duncan's Multiple Range Test

Figure 5 Buffer capacity of *Dendrocalamus asper* at different culm locations



Source: [a] Sauter (1996)

Figure 6 Effect of raw material type on pH changes during the acid addition.

Bonding Strength Development of MF, MUPF and PF adhesives

The development of bond strength was observed in terms of the shear strength of each adhesive as a function of pressing time and temperature. A typical bond strength development of MF, MUPF and PF adhesive is shown in Figure 7, 8 and 9, respectively.

The results of ABES test indicate that bonding strength of glue-line vary significantly with different adhesive type, pressing temperatures and time. The maximum value of shear strength is 8.90 N/mm^2 for MF resin at 170°C and 200 seconds (as shown in Figure 7), while the minimum value of shear strength is 0.15 N/mm^2 for MUPF resin at 130°C and 20 seconds (as shown in Figure 8).

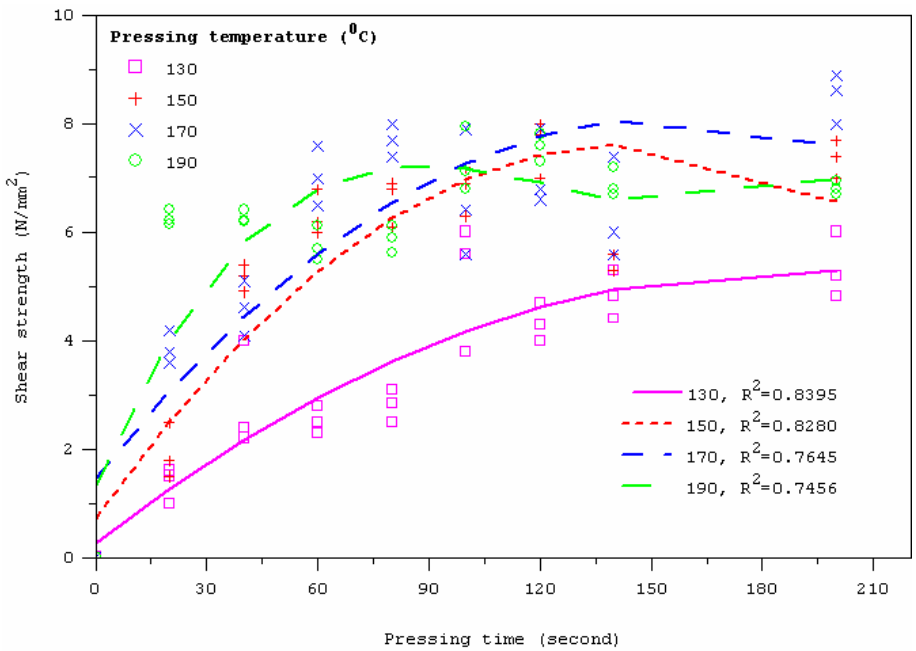


Figure 7 Development of shear strength of MF glued bamboo strands tested by ABES method as a function of pressing times and temperatures.

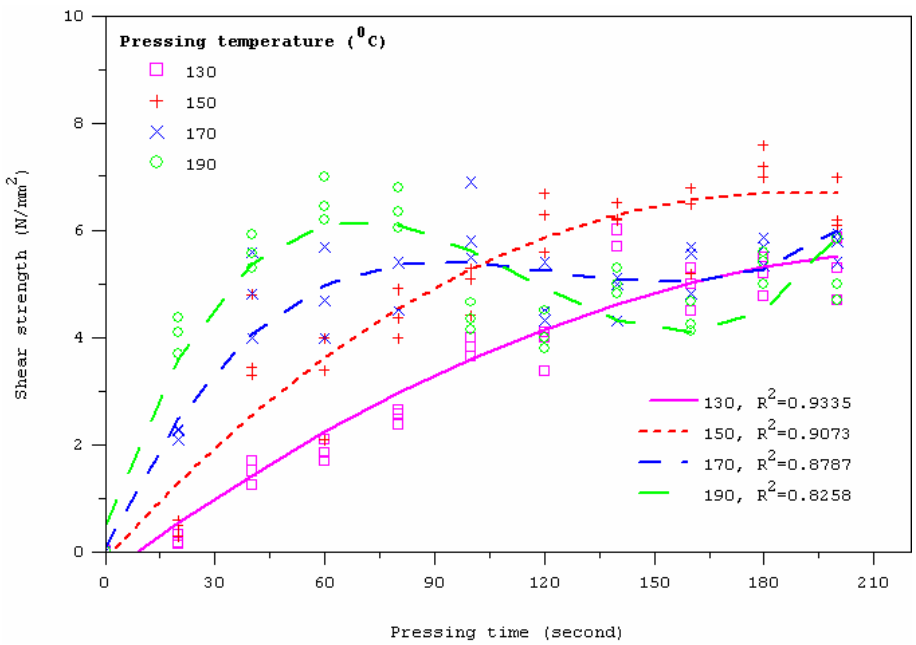


Figure 8 Development of shear strength of MUPF glued bamboo strands tested by ABES method as a function of pressing times and temperatures.

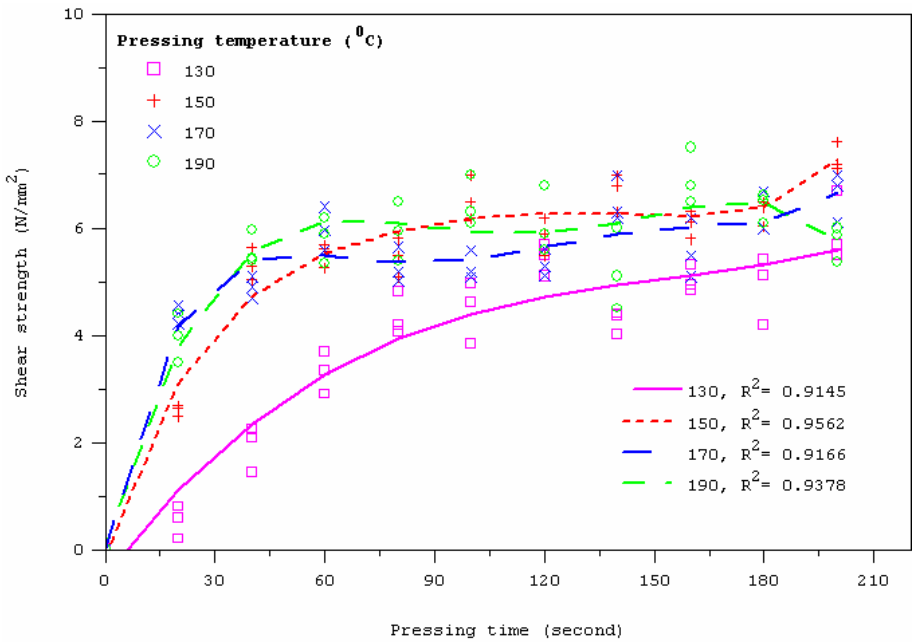


Figure 9 Development of shear strength of PF glued bamboo strands tested by ABES method as a function of pressing times and temperatures.

Influence of Pressing Temperature and Time

The results also indicate that bonding quality vary significantly with different pressing times. The effect of the higher pressing temperature is mainly related to an increase in shear strength in the glueline. The temperature increase influences the rate at which adhesive bonds develop which can be suggested by the rapidly increasing of initial strength. As usual, heat is used during the pressing for faster bonding development. The resin can cure fast when the pressing temperature increases. At low temperatures, the bonding strength is limited because the resin can not completely cure, but an excess temperature can reduce or eliminate the bonding strength in glueline as illustrates at 190°C for MF and MUPF resin (as shown in Figure 7 and 8, respectively).

Notably, most of curves for shear strength development related to pressing time could be separated into two distinct phases, where each phase can be explained the observed relation. In the first phase, which can be denoted as an initial, the shear strength is low at the beginning of the hot pressing for each temperature level since the tiny bond line occurs. After 20 seconds of pressing, strong adhesion between the adhesive and bamboo start to build up, resulting in a rapid increasing of bonding strength which causes the growth as a linear fraction of the shear strength graph. The results suggest that the higher pressing temperature, the shorter the first phase, as distinctly illustrated in Figure 9. At 150°C, the end of first phase is reached at 80 seconds pressing time, while the end of first phase for 170°C is reached in 40 seconds pressing time.

In the second phase, the bonding strength further increase with the increasing pressing time until the maximum value of each graph is reached, where the bonding strength value is highest. With the further pressing time, the strength is slightly constant. During the end of this phase, the shear strength slightly decreases with the longer pressing time at higher pressing temperature, as distinctly illustrated in 170°C for MF and 170, 190°C for MUPF resin (as presented in Figure 7 and 8, respectively). It can be observed that longer pressing time would deteriorate the completed bond which already occurs in the glueline.

Noteworthy, the bonding strength development, which were taken place at the excess temperatures (in the case of 190°C for MF and MUPF resin) behave differently. They are slightly constant and show small shear strength values. In accordance with Blomquist et al. (1983), PF resin requires high press temperatures for condensation reaction. Actually, this is the basic results on the laboratory scale. Further study is requested in order to explore this in an optimal parameter on an industrial scale.

Furthermore, the pressing temperature has a greater influence than the pressing time. At lower temperature, a longer pressing time is needed to reach the maximum bonding strength, whereas the shorter pressing time is used at a higher temperature, as distinctly illustrated in Figure 8. At 150°C, the maximum shear strength is 7.60 N/mm^2 at 180 seconds pressing time, while the maximum shear strength for 170 and 190°C is 6.90 and 7.00 N/mm^2 at 100 and 60 seconds pressing time, respectively.

Influence of Resin Types

The three adhesives, which were evaluated in this study, show different maximum shear strength. It can be seen that MF resin shows the highest shear strength value (8.90 N/mm^2) as shown in Figure 7, while the maximum shear strength value for MUPF (7.60 N/mm^2) is quite similar to that of PF (7.90 N/mm^2) as shown in Figure 8

and 9, respectively. The results suggest that all of them appear to have a similar pattern for the bond strength development, although the times, when particular phases occurred, vary with the different adhesives. Furthermore, all of them are thermosetting resins. Their cross linking reactions take place in the bond under applied pressure and heat, but their network bonding can be effect by excess temperature. It is important to note that the adhesive types vary significantly in the bonding conditions for which they are require in use, especially with regard to pressing temperature and time. MF and MUPF can harden and bond properly at lower temperature (150-170°C), while PF requires higher temperature (190°C).

Conclusions

The pH value, buffer capacity of *Dendrocalamus asper* and its bonding strength development have been analyzed. The following conclusions can be drawn from this part of the study:

1. *Dendrocalamus asper* has pH value on acid side (an average value is 5.40) which is compared to other wood species, particularly softwood. The pH value does not vary along the location of the culm.
2. Buffering capacity of the *Dendrocalamus asper* strands is shown to be 5 times higher than those of other wood species. The value slightly varies along the culm location.
3. The bond strength between bamboo strands and adhesive is improved according to ABES tests by increasing the hot pressing time and temperature. Several adhesives exhibited satisfactory bond strength. The best glueline strength between bamboo strands was found by the ABES method to be MF.

Acknowledgements

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Experimental Study of Glued Laminated Guadua as Building Material: Adhesive Calibration

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Abstract

Round G*uadua angustifolia Kunt* bamboo has been used as a structural material in Colombia for the construction of traditional houses mainly in the coffee growing region. Nonetheless, its use in large structural applications has been limited mainly because of the variation of bamboo geometrical and mechanical properties. As a consequence, and taking into account the current standardization of the construction industry, Glued Laminated Guadua (GLG) has emerged as an excellent alternative for the construction of large structural elements. Only exploratory studies have been done on the potential use of GLG as a construction material. The Universidad de Los Andes in Bogotá-Colombia is performing for the first time in Colombia a comprehensive study on the structural behavior of the GLG. The best type of adhesive as well as its optimum spread rate, based on an experimental adhesive calibration program, was determined in the first stage on this study. Static bending and glued line shear tests were performed on GLG specimens assembled with four types of adhesives and using the manufacturer recommended spread rate. Urea-Formaldehyde (UF), Melamine-Formaldehyde (MF), Melamine-Urea-Formaldehyde (MUF), and mixture of 50% of UF and 50% MF were the adhesive selected for this study. Bond shear strength of specimens manufactured with MUF was slightly higher than those using the other type of adhesives. However, the differences in shear bond strength, bending strength, and modulus of elasticity among all the adhesives were not significant, indicating that the recommended adhesive spread rate is excessive. In addition, tests were performed using six different adhesive spread rates of the mixture of 50% of UF and 50% MF, and optimum adhesive spread rate was proposed.

Introduction

Based on the Department of National Planning of Colombia, there is a lack of housing of about 2.3 million in the country. In addition, the offer to demand ratio of houses is about 0.53 showing that the housing construction is not enough to cover the demand of the growing of the population. There is also a need of new construction materials and systems in order to solve this problem. Bamboo is an interesting material to use since it has high strength to weight ratio, relative low cost, fast growing rate and reproduction capabilities (sustainability), and it helps with oxygenation of the environment and captures carbon dioxide (eco-friendly). A giant specie of bamboo called G*uadua angustifolia Kunt* grows naturally in Colombia, Venezuela and Ecuador and it has been

introduced in other Andean and Central American Countries. In Colombia, there exists about 35.000 hectares of *Guadua angustifolia kunt* and only 40 % of these Guadua is used in construction mainly as a material for falsework of concrete floors. Although, Guadua has been used in construction of structures with relative success, it has been done following experiences from previous generations called non-codified standard. In order to define the potential applications of Guadua as a construction material and its possible implementation in buildings codes extensive research need to be done to evaluate its structural behavior.

Studies have shown that round Guadua has excellent mechanical properties (Durán et al. 2002; Lopez et al. 2002; Prieto et al. 2002; Pantoja et al. 2005). Nevertheless, one of the problems with round Guadua is the variability of its geometry, mechanical properties and anatomical composition that makes this material difficult to characterize (Gritsch et al. 2004) and affecting its use in large structures. Glued laminated Guadua (GLG) has emerged as an excellent alternative, since preliminary studies (Barreto 2003; Duran 2003, Correal et al. 2008) indicated that GLG has mechanical properties as good as the best structural wood in Colombia. However, more studies are required in order to determine the actual potential use of Guadua as a construction material. The Universidad de Los Andes in Bogotá is conducting in Colombia a detailed research program on round Guadua and Glued Laminated Guadua (GLG) in order to understand the structural behavior not only under static loads but also under dynamic loads like earthquakes. This research consists of physical and mechanical characterization, strength verification of structural elements, behavior of typical connections, and seismic validations of construction systems. As a part of the mechanical characterization of the GLG an adhesive calibration experimental program has been developed. This paper reports the effect of different adhesive types and adhesive spread rate on the GLG flexural properties and internal shear bond strength. Finally, an optimum amount of adhesive is proposed based on the experimental program results.

Material

Four-year-old *Guadua angustifolia kunt* bamboo culms with an average base diameter of 7 to 14 cm and 30 m height were obtained from the city of Caidedonia-Colombia located at 1400 meters in elevation. The average thickness of the culm wall varies from 2.0 to 0.8 cm. The culms are cut into 2 to 3 meters long pieces and they were taken into the warehouse of the Colguadua Ltda factory. The fabrication process of the GLG is summarized in Figure 1(a). The 2 to 3 m long culm pieces are cut again into 1 to 1.5 m long in order to have straight pieces. Each piece is split in the radial direction into proper number of slices, and the nodes are removed from the culms. The quasi-flattened Guadua slices are passed through a grinding machine to remove the inner and outer layers. These slices are then immersed in a chemical solution to protect bamboo against insects attack, and then dried in an oven at 80 ^{o}C to reach an average moisture content of 5%. Once the slices are dried, their four faces are polished with a machine to flatten their surfaces obtaining Guadua laminae. Each Guadua lamina is about 7 to 10 mm thick, and 1 to 1.5 m long. All laminas are impregnated with adhesive resin along the narrow face (Figures 1(a) and 1(b)) and stacked to form Guadua sheeting. A hot press at 100 ^{o}C with a lateral pressure of 1.2 MPa is applied to the laminae. Once the adhesive is cured, the Guadua sheets are glued together by the wide faces in order to form boards in a hot press at a pressure of 2 MPa for 15 minutes at 100 ^{o}C.

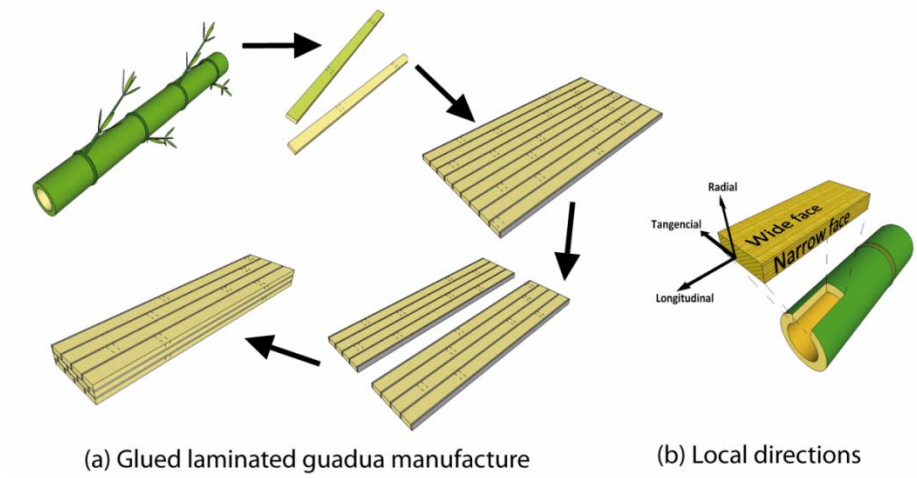

Figure 1. Manufacturing process of glued laminated Guadua

Experimental Program

The adhesive calibration program consisted of two phases. The objective of phase I was to determine the best adhesive from the point of view of its strength. For this stage four types of adhesive and two adhesive spread rate applied to the narrow and wide faces of the laminae (Figure 1b) were selected. The adhesives used were Urea-Formaldehyde (UF), Melamine-Formaldehyde (MF), Melamine-Urea-Formaldehyde (MUF), and mixture of 50% of UF and 50% MF. The adhesive spread rate used over the wide faces was 400 g/m^2 and 450 g/m^2 while adhesive spread rate used along the narrow faces was 200 g/m^2 and 250 g/m^2. This amount of adhesive was based on the adhesive manufacturer specifications and recommendations. Once the best type of adhesive is selected based on phase I results, phase II began to estimate the optimal spread rate. The spread rate used along the narrow faces was half of that used on the wide faces. The amount of adhesive on wide faces in g/m^2 selected was 260, 280, 300, 400 and 450. Five samples for each adhesive type and adhesive spread rate were tested.

Test procedures selected for the adhesive calibration program were static bending and glued line shear. Samples were tested on a MTS Universal Testing Machine in the Structural Model Lab of the Universidad de Los Andes in Bogotá, Colombia. Specimens followed the specifications given by the Colombian Institute of Standards Techniques (ICONTEC) for woody materials which are based on the ASTM standards D1037 (2006) and D143 (2007) for glued line shear and the static bending tests, respectively. The specimens used for the static bending tests were 50 x 50 mm in section, and 760 mm in length. The load was applied at the center of the 380 mm span with a load rate of 2.5mm/min. The failure load and displacement at the middle of the span were recorded, and the modulus of elasticity (MOE) and rupture (MOR) were calculated. Figure 2 presents the dimensions of the test specimen and setup for the glued line shear test. The load was applied through a self aligning seat with a continuous motion of the movable head of the testing machine with a rate of 0.6mm/min. Shear strength at failure based on maximum load was determined.

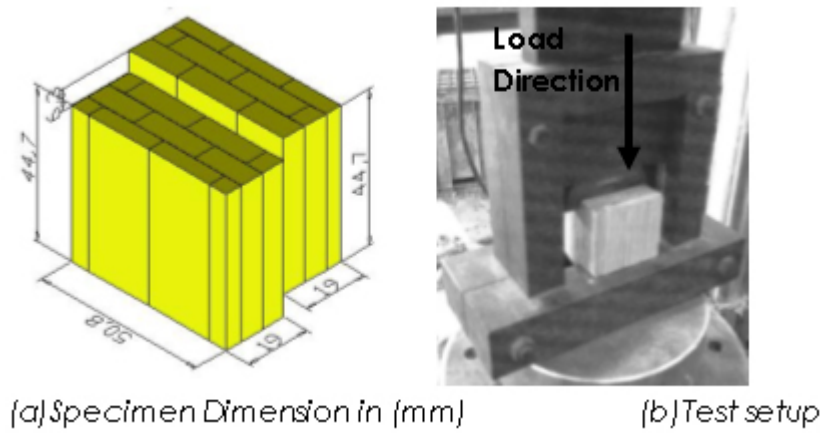

Figure 2. Glued line shear test

Results and Discussion

A total of two hundred samples were tested during the adhesive calibration program. A summary of the average stresses for glued line shear and bending tests, along with the corresponding coefficients of variation (CV) for both phases are presented in Table 1. A comparison of the bond shear strength for different types of adhesives using the spread rate specified by the manufacturer (phase I) is shown in Figure 3. Although the specimens with MUF adhesive exhibited slightly higher values of bond shear strength, there were no significant differences in this value among the four adhesives used. Moreover, the amount of the adhesive applied on the wide and narrow faces did not affect the value of bond shear strength. Similar behavior was observed for the MOE and MOR obtained from the bending tests with different type of adhesives and spread rates. Failure of the substrate (Guadua) was observed in all the specimens of glued line shear and bending tests. It seems that spread rate specified by the adhesive manufacturer was on the conservative side producing failure of the substrate.

Table 1. Summary of the average stresses for glued line shear and bending test.

PHASE I							
Adhesive		Bond Shear Stress		Bending Stresses			
				MOE		MOR	
Type	Spread Rate [g/m^2] Wide/Narrow Faces	Average Stress [MPa]	CV [%]	Average Stress [MPa]	VC [%]	Average Stress [MPa]	CV [%]
UF	400/200	12.3	3.3	13821	5.8	112	8.6
	450/200	12.9	4.0	13645	4.5	116	7.7
	400/250	12.3	6.0	14125	4.1	117	6.8
	450/250	12.7	7.7	13676	4.8	114	3.4
MF	400/200	12.9	7.1	13190	3.0	113	9.0
	450/200	13.0	2.8	14163	6.6	118	9.0
	400/250	12.0	2.9	14077	5.2	116	7.2
	450/250	13.0	6.4	13778	4.3	117	8.7

Table 1. Summary of the average stresses for glued line shear and bending test. (continuation)

PHASE I							
Adhesive		Bond Shear Stress		Bending Stresses			
				MOE		MOR	
Type	Spread Rate [g/m^2] Wide/Narrow Faces	Average Stress [MPa]	CV [%]	Average Stress [MPa]	VC [%]	Average Stress [MPa]	CV [%]
MUF	400/200	12.9	4.9	13373	2.9	110	5.2
	450/200	13.1	3.3	13301	4.8	116	3.2
	400/250	13.0	6.4	13599	4.6	113	7.2
	450/250	13.1	2.3	13451	4.0	117	6.9
50% UF + 50% MF	400/200	12.7	4.8	13737	4.2	113	6.9
	450/200	12.8	4.2	13974	7.6	116	7.7
	400/250	12.8	5.2	14022	7.8	115	6.1
	450/250	12.9	5.6	14095	4.7	117	6.4
PHASE II							
50% UF + 50% MF	260/130	9.6	12.9	13220	4.9	103	7.4
	280/140	9.5	12.3	13058	7.0	104	8.7
	300/150	13.1	7.7	13732	6.2	113	6.8
	350/175	12.9	7.5	13658	6.4	113	6.5

Durability is one of the most important properties in a structural element. Thus, it is necessary to have weather and water resistance adhesive for exterior or semiexterior structural applications in GLG. UF adhesives have low water resistance and it can be used for interior applications. In the other hand, MUF adhesives have higher

resistance to water attack compare to UF adhesives but they are usually more expensive. Therefore, a combination of UF and MF might be a practical and economical solution having an adequate performance for exterior applications. Based on phase I results, it seems that all the adhesives behave well from the strength point of view. Taking into account strength, durability and cost, the 50% UF +50% MF was the adhesive selected for the phase II of the calibration program. Figure 4 shows the average bond shear strength ± standard deviation of the specimens with 50% UF+50% MF adhesive and different spread rate. Bond shear strength remained practically constant with an average value of 13 MPa for an adhesive spread rate at wide/narrow faces of 300/150 g/m^2 and higher. For lower adhesive spread rate, 280/140 and 260/130 g/m^2, the bond shear strength was 9.5 MPa, which is 27% lower than that obtained for higher adhesive spread rates. Failure of the substrate was observed in the glued line shear specimens with adhesive spread rate at wide/narrow faces of 300/150 g/m^2 and higher. Whereas, combined failure of the adhesive and substrate was observed in the specimens with adhesive spread rate at wide/narrow faces of 280/140 g/m^2 and lower. This combine failure was achieved because the value of shear bond stress is almost the same as the value of strength parallel to the grain of GLG reported by Correal et al. (2008). In general, these results indicate that adhesive spread rate at wide/narrow faces of 300/150 g/m^2 seems to be the optimal amount of adhesive

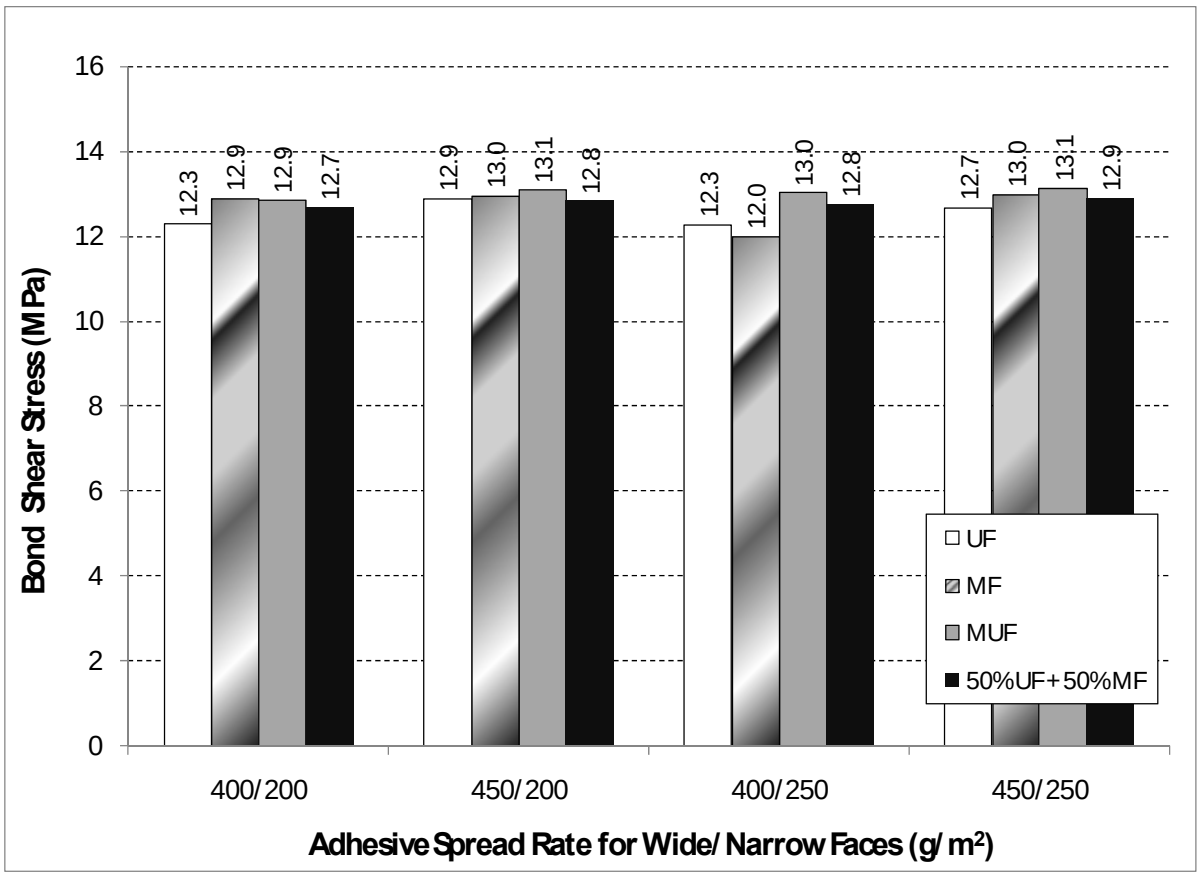

Figure 3. Bond shear strength for different types of adhesives and spread rate.

In contrast with bond shear stress, bending stresses were not drastically affected by the adhesive dosage as can be seen in Figure 5. Like bond shear strength, MOR did not change for adhesive dosages of 300/150 g/m^2 and higher. Difference of 4.5% and 7.7% were found between adhesive dosages at wide/narrow faces of 300/150 g/m^2 and 280/140 g/m^2 for MOR and MOE, respectively. MOE and MOR values are not affected by adhesive dosage because the maximum horizontal shear stress producing in the bending tests was about 4.0 MPa. This value is only 50% of the lowest bond shear strength obtained of 8.3 MPa. As a result, all of the bending specimens exhibited failure of the substrate without any delamination.

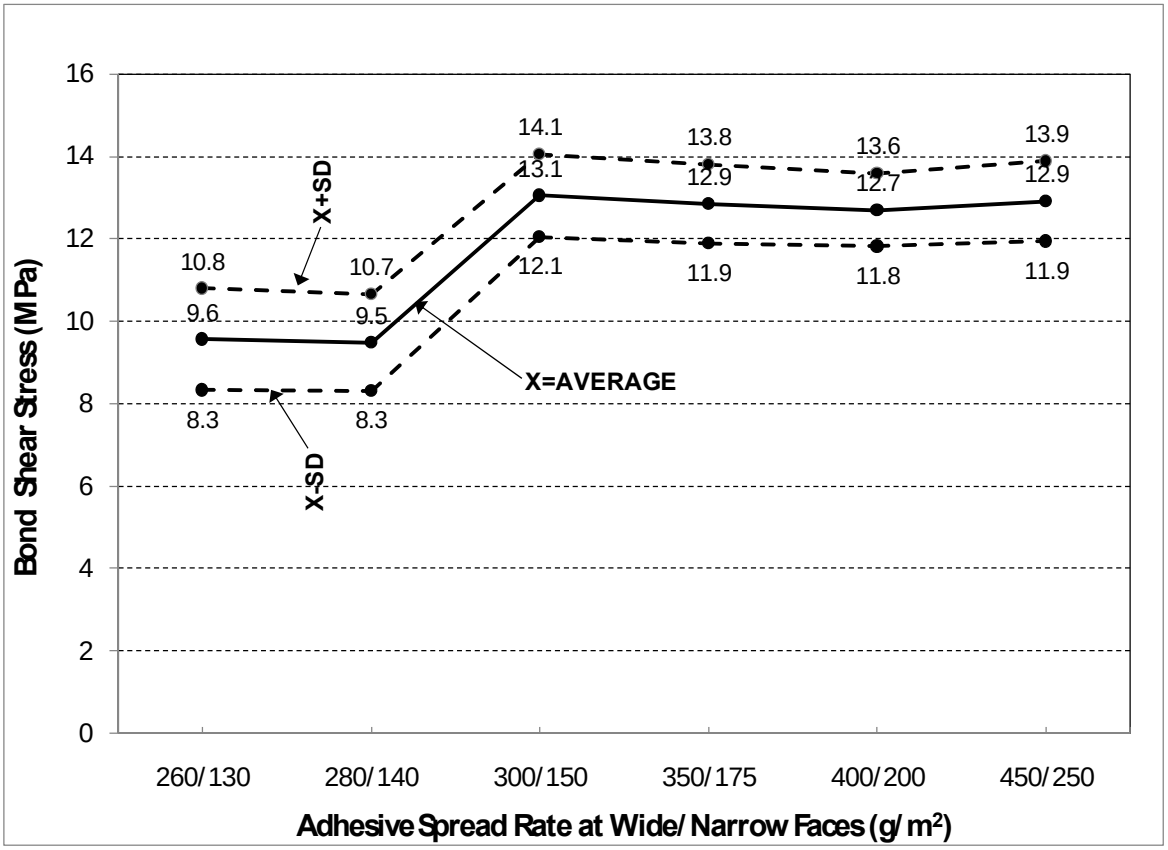

Figure 4. Bond shear strength for different adhesive spread rate of 50% UF +50% MF adhesive.

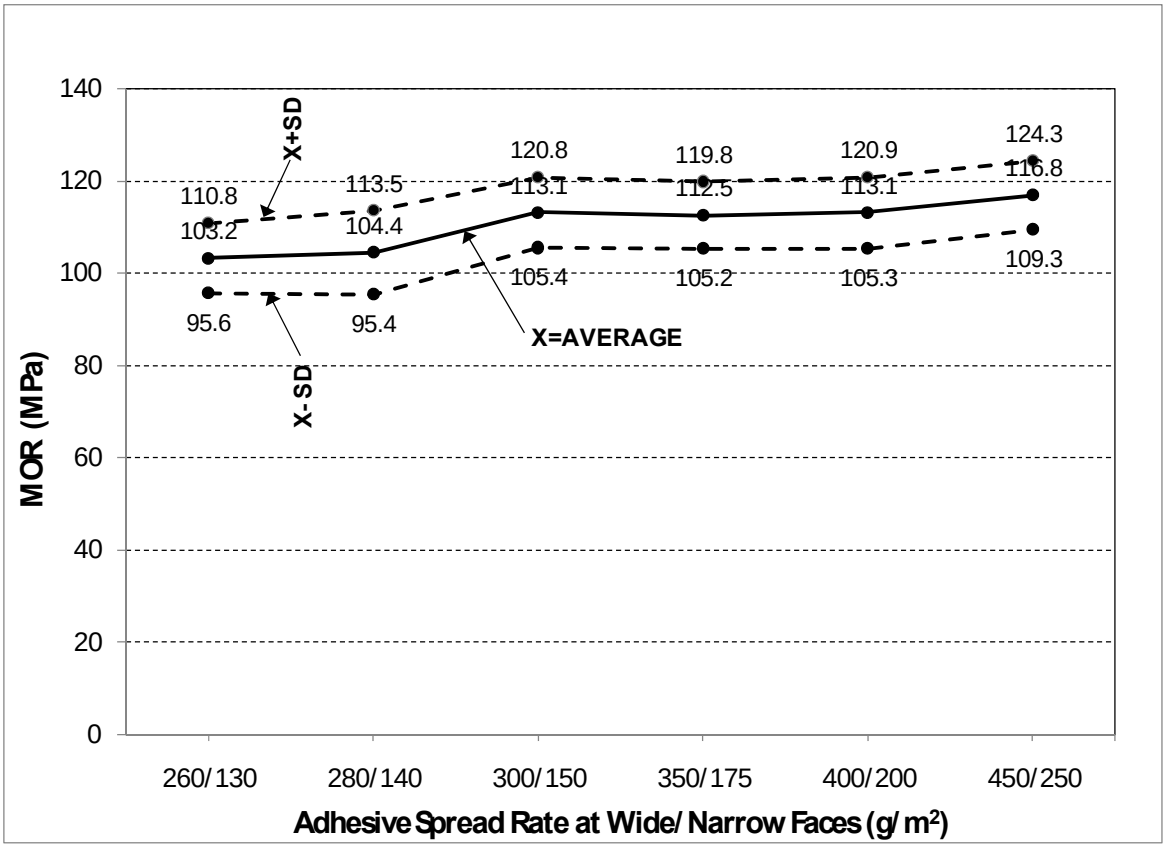

Figure 5. Modulus of rupture for different adhesive spread rate of 50% UF +50% MF adhesive.

Conclusions

Based on the results of this study, the following conclusions are drawn:

1. Bond shear strength is a good indicator of the optimal amount of adhesive to be used in any glued laminated material. The optimal amount of adhesive is reached when bond shear strength is close to the strength of the substrate, and failure of substrate is achieved. Adhesive failure need to be avoided since it is very difficult to predict.
2. Particularly for GLG, 300gr/m^2 of adhesive applied on the wide faces and 150gr/m^2 along the narrow faces is the right adhesive spread rate to use. Taking into account the adhesive spread rate recommended by the adhesive manufacturer and the optimal adhesive spread rate established in this study, substantial savings can be obtained since 66% of adhesive can be saved.
3. Bending properties (MOE and MOR) of GLG are not affected by the adhesive spread rate used in this study. This behavior is explained by the fact that the horizontal shear stresses induced by bending are lower than the bond shear strength and failure of the substrate will occur first than bond failure (delamination).

Acknowledgement

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Mechanical Properties and Failure Characteristic of Phenolic-Treated Plybamboo

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Abstract

The mechanical properties and failure characteristic of phenolic-treated (low-molecular-weight phenol formaldehyde) plybamboo made from *Gigantochloa scortechinii* were studied. The MOR, MOE and compression parallel to grain of the phenolic-treated plybamboo were significantly higher compared to those of untreated plybamboo. The failure in bending test occurred in compression and tension failure for 3 ply and rolling shear for 5-ply for phenolic-treated plybamboo. In compression parallel to grain, the crushing failure occurred. Generally, the treatment of bamboo strips with LMwPF resins was found to significantly improve the properties of plybamboo.

Keywords: impregnation, phenolic resin, plybamboo

Introduction

The improvements of lignocelluse material using impregnation method have been widely studied (Stamm and Beacheler, 1960; Hill, 2006). A significant improvement in mechanical and dimensional stability was reported when sliced birch (*Betula pendula*) was impregnated with polypropylene (Mahlberg *et al.,* 2001). Deka *et al.* (2003) noticed that when bamboo was impregnated with resin (phenol formaldehyde, urea formaldehyde or melamine formaldehyde) it caused significant increase in strength properties and exhibited higher dimensional stability.

Like many other modification systems, resin treatments are expected to influence the strength properties (Mahlberg *et al.,* 2001; Deka *et al.,* 2003; Shams *et al.,* 2004). Zaidon *et al.* (1990) found that the polyacralate influenced the mechanical properties of wood. The objective of this study was to evaluate the mechanical properties and failure characteristics of plybamboo manufactured from strips of 4-year-old *Gigantochloa scortechinii* that have been impregnated with low molecular weight (LMwPF) resin.

Material and methods

The bamboo (*Gigantochloa scortechinii*) was collected from the Forest Research Institute Malaysia (FRIM), Kepong, Selangor. The age of the bamboo was four years old. The bamboo strips were impregnated with low molecular weight phenol formaldehyde (LMwPF) resin and then the samples were dried in an oven for a few hours. The phenolic-treated bamboo strips were glued together edge-to-edge using phenol resorcinol formaldehyde (PRF) resin to produce a veneer. The veneers were then assembled perpendicular to each other to form a 3-ply (12 mm) and 5-ply (20 mm) plybamboo using phenol formaldehyde resin as a binder. The plybamboo were hot pressed at an optimum pressing condition of 140°C.

Results and Discussions

Generally, the mechanical properties of phenolic-treated plybamboo meet the minimum requirement stipulated in the Forestry Trade Standard of the People's Republic of China: LY 1055-91 (Anon, 1992[a]). Table 1 shows the effects of the resin treatment on the mechanical properties (modulus of rupture, modulus of elasticity and compression parallel to grain) of the plybamboo. Clearly, phenolic treatment had significantly ($p \leq 0.05$) improved the mechanical properties of the plybamboo. The presence of LMwPF resin apparently had strengthened the weaker parenchymatous cells comparable to the vascular bundles. Similar observation using different materials has been reported by other researchers (Kajita and Imamura, 1991; Wang *et al*., 2000; Shams *et al.,* 2004; Paridah *et al.,* 2006).

The mean value for modulus of rupture (MOR), modulus of elasticity (MOE) and compression parallel to grain of untreated and phenolic-treated plybamboo were shown in Table 1. The mechanical properties of untreated (3- and 5-ply) were lower than phenolic-treated plybamboo. For 5-ply, the values for MOR, MOE and compression parallel to grain values of phenolic-treated plybamboo were 38%, 30% and 33% higher than the untreated plybamboo (Table 1). The effect from the phenolic-treatment (LMwPF resin) was apparently more dominant in bending strength for 5-ply and in compression parallel to grain in 3-ply.

Table 2 shows the specific strength (SS, i.e., strength / density) of each sample for untreated and phenolic-treated plybamboo. The overall specific values of MOR, MOE and compression parallel to grain of untreated plybamboo, were significantly lower compared to those of phenolic-treated boards. The results suggest that, phenolic treatment did increase the mechanical strength of the plybamboo significantly ($p \leq 0.05$) as can be seen in the higher specific strength value.

The mechanical properties of phenolic-treated samples were increased due to the presence (through bulking process) of the LMwPF resin. The improvement due to: (1) the LMwPF resin increases the strength of the bamboo strips by filling the voids either fully or partially in the parenchyma cells and (2) the improvement of bonding properties due to crosslinking between LMwPF (in the strips) and PF resin (on the surface of the strips).

The failure characteristics of phenolic-treated plybamboo (3-ply) were observed to occur as compression and tension failure (Plate 1). The failure for compression originates from the area where stress is applied (from load head) and progresses vertically in both the phenolic-treated and untreated plybamboo. Tension failure was also

observed at the bottom of the samples. Same trends were noted by Zaidon *et al.* (1990) in the failure of treated wood (sweetgum and southern pine) failed normally in compression and followed by tension.

However, the rolling shears influence the stress distribution in 5-ply phenolic-treated plybamboo. From the observation during static bending,, the rolling shear occurred at perpendicular direction at 4th layer from the load head. The failure (5-ply) apparently started from compressive failures at first layer and followed by a rolling shear as shown in Plate 2. These indicate the layer (4th layer) was the weakest point where the rolling shear occurred between the vascular bundles and parenchyma.

Conversely, in untreated plybamboo (5-ply), the failure mainly occurs at the glue line between 3rd and 4th layer due to shear stress between PF glueline and bamboo veneer. Indeed, this phenomenon (glue line shear) had been used earlier by Newlin and Trayer, (1956) to explain the failure between adhesive and adherend where the failure is countered at the interfacial due to excessive shear deformation.

In compression parallel to the grain test, when the stress were applied on axial on the plybamboo samples, the outer region (first and fifth layer of a 5-ply board) shows signs of collapsing first while the middle layer resists. However, as the first layer collapses, the stresses rapidly concentrate and spread at the perpendicular orientation and thus forming which perform crack across the thickness of the lamilae. The failure occurred mainly at the topside of the specimen either 3- or 5-ply (Plate 3) of untreated and phenolic-treated plybamboo, which was indirect contact under the loading head.

Hamdan (2004) noted the failure in axial compression is usually initiated by the formation of minute compression failures ("kinking" or slip planes) in the cell wall and when the maximum strength is attained, gross macroscopically visible crushing and shearing bands arise due to buckling of the cell wall. Hidalgo (1993) explained that the uneven distribution of stress in the bamboo culms induces relative tensions in the innermost ring resulting in stress-displacement difference leading to longitudinal crack formation.

Conclusions

The study has proven that treating the bamboo strips with LMwPF resin had improved the strength of plybamboo made from it. Based on the mean value and specific strength (i.e., strength/density) of phenolic-treated plybamboo, these improvements were significant even after excluding the board density factor. In terms of failure characteristics, there is similar failure behavior between untreated and phenolic-treated plybamboo for 3-ply in compression and tension. The modes of failure were different for 5-ply phenolic-treated and untreated plybamboo. Crushing failure at the top end of the sample occurred during compression parallel to the grain test.

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Table 1. Mechanical properties of untreated and phenolic-treated plybamboo

Plybamboo specimen	Mean value (Nmm^{-2})			Strength improvement (%)		
	MOR	MOE	Comp.//	MOR	MOE	Comp.//
	3-ply (12 mm)					
Untreated	127[a] (8)	16778[a] (1375)	41[a] (5)			
Phenolic-treated	164[b] (18)	19767[b] (2393)	60[b] (5)	29	18	46
	5-ply (20 mm)					
Untreated	115[a] (7)	13561[a] (1245)	45[a] (5)			
Phenolic-treated	159[b] (16)	17648[b] (1474)	60[b] (4)	38	30	33

Note: MOR= Modulus of Rupture; MOE: Modulus of Elasticity; Comp.//: Compression parallel to the grain.
Values are average of 240 specimens
Values in parentheses are standard deviations
Means followed with the same letters [a,b] in the same column are not significantly different ($p \leq 0.05$)

Table 2. Specific strength of untreated and phenolic-treated plybamboo

Plybamboo specimens	Specific strength ($MNm\,kg^{-1}$)		
	SS MOR	SS MOE	SS Compression // to grain
		3-ply (12 mm)	
Untreated	0.16^{a}	20.8^{a}	0.05^{a}
Phenolic-Treated	0.19^{b}	23.4^{b}	0.07^{b}
		5-ply (20 mm)	
Untreated	0.14^{a}	16.3^{a}	0.05^{a}
Phenolic-Treated	0.17^{b}	19.2^{b}	0.07^{b}

Note: SS MOR = Specific strength MOR= MOR/Density
SS MOE = Specific strength MOE= MOE/Density
SS Compression$_{//}$ to grain = Specific strength Compression parallel to grain = Compression$_{//}$ to grain /Density
Means followed with the same letters ^{a,b} in the same column are not significantly different ($p \leq 0.05$)

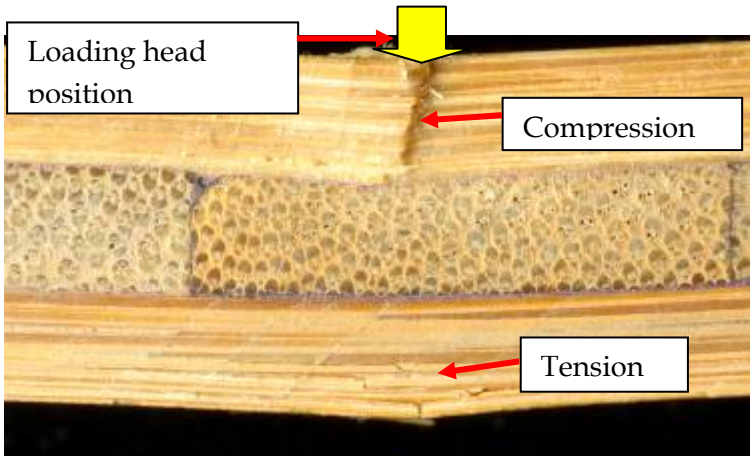

Plate 1. Failure of 3-ply phenolic-treated plybamboo in compression and tension after static bending test

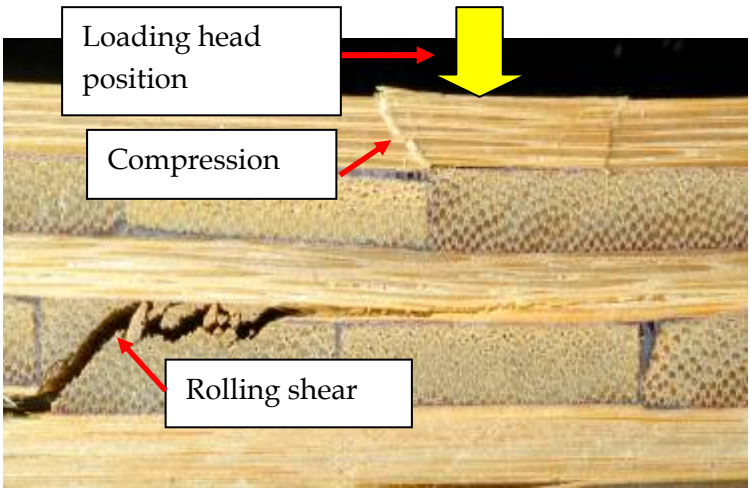

Plate 2. Failure of 5-ply phenolic-treated plybamboo in compression and rolling shear at 4th layer during static bending test

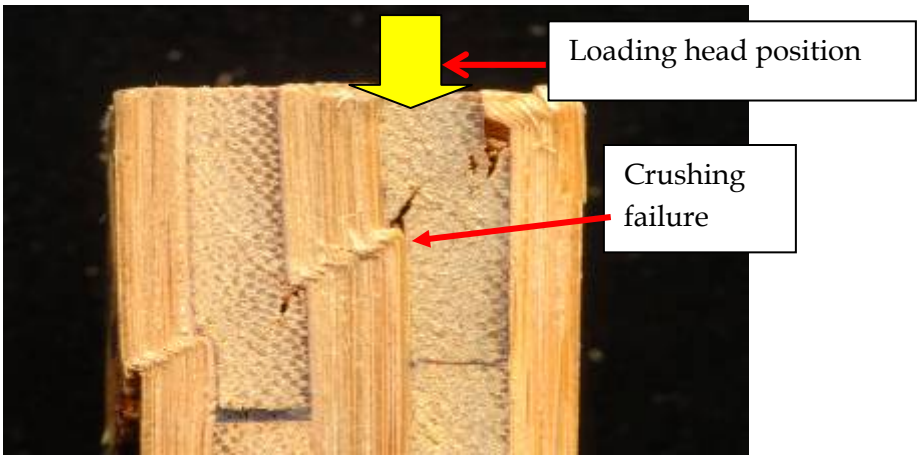

Plate 3. Failure at 5-ply phenolic-treated plybamboo in compression parallel to the grain test (edge view)

Alkali-oxygen Pulping on Steam-explosion Pretreated Bamboo Species

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Abstract

A study was conducted on the morphology of the fibers and chemical composition of the 3-years-old bamboo-culm of *Thyrsostachys siamensis*, *Dendrocalamus latiflorus*, and *Bambusa arundinacea* for pulping them by alkali-oxygen process. This pulping conditions was pretreatment with steam pressure varied at 21 kg/cm^2 for 5 minutes follow by soaking with 1% NaOH, liquor to wood ratio 10:1 at 90 ^{o}C for 10 minutes and cooking with 15% NaOH, liquor to wood ratio 4:1 with oxygen pressure at 7 kg/cm^2 at 105 ^{o}C for 90 minutes. Pulps produced from different species of bamboo-culms were about 38.80-55.40% yield at the Kappa numbers ranged 9.74-15.91. Bleaching in different sequences both ECF and TCF, Z-P-Z-P bleaching sequence provided appropriate high brightness of all species and followed by D-P-D-P bleaching sequence and P-P bleaching sequence. Bleached Pulps manufactured from alkali-oxygen process and bleached with Z-P-Z-P sequence from 3 years-old *T. siamensis*, *D. latiflorus*, and *B. arundinacea* had high brightness of 80.00-90.70% and good strength properties in burst index, tear index, tensile index and folding endurance of 1.18-1.75 KPa.m^2/g, 5.84-9.11 mN.m^2/g, 15.49-29.21 N.m/g, and 1.36-4.74, respectively and also are classified as fitting for printing and writing paper.

Keywords: The 3-Years-old Bamboo Culms of *Thyrsostachys siamensis* , *Dendrocalamus latiflorus*, and *Bambusa arundinacea*, Alkali-oxygen Process, Product Quality from Bleached Pulp with ECF and TCF Bleaching, and Utilization.

Introduction

There are numerous species of edible bamboo in Thailand. Bamboos are planted widely in several provinces, most are in central Thailand such as Kanchanaburi, Nakornayok and Pachinburi etc. The most important purposes are for food, craft, industry, furniture, house structure in addition to raw material for pulping (11). Bamboo has been used as a raw material for pulping in Thailand for most 30 years. Bleached pulp produced from bamboo has good quality and is excellent for wrapping paper and printing and writing papers (3, 9, 12). In India bamboo is used as raw material for pulping about 66% of all pulp productions (10). Bamboo has long fiber and is a major raw material as a non-wood (9). Chemical pulping creates deplorable environmental pollution and

appalling odor. Throughout the preceding few decades new pulping technology has been developed to resolve the environmental dilemma. New technologies are implemented in countless industries including pulp and paper industry. The purpose of this study is pulping from three species of bamboo-culms by a flawless technological process in implementing an alkali-oxygen process and this process condition is pretreatment with steam pressure at 21 kg/cm^2 for 5 minutes follows by soaking with 1% NaOH, liquor to wood ratio 10:1 at 90 ^{o}C for 10 minutes and cooking with 15% NaOH, liquor to wood ratio 4:1 with oxygen pressure at 7 kg/cm^2 at 105 ^{o}C for 90 minutes (1). Pulps produced are bleached by total chlorine-free (TCF) using Ozone (Z) – Hydrogen peroxide(P)-Ozone(Z)-hydrogen peroxide(P) sequence to compare the quality pulps, those bleached by total chlorine-free using P-P sequence and by elementary chlorine free (ECF) using Chlorine dioxide (D)-P-Chlorine dioxide, (D)-P sequence and also estimate to bleached pulp utilization of paper industry.

Experiment

Bamboo culms of species *Thyrsostachys siamensis* , *Dendrocalamus latiflorus*, and *Bambusa arundinacea* , 3 years old were supplied from project areas in Kanchannburi province and chipped in a laboratory by a chipper. Chips were screened to eliminate the undersize and oversize and to get the acceptable length of 5/8-1 inches and, subsequently seasoned to dry.

1. Morphological raw fiber was analysed for standard dimensions e.g. length, width, lumen diameter and cell wall thickness in according to the Franklin method (8). The calculations were made on Runkel ratio, flexibility coefficient, slenderness ratio and percentage of wall fraction for predicting fiber quality.

2. Chemical analyses of raw material made use of an average with respect to the Technical Association of the Pulp and Paper Industry (TAPPI) test method (5) such as solubility in alcohol, alcohol-benzene (T204-cm-97), hot water (T207-cm-97), 1%NaOH (T212-om-98), ash (T211-om-93), lignin(T222-om-88), alpha-cellulose (T203-om-88) and pentosan (T223-cm-01) with the exception of holocellulose by sodium chlorite method (6).

3. Pulping from the bamboo chips by alkali-oxygen process were prepared with steam pressure varied at 21 kg/cm^2 for 5 minutes follow by soaking with 1% NaOH, liquor to wood ratio of 10:1 at 90° C for 10 minutes and cooking with 15% NaOH, liquor to wood ratio of 4:1 under oxygen pressure 7 kg/cm^2 at 105° C for 90 minutes (1). Bamboo pulps from this process were analyzed by average the means of mutually screened and rejected yield and kappa number (T236-cm-99)

4. Bleaching pulps by D-P-D-P series for alkali-oxygen pulp. The conditions used are summarized in table 1.

Table 1: Condition for bleaching by D-P-D-P sequence

Items	Stage			
	D	P	D	P
Chemical charge,%	0.2xkappa no.	1	0.2	1
NaOH,%	-	1	-	1
Na_2SiO_3, %	-	1	-	1
$MgSO_4$,%	-	0.05	-	0.05
Consistency,%	10	12	10	12
Temperature, ^oC	80	90	80	90
Time, minute	120	120	120	120

Pulps produced were bleached by Z-P-Z-P sequence or P-P sequence for alkali-oxygen pulp. The conditions used are summarized in table 2.

Table 2: Condition for bleaching by Z-P-Z-P or P-P sequence

Items	Stage			
	Z	P	Z	P
Chemical charge,%	2.5	2	2.5	2
CH_3COOH, %	10	-	5	-
NaOH,%	-	1	-	1
Na_2SiO_3, %	-	1	-	1
$MgSO_4$,%	-	0.05	-	0.05
Consistency,%	4	12	4	12
Temperature, ^oC	25	90	25	90
Time, minutes	40	120	40	120

5. Physical properties analyzed by averaging those screened pulp yields used each species of bamboo-culms of the same pulping processes were disintegrated for 5 minutes, beating with appropriated revolutions and measured freeness of 300 ml (T227-om-99). The standard hand-sheets were tested for physical properties according to TAPPI Standards (T220-sp-01) on weight basis, burst strength, tear strength, tensile strength, stretch, folding endurance, brightness and opacity.

Results and Discussion

1. Morphological fiber

Mean average of fiber dimensions of 3 years-old *T. siamensis* , *D. latiflorus*, and *B. arundinacea* are shown in Table 3.

Table 3: Morphological fiber of three species of bamboo culms and anatomical properties

Items	*Thyrsostachys siamensis*	*Dendrocalamus latiflorus*	*Bambusa Arundinacea*
Length, mm	2.80	2.18	2.27
Width, µm	27.25	21.01	23.19
Lumen width, µm	10.51	11.35	3.45
Cell wall thickness, µm	8.37	4.83	9.87
Runkel ratio	1.59	0.85	5.72
Flexibility coefficient	0.39	0.54	0.15
Slenderness ratio	102.59	103.56	97.90
Wall fraction (%)	61.44	45.99	85.12

The table 3 showed that the lengths of fiber were respectively 2.80, 2.18 and 2.27 mm and defined them as long fibers(2). The highest length, width, lumen width and cell wall thickness were shown of *T. siamensis*, *T. siamensis*, *D. latiflorus*, and *B. arundinacea*, respectively. The lowest length, width, lumen width and cell wall thickness were for *D. latiflorus*, *D. latiflorus*, *B. arundinacea* and *D. latiflorus*, respectively. The range of Runkel ratio, flexibility coefficient, slenderness ratio, and percentages of wall fraction were respectively 0.85-5.72, 0.15-0.54, 97.90-103.56 and 45.99-85.12%. It is probable that pulp properties with Runkel ratio more than 1 would be harder in tension for fiber and less oriented fiber to make paper into fluffiness(7) except *D. latiflorus*, with flexibility coefficient less than 0.5. The paper had low tensile strength, burst strength and folding endurance apart from *D. latiflorus*, with slenderness ratio more than 75 were the paper of the best tear strength and with percent of wall thickness more than 40 percent would be thus poor paper while fibers completely oriented to get lower tensile and burst strength.

2. Chemical composition

The chemical compositions of 3 years-old *T. siamensis*, *D. latiflorus*, and *B. arundinacea* were showed in table 4.

Table 4: Chemical compositions of three species of bamboo-culms

Component (% by ODRM)	*Thyrsostachys siamensis*	*Dendrocalamus latiflorus*	*Bambusa arundinacea*
Alcohol-benzene solubility	6.19	3.53	3.96
Alcohol solubility	2.22	1.49	2.01
Hot water solubility	3.02	4.54	5.52
Total extractive	11.43	9.51	11.48
1%NaOH solubility	23.63	26.81	25.79
Ash	2.49	1.71	2.23
Lignin	23.79	23.31	23.02
Holocellulose	62.30	65.48	63.27
Alfa cellulose	36.22	41.02	38.20
Pentosan	11.94	14.35	12.12

The table 4 showed that *T. siamensis* had the highest solubility in alcohol and alcohol-benzene, and *B. arundinacea* was the highest in water solubility. *D. latiflorus* had the lowest solubility in alcohol and alcohol-benzene and *T. siamensis* had the lowest solubility in water and 1% NaOH. *B. arundinacea* had the highest extractive, and *T. siamensis* had the highest ash content while the lowest was shown *D. latiflorus*. Lignin content was highest for *T. siamensis* and lowest for *B. arundinacea*, and were in the range of 23.02-23.79% on the ovendried basis of raw material (percentage of ODRM). These values are on the side and showed that the pulps were somewhat easy to delignify. Holocellulose and alfa-cellulose content were highest for *D. latiflorus* and the lowest for *T. siamensis*, and in the range of 62.30-65.48, 36.22-41.02% of ODRM. It signified that the pulp yield was expected to be higher for *D. latiflorus* in relative to *B. arundinacea*, and *T. siamensis*. Pentosan content ranged from 14.35% of ODRM for *D. latiflorus* to 11.94% ODRW for *T. siamensis*. This implied the insufficient amount remained on pulp to increase physical properties of paper in burst strength and folding endurance.

3. Pulp yield production

Pulp yield and kappa number of three species of bamboo-culms by alkali-oxygen process are in tables 5.

Table 5: Yield and kappa numbers of three species of bamboo-culms by alkali-oxygen process

Species	Steam pressure (kg/cm2)	Yield (%)		Kappa no.
		Accepted	Reject	
Thyrsostachys siamensis	21	38.80	0.30	15.91
Dendrocalamus latiflorus	21	52.16	0.02	9.74
Bambusa arundinacea	21	55.40	0.35	13.29

Remark: Alkali-oxygen process was pretreatment with steam pressure at 21 kg/cm^2 for 5 minutes followed by soaking with 1% NaOH, liquor to wood ratio 10:1 at 90 ^{o}C for 10 minutes and cooking with 15% NaOH, liquor to wood ratio 4:1 with oxygen pressure at 7 kg/cm^2 at 105 ^{o}C for 90 minutes

Table 5 showed that pulping with steam explosion pre-treatment of 21 kg/cm^2, *B. arundinacea* pulp yield of 55.40% was higher than *D. latiflorus* and *T. siamensis* of 52.16, 38.80% of ODM respectively. *D. latiflorus* had lower Kappa number than *B. arundinacea* and *T. siamensis* (9.74, 13.29 and 15.91 respectively).

4. Physical properties of pulp

The pulps from *T. siamensis, D. latiflorus* and *B. arundinacea* by alkali-oxygen process was beaten until freeness of 300 ml obtained, then formed them to the standard hand-sheets. Physical properties were shown in table 6.

Table 6: Comparison of physical properties of three species of bamboo-culms pulp by alkali-oxygen process at 300 ml freeness

Items	*Thyrsostachys siamensis*	*Dendrocalamus latiflorus*	*Bambusa arundinacea*
PFI mill, rounds	2,536	544	2,692
Burst index, KPa. m^2/g	1.30	0.83	2.02
Tear index, mN. m^2/g	7.88	2.75	11.73
Tensile index, N.m/g	21.56	10.92	31.51
Breaking length, km	2.19	1.12	3.20
Stretch, %	1.26	0.62	1.87
Folding endurance,	16.60	0.00	7.75
Brightness, %	15.75	47.44	39.92
Opacity, %	99.26	95.63	96.15

Tables 6 showed that strength properties between the bamboo genus and species for alkali-oxygen process, *B. arundinacea* was highest in burst index, tear index and tensile index. *T. siamensis* had highest folding endurance, and *D. latiflorus* had the highest brightness. If strength properties were to be taken into account

between species; it indicated that *D. latiflorus* pulp was weaker in burst index, tear index, tensile index, and folding endurance, but brighter than *B. arundinacea* and *T. siamensis*, respectively.

5. Physical properties of bleached pulp

The alkali-oxygen pulp of *T. siamensis, D. latiflorus* and *B. arundinacea* bleached by P-P, Z-P-Z-P and D-P-D-P sequence and were shown in tables 7, 8 and 9.

Table 7: Comparison of physical properties of three species of bamboo-culms bleached pulp with P-P by alkali-oxygen process at 300 ml freeness

Items	*Thyrsostachys siamensis*	*Dendrocalamus latiflorus*	*Bambusa arundinacea*
PFI mill, rounds	2,034	367	2,722
Burst index, KPa. m^2/g	1.38	0.80	1.52
Tear index, mN. m^2/g	8.76	2.12	5.65
Tensile index, N.m/g	24.19	7.41	20.60
Breaking length, km	2.45	0.75	2.11
Stretch, %	1.40	0.48	1.24
Folding endurance,	4.78	0.00	1.89
Brightness, %	29.45	72.74	59.08

Table 8: Comparison of physical properties of three species of bamboo-culms bleached pulp with Z-P-Z-P by alkali-oxygen process at 300 ml freeness

Items	*Thyrsostachys siamensis*	*Dendrocalamus latiflorus*	*Bambusa arundinacea*
PFI mill, rounds	2,000	1,100	1,900
Burst index, KPa. m^2/g	1.75	1.18	1.68
Tear index, mN. m^2/g	5.96	5.84	9.11
Tensile index, N.m/g	17.93	15.49	29.21
Breaking length, km	1.89	1.59	2.97
Stretch, %	0.34	0.27	0.41
Folding endurance,	1.75	1.36	4.74
Brightness, %	83.71	90.70	80.00

Table 9: Comparison of physical properties of three species of bamboo-culms bleached pulp with D-P-D-P by alkali-oxygen process at 300 ml freeness

Items	*Thyrsostachys siamensis*	*Dendrocalamus latiflorus*	*Bambusa arundinacea*
PFI mill, rounds	2,366	691	2,548
Burst index, KPa. m^2/g	1.50	0.82	2.02
Tear index, mN. m^2/g	8.64	2.52	8.52
Tensile index, N.m/g	25.68	8.35	25.56
Breaking length, km	2.61	0.86	2.50
Stretch, %	1.42	0.63	1.68
Folding endurance,	5.43	0.00	4.04
Brightness, %	54.05	90.05	88.91

Tables 7, 8 and 9 showed the strength properties of alkali-oxygen bleached pulps by P-P sequence, *D. latiflorus* was somewhat brighter (72.74%) than the others (29.45-59.08%), but *T. siamensis* had higher tear index, tensile index and folding endurance and *B. arundinacea* had higher burst index than others. With the Z-P-Z-P sequence , *D. latiflorus*, *T. siamensis*, and *B. arundinacea* were brightness of 90.70-80.00%, and they had burst index, tear index, tensile index and folding endurance of 1.18-1.75 KPa.m^2/g, 5.84-9.11 mN.m^2/g, 15.49-29.21 N.m/g, and 1.36-4.74, respectively. It is evident from this table 8, these three species of bamboo-culms pulped with the alkali-oxygen process and bleached with Z-P-Z-P sequence are probably appropriate for printing and writing paper in compliance with Thai Industrial Standards - TIS (4) as they have burst index of 1.18 -1.75 KPa.m^2/g, and brightness of 80.00-90.70%. And with the D-P-D-P sequence, *D. latiflorus*, and *B. arundinacea* were brighter (90.05-88.61%) than *T. siamensis* that only achieved 54.05%. *B. arundinacea* had higher bursting index, tear index, tensile index, and folding endurance than *D. latiflorus*. It is evident from this table 9, *B. arundinacea* pulped with the alkali-oxygen process and bleached with D-P-D-P sequence are probably appropriate for printing and writing paper in compliance with Thai Industrial Standards - TIS (4) as they have burst index of 2.02 KPa.m^2/g, and brightness of 88.91%. If the strength properties of alkali-oxygen bleached pulps were to taken into account between bleaching procedure to be found that Z-P-Z-D sequence and D-P-D-P sequence gave brighter pulps than P-P sequence.

Conclusions

Bamboo culms are a viable alternative for paper makers in quest of an ideal quality, an inexpensive source of non-wood fiber. It is obvious that all of bamboo culms yield anatomically long fiber. They have diverse morphological fiber and chemical composition affect of pulp yield and pulp quality. The different species of bamboo-culms were produced pulp about 38.80-55.40% yield at the Kappa numbers ranged 9.74-15.91. by alkali-oxygen process with steam explosion pretreatment at 21 kg/cm^2 for 5 minutes, followed by soaking with 1% NaOH, liquor to wood ratio 10:1 at 90 ^oC for 10 minutes, and cooking with 15% NaOH, liquor to wood ratio 4:1 with oxygen pressure at 7 kg/cm^2 at 105 ^oC for 90 minutes. Bleaching in different sequences both ECF and TCF, Z-P-Z-P bleaching sequence provided appropriate high brightness of all species and followed by D-P-D-P bleaching sequence only two(*D. latiflorus*, and *B. arundinacea*) and P-P bleaching sequence only one(*D.*

latiflorus). Bleached Pulps manufactured from alkali-oxygen process and bleached with Z-P-Z-P sequence from 3 years-old *T. siamensis*, *D. latiflorus*, and *B. arundinacea* had high brightness of 80.00-90.70% and good strength properties in burst index, tear index, tensile index and folding endurance of 1.18-1.75 KPa.m^2/g, 5.84-9.11 mN.m^2/g, 15.49-29.21 N.m/g, and 1.36-4.74, respectively and also are classified as suitable for printing and writing paper.

Acknowledgments

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Study of the Behaviour of Guadua Angustifolia Kunth Frames

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Abstract

As the Colombian code for earthquake resistant design and construction of buildings NSR-98 does not include provisions for the design of bamboo frames and the use of frames is an alternative to the load-bearing walls systems, The National University of Colombia has carried out an extensive research project about the behaviour of bamboo frames, aimed at the application of this sort of structures to house construction. In a first part of the research was investigated the behaviour of four different types of beam-column connections, as well as the performance of the best connection as part of a planar frame. For this, a real scale frame was build, with its beam-column joints easily to build and all the elements cut straight. In a second stage, planar frames with diagonal cables to restrict the lateral movement were tested. In a third stage, the behaviour of two different kinds of wall boards was investigated, in addition to the performance of the frame built with the panels. For this stage, numerical simulations were carried out for all the structural elements tested. Finally, in the last stage were tested tridimentional frames with diagonal bamboo elements and with the results was suggested the best structural configuration for a two-story house.

Keywords: Bamboo frames, Guadua Angustifolia Kunth, beam-column connections.

Introduction

Since many years ago, it has been common in Colombia build traditional houses using bahareque wall systems (the main constructing material is the local bamboo, combined with chicken steel meshes and plastered with cement mortar), however, the first construction recommendations were made just after the Quindio earthquake

in 1999. The title E of the Standard Building "Bahareque houses of one and two stories" was proposed by the Colombian National Association of Earthquake Engineering (AIS) after an investigation about this construction system. Despite the fact that many investigations have been carried out, there are still some questions about the design of bamboo structures; especially with bamboo frame systems.

As structural systems of seismic resistance can be classified the moment-resistant frames, the concentric or eccentric frames with diagonals, or the load-bearing walls. In the first and second systems the frames are responsible for resisting both vertical and horizontal loads, while in the load-bearing walls system the walls are responsible for that function. It is possible as well to have combined systems, where the vertical loads are not necessarily supported by moment-resistant frames and the horizontal loads are supported by frames with diagonals or structural walls.

The bahareque structures work similar to the load-bearing wall systems, resisting the vertical and horizontal loads. However, the use of frames gives more architectonic flexibility because there is no necessity of some geometrical restrictions. Taking into account the benefits of using bamboo frames and considering that the Colombian code for earthquake resistant design and construction of buildings, NSR-98, does not include provisions for the design of bamboo frames, in the National University of Colombia has carried out an extensive research project that include several topics about the behaviour of bamboo frames.

In a first part of the research was investigated the behaviour of four different types of beam-column connections and the performance of the best connection as part of a planar frame. For this, a real scale frame was build, with its beam-column joints easily to build and all the elements cut straight. In a second stage, planar frames with diagonal cables to restrict the lateral movement were tested. In a third stage, the behaviour of two different kinds of boards was investigated, in addition to the performance of the frame built with the panels. For this stage, numerical simulations were carried out for all the structural elements tested. Finally, in the last stage were tested special frames with diagonal bamboo elements and with the results was suggested the best structural configuration for a two-story house.

Standard Frame

The same planar frame with standard dimensions was used throughout the entire project. The process of design and construction are summarised below.

Design

The construction of the guadua frames was planned to be quick and inexpensive, with an industrialized process carried out mechanically and in a short time.

Elements

The structures built in this research had two stories and one or two spans in each direction. The length of the spans depended on the internal architectonical distribution. Defined the dimensions of the structure, the bamboo

elements were revised in order to have enough section to resist the external loads, and the culms were properly assembled.

Because of its natural conditions, the geometry of bamboo is a prismatic tube of hollow circular section. In order to form a structural section, each culm had its axis parallel to the longitudinal axis of the element, either a column or a beam, so the cross section of the structural element is made up of circular hollow sections.

In order to increase the inertia of the assembled structures and to make the construction of the connections easy, each culm was separated of each other using additional elements. The columns were formed by four culms and had additional elements forming cross sections. The beams were formed by two culms along its length, separated by short elements of bamboo (figure 1). All the bamboo elements were connected together by threaded bolts.

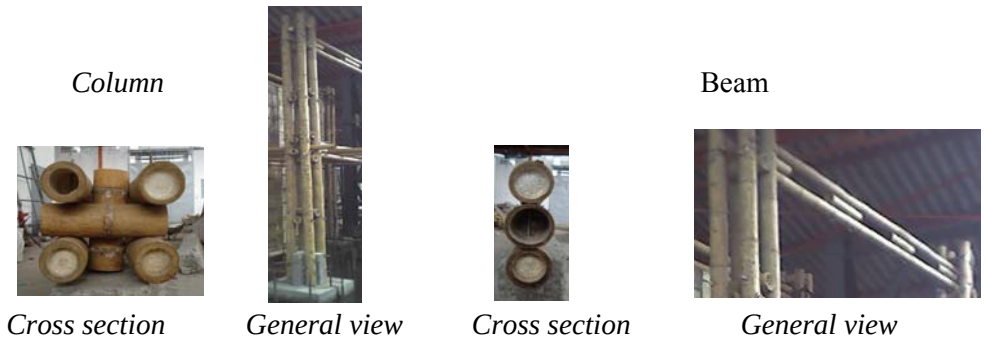

Figure 1. Cross section and general views of the column and the beam of the standard frame

Design of connections

Easy and speed connections were selected and built, so complex cuttings and anchorages were eliminated because of the delay in the execution and the increase of the costs. All the element cuttings were straight and simple. On the other hand, in the connection design was included the geometry of beams and columns, so the beams fitted within the four column culms. The connection between those elements was made with threaded rods.

Construction

Materials

The structures were made up with Guadua Angustifolia Kunth, Macana variety not immunized. With an age ranged between 4 and 5 years, obtained from Armenia (Quindío, Colombia). For the beams the diameter of the elements ranged between 8 and 13 cm, and for the columns it ranged between 10 and 13 cm. After an exhaustive selection were not included elements with twists or cracks, and was not observed the presence of fungi or insects.

Construction

Figure 2 shows the selection of the elements to form beams and columns.

Figure 2. Elements selected and cut for construction of the standard frame

Figure 3 shows the construction of the frames after the prefabrication of beams and columns

Figure 3. Frame assemble

Investigation of the behaviour of a guadua angustifolia beam–column connection

In this first stage of the project was investigated the mechanical behaviour of a beam-column connection. A total of fifteen experimental tests of four different kinds of beam–column joints and three tests of planar frames were carried out. In addition, the best connection was analyzed using the finite element method, while the frames were studied theoretically using standard matrix analysis. (Lamus 2008).

Experimental methods

The mechanical properties of the bamboo were determined following the ISO 22157 recommendations. 40 tests of shear strength parallel to the fibre, 40 tests of compressive strength parallel to the fibre, and 20 tests of tensile strength parallel to the fibre were carried out. In addition to the standard tests, several non-standardized tests were done, such as 20 tests of radial compressive strength, 20 tests of tensile strength perpendicular to the fibre, and two torsion tests (Figure 4).

Figure 4. Laboratory tests: Shear parallel to the fibre, compression parallel to the fibre, tension parallel to the fibre, radial compression, tension perpendicular to the fiber, torsion.

With the results of the initial tests, the characteristic properties and values were calculated, including the longitudinal elastic modulus, the circumferential elastic modulus, and the shear modulus of rigidity.

The configuration of the connections used during the tests was determined assuming that these corresponded to the intermediate node of a two-story planar frame (2.9 m height and 4m of span). As a result, a T-shaped union was evaluated. In each test the column was supported horizontally at two points separated 2.9 m and the beam was in vertical position attached to the column at one end, and the other at cantilever. The load was applied horizontally in the same plane than the connection to the beam. Displacement measurements were taken at the top of the beam, at the support where the load was applied and at the connection. (Figure 5)

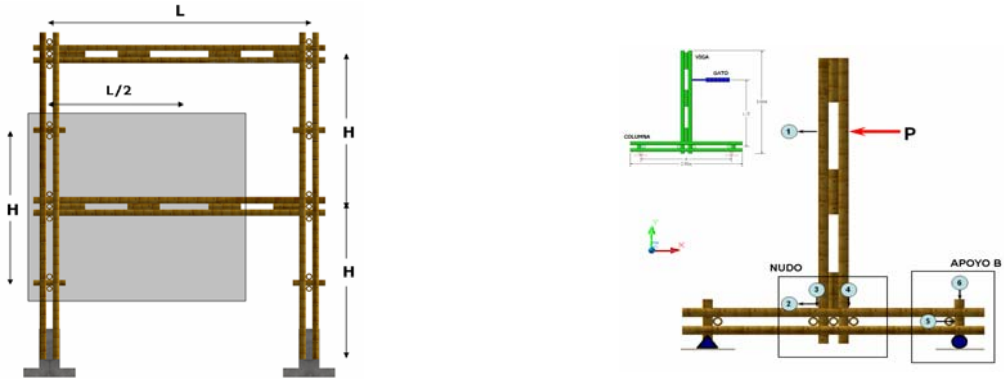

Figure 5. Beam-column connection: Localization in the frame, drawing of the connection

To the connections two kinds of tests were applied: monotonic and cyclic tests. In the fist group the load was increased until a maximum displacement, whereas in the second group, 6 cycles of loading and unloading were applied until a maximum displacement was obtained in the last cycle.

As the main mechanisms of failure for the beam-column connections are due to the shear parallel to the fibre and to the tensile perpendicular to the fibre, the connections were confinement with some wrapped metal hoops, and in order to prevent the crushing of the bamboos, polyurethane filler was used.

As was mentioned before, four groups of connections were tested. In a first group the connection had threaded rods; in a second group in addition to the rods, the connection had some hoop wrapped. In a third group, the connection had rods and polyurethane filler with some wood pieces. In the last group, known as full connection, were used rods, hoop wrapped, and filler. The number of experiments done was 15. The first group had 3 tests (1 monotonic and 2 cyclic), instead the other groups that had 4 tests (1 monotonic and 3 cyclic).

In the last stage of this initial project, the joint known as full connection was tested in three planar frames under cyclic load. The frames had two stories high, a spam of 4.05 m and because of space limitations, a total height of 4.6 m (2.1 high and 0.4 m of support). (figure 6)

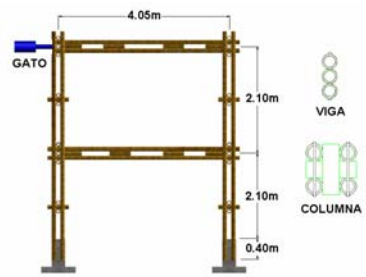

Figure 6. Test frame in guadua angustifolia

Numerical modelling

In the modelling of the connections was used the finite element method with the commercial software ANSYS. Because of the differences in the materials, was assumed an elastic behaviour for the bamboo and the polyurethane, instead of the steel rods which had elastoplastic behaviour. The mechanical properties obtained in the first part of the research were used to define the materials, assuming an orthotropic section. The confinement provided by the wrapped hoops was modelled as a pressure distribution over the element. (Figure 7)

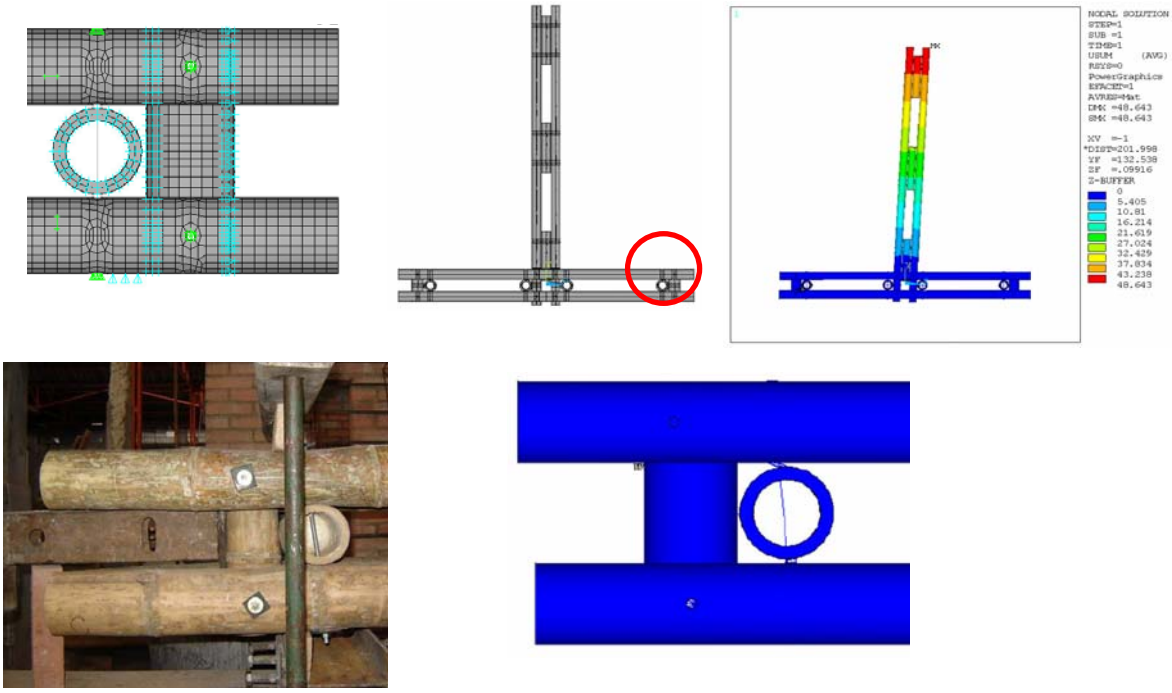

Figure 7. Numerical modeling of the beam-column connection. Comparison among numerical and experimental results

The frames were modelled using traditional structural matrix analysis with the commercial software SAP 2000. A linear elastic model was used. It was assumed that the bamboo is an isotropic material, in addition, was considered in the beam column joint a semi-rigid connection, where the stiffness spring constant was calculated from experimental data.

Conclusions

The main conclusions of this part of the research are summarized below.

The characteristic value of the shear strength parallel to the fibre was 4.38MPa, of the compression strength parallel to the fibre was 36.6MPa, of the tensile strength parallel to the fibre was 100.46MPa, and of the tensile strength perpendicular to the fibre was 0.46 MPa.

The elastic properties calculated from the tests were: longitudinal modulus of elasticity 14164.10 MPa, circumferential elastic modulus 668.51MPa, and shear modulus of rigidity 630MPa.

The rods used in the connections had an insufficient diameter. The deformation obtained was permanent and increased the bending rotation of the connection.

The slack that was left to the drilling rods also affected the relative rotation of the beam with respect to the column.

It was noted that the joint with the best behaviour was the full connection. The metal confinement was appropriate, avoiding failure by crushing or shear parallel to the fibre. In the same way, the Polyurethane filler avoided crushing failures in the connections.

The beam-column connection investigated is a Semi-rigid connection; the stiffness measured experimentally was 60.2 kN-m/rd. This value can be used in analytical models that use bamboo frames with this type of connection.

As the horizontal displacements measured in the frames were excessive, it is recommended to combine the structural system with walls or diagonals in order to restrict the horizontal displacements.

Stability of frames of guadua angustifolia braced with cables

Experimental methods

In this study, named "Stability of frames of guadua angustifolia braced with cables" (Malaver, 2007) the physical-mechanical properties of the guadua angustifolia used for the construction of the frames were found by means of 20 tests of compression parallel to the fibre, 20 tests of shear parallel to the fiber and 14 test of tension parallel to the fiber. The guadua had a natural drying to the environment for a period of six months.

6 planar frames of double height were tested with height of each floor of 2.1m and a spam of 4.05m under cyclic horizontal load applied at the nearest beam-column connection and the horizontal displacements were measured at the top, the first floor and the support and the vertical displacement measurement was taken at the support. 3 frames were tested without cables and 3 with cables, one of these with simple cable and the others with double cables. (figure 8)

Figure 8. Frame of guadua with diagonal cables. Diagonal cable leaving the joint

Conclusions

With the test of the six frames it was found that the structure is not unstable although the beam-column connections and the supports don't behave as rigid connection. The frames had a great displacement and once discharged they recovered their initial position.

The top beam transmitted the load appropriately to the far column, since it was not observed a buckling of the beam neither failure of the connections.

The frames braced with cables were more rigid than the frames without cables. The maximum drift of the first ones in the second floor was 6.7% while in the second case was of 9.5%.

In the case of the frames with cables a slight deformation outside of the plane was observed, this, because it exists the possibility that for the type of the connection in a side of the frame the cable transmitted more load that in the other one.

In the case of the frames with cables the system of the cable failed. In the case of the frame with simple cable this it broke, in the second case slip of the cable was presented in the last frame the failure was presented in the tension device. After the cable was broken the frames behave like the frames without cables.

Structural behavior of frames in guadua angustifolia, stiffened by means of panels prefabricated of "bahareque" and narrow sheets of guadua.

In the first study developed by Lamus (2008), it was found that the beam-column connection was a semi-rigid connection, reason why the drift of the frames was very high. In this study (Herrera, 2008), the behaviour of two different kinds of wall boards was investigated, in addition to the performance of the frame built with the panels.

Experimental methods

In the study, three types of boards of guadua were tested (3 boards for each type) which had a structure that consists of a wooden frame, a diagonal and some vertical elements in guadua. Of the three types of boards, two were covered, the first one with sheets of guaduas, combined with chicken steel meshes and plastered with cement mortar (bahareque encementado) and the second type with sheets of guadua of 5 cm of wide in a diagonal array. (Figure 9)

Figure 9. Structure of the guadua board. Board of guadua of bahareque encementado. Board with narrow sheets cover.

The frames of double height and simple spam, had a total height of 4.7 m and a width of 4 m. 3 frames were tested for each type of board (6 tests in total). After the frames were built, the boards were placed with one of the face covered. Then, the second face was applied (Figure 10).

Figure 10. Drawing of guadua frame with the structure of four boards for floor. Frame with boards of bahareque encementado. Frame with board with narrow sheets cover.

The load was applied horizontally at the top of the frame. Horizontal displacement measurements were taken at the top, at the level of the first floor and at the supports, also vertical displacement measurements were taken at the supports. In each test, 6 load cycles were applied.

Numerical modelling

A lineal model was made for each one of the boards using the values of module of elasticity, density and poisson relation obtained experimentally in previous investigations. In the models the linear elements were "beam" elements with articulations in their ends. For the board with "bahareque encementado" the cover was analyzed with "shell" elements and for the other type of board the narrow sheets were considered as "beam" elements with articulations in their ends.

For the study of the frame with boards of bahareque encementado two lineal models were made (Figure 11). In the first one, each one of the guaduas were analyzed as "beam" element and the cover as "shell" element as a whole. The second model included the structure of each board and its cover.

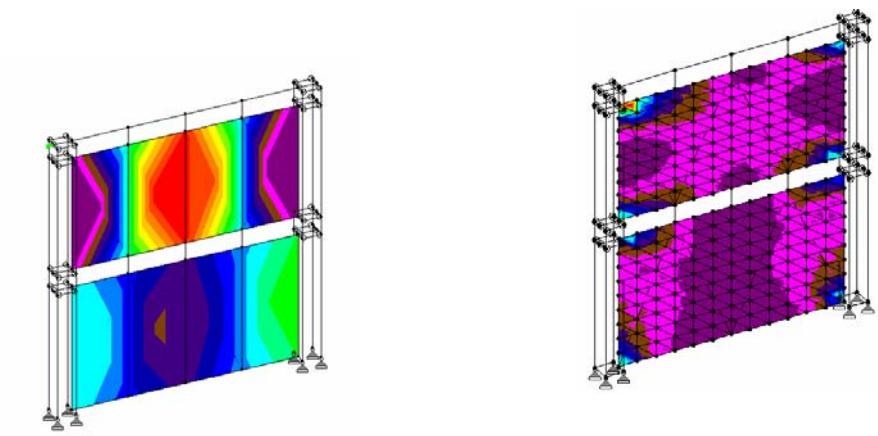

Figure 11. Models of analysis of guadua frames with boards of bahareque encementado

In the same way two models were carried out to study the behavior of the frames with sheets of guadua (Figure 12). In the first model it was considered the elements of the frames and the elements of the structure of each one of the páneles. In the second model it was considered each one of the sheets additionally.

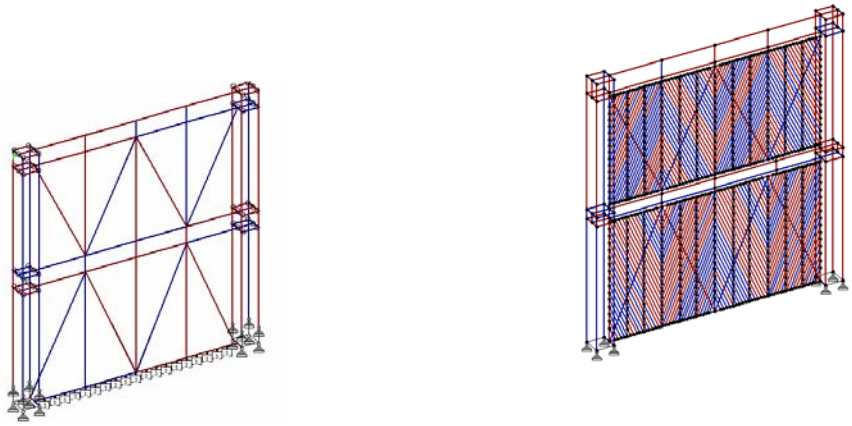

Figure 12. Models of analysis of guadua frames with boards with narrow sheets cover.

Conclusions

The cover increases the resistance of the boards; the last load of the panel with sheets was 41.6% of that of the panel without cover, in the case of the panel of “bahareque encementado” the resistance increment was of 50.4%

The simplified lineal model of the board was not the most appropriate because it was found that the boards had an inelastic behavior.

When comparing the results obtained in this study with the results obtained by Eng. Lamus it was found that the frames with boards are around 50 % more rigid.

The difference of displacements among the two types of boards is smaller than 25%. If it is considered that the weight of each panel of bahareque encementado is 105 kg and of each panel of sheets of guadua is 65 kg, additional at the biggest hand work and time that the first system implies, the panel with sheets of guadua is a good solution for system of stiffness of the system.

Structural behavior of frames in guadua, braced by means of guadua diagonals

In the last study, the behavior of frames in guadua braced with guadua diagonals was studied and it was found that they have enough rigidity so they can be used in the design of houses of two floors.

The experimental part of the study named " Structural behavior of frames in guadua, braced by means of guadua diagonals" (Rivera, 2009), included the characterization of the guadua, the test of connections of the diagonals with the frames, and the test of space frames.

The frames were modelled using traditional structural matrix analysis and with the results was suggested the best structural configuration for a two-story house.

Experimental methods

For the experimental part, not immunized Guadua Angustifolia Kunth was used, with ages among 4-5 years of age, extracted of the half part of the culmo. The diameter of the guadua varied between 9 and 13 cm.

For the characterization they were carried out test of compression, tension and shear parallel to the fibre following the procedures of the norm ISO 22157. Of each type, 10 samples were tested obtaining characteristic values of resistance to compression, tension and shear parallel to the fibre, as well as compression and tension longitudinal elastic modules. Also it was also carried out torsion test to find the module of rigidity.

Thinking of the geometry of the standard frame built in the investigations of Lamus (2008), Malaver (2007) and Herrera (2008), double diagonals of guadua were designed, with double height and an angle of inclination of 42º with to the vertical. The type of connection allowed the diagonals arrived to the joint in a concentric way and with a big contact area.

To study the behavior of the connection of the diagonals, they were carried out 12 tests of connections. Six of them had external reinforcement with glass fiber and six didn't have glass reinforcement. (figure 13)

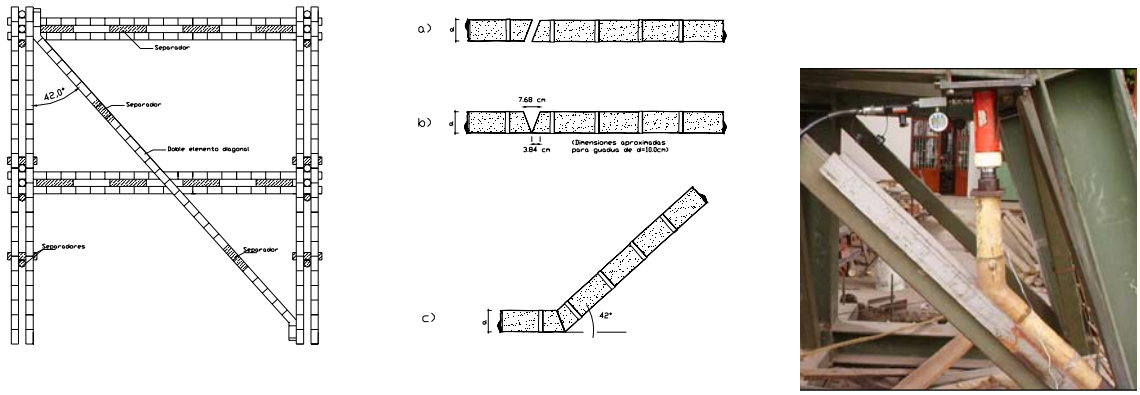

Figure 13. Drawing of the localization of the diagonal in the frame and the process of elaboration of the diagonal. Test of diagonal connection.

To study the behavior of the frames with diagonals they were test with cyclic load 6 space frames. The frame had a distance among column axes of 3.90 m, wide of 1.60 m and a total height of 4.40 m.

5 of the 6 frames were tested with diagonals and one without diagonals. Of the five frames with diagonals, three were loaded with vertical load 1,80kN/m2 at the first level and 0,50kN/m2 at the top like live loads in a typical housing. (Figure 14)

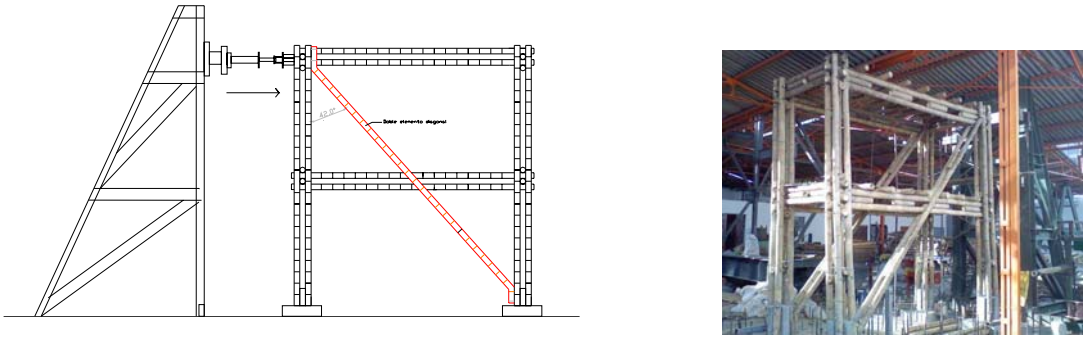

Figure 14. Drawing of the test frame with diagonal. Space frame with diagonal.

Numerical modelling

4 models were carried out; the first of them, a frame without diagonals, the second model included diagonals additionally, the third model corresponded to a structure for a housing, composed by four modules using

diagonals in all of the plane frames and the fourth model was similar to the former, but using diagonals only in the perimeter of the structure.

In the analysis, the guadua elements were in the elastic range, using a longitudinal elastic modulus obtained in the compression tests. The elements for the beams, columns and diagonals were type beam (with six grades of freedom in each end). The connections of the ends of the diagonals were considered plastic articulations. As the beam-column connection is semi-rigid it was used the value calculated in the research of the Eng. Lamus.

The first model (space frame without diagonals) was calibrated using the experimental data (figure 15).

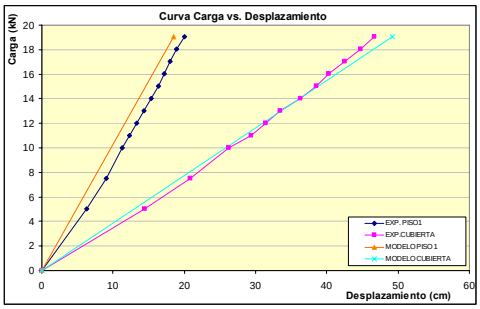

Figure 15. Numerical and experimental loads vs displacement diagram of the model 1.

To establish the parameters related with the diagonal in the second model a pushover analysis was made, where the diagonals were added so that they worked to compression with plastic articulations in their ends (Figure 16).

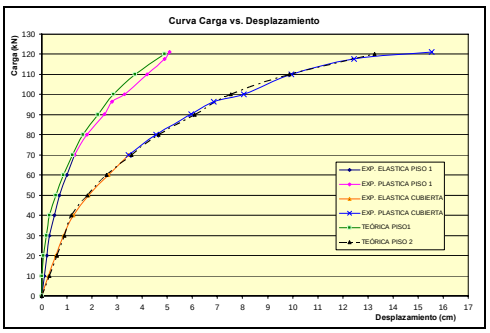

Figure 16. Numerical and experimental loads vs displacement diagram of the model 2.

Based on the second model it was carried out an pushover analysis for a third and fourth model for the structure projected. In the third model it was placed diagonals in all the plane frames while in the fourth model they were only located in the external perimeter.

The configuration of the previous structure and the analytical results allows the construction of two houses of two floors, with minimum areas to accommodate the basic facilities with a basic area of 67,2 m2 (Figures 17)

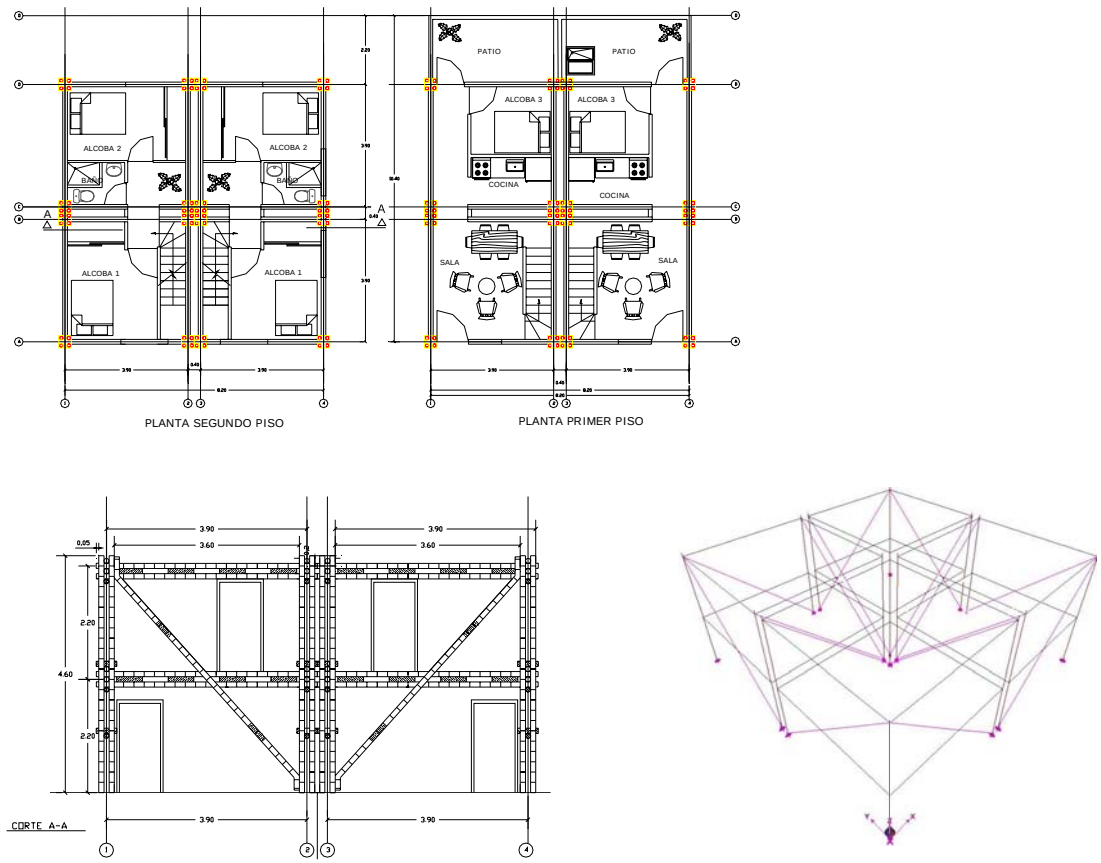

Figure 17. Distribution plants of first floor, second floor of the house. Drawing of the model 3.

Conclusions

The resistance to compression of connections without fibre glass reinforcement was 84% of the one obtained in the test with samples with fibre glass reinforcement.

The ultimate load of the frame without the diagonals, was 12,5% of the maximum load registered in the frames with diagonals tests.

Although comparatively the damages in the braced piazzas were bigger than in not braced structures, in any case they represented risk of collapse.

In the analyses of the structures proposed for a house, drifts obtained were smaller than 1%, that is the maximum drift value that prescribes the Colombia Construction Code NSR-98.

Considering the values of resistance found in the tests, the frames of the proposed structures support the loads appropriately.

The diagonal proposal, is a viable solution as brace suystem of the structures in guadua from the structural and architectural point of view, because to the being of double height, the diagonals don't interrupt the necessary holes for the disposition of doors and windows.

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Bamboo Composite Pole

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Abstract

In a nation of more than one billion people, India needs proper use of its resources and a strong back-up to its infrastructural needs. This is an attempt in providing a solution by incorporating abundantly available natural resource, a simple, cost effective manufacturing technique and understanding of composite technology applications. Bamboo is a naturally available renewable material. Bamboo is a natural 'composite' material having longitudinal fibers bonded by strong internodes. This inherent strength is further enhanced by winding glass fibers in transverse direction with polyester resin matrix to form a strong and durable member. The composite pole made in this process gives strength in longitudinal as well as transverse direction. This Bamboo Composite pole gives high strength to weight ratio and a cost effective product. It can be used for various applications such as Lamp poles, insulating connecting rods for Electricity distribution lines, structural members for rural & disaster housing.

The manufacturing process takes inspiration from Mahatma Gandhiji's principle of self reliance and involvement of grass root people. The equipment required for manufacturing of this pole runs without electricity and can be handled by an ordinary semi-skilled worker. It takes inspiration from the 'Charkha' promoted by Gandiji.

Various applications of this Bamboo Composite Pole has been worked out.

Overview

Concrete with reinforcing steel has a greater ability to be custom engineered for various specific applications. However the resulting products are extremely heavy and in case of load-carrying structures, such as bridges, the greatest portion of the structure is involved in holding itself. This extreme weight forces many concrete structures to be fabricated on-site as opposed to being built in the factory. This adds greatly to the cost of these products. Also, concrete is very sensitive to motion, such as caused by earthquakes. A lightweight load bearing beam, column or cross-tie that would not be sensitive to seismic or temperature changes would be very desirable replacement for concrete.

Structural steel is extensively used for beam and column applications due to its strength, and workability. Steel has an on-going problem due to rust and corrosion that shortens its life span. Also, energy costs to produce steel and to fabricate and maintain steel components are quite expensive, keeping the price of the materials and finished products high.

The Bamboo Composite Pole (BCP) seeks to provide an improved composite that has the ability to overcome the disadvantages of the presently available structural materials. It seeks to eliminate the disadvantages by providing a low cost, high strength composite formed from Bamboo pole bonded with thermosetting polymers.

Bamboo has been an integral part of Indian culture and has host of traditional uses in many regions in India, and in many other countries. Due to a large variety of traditional uses bamboo has been aptly described as poor man's timber, green gold, friend of people, cradle to coffin timber and green gasoline.

During the recent years, bamboo has emerged as a major source of renewable fiber for making high value added products as alternate to wood and other materials. Use of bamboo in manufacturing such products not only generates additional employment opportunities but also ensures better earning to the people engaged in various bamboo industries. Greater use of bamboo products will help in reducing the depletion of forests through wood substitution and also encourage bamboo cultivation and thus benefit the environment.

Being very fast growing woody grass, bamboo produces considerable amount of biomass and is very efficient for sequestering atmospheric carbon. It is stated that one hectare of bamboo plantation can absorb about 17 metric tons of carbon every year. The absorbed carbon returns to the atmosphere only when bamboo is burnt. On the other hand when bamboo is used for making durable products the absorbed carbon remains fixed as long as the product lasts.

Locally available *Bamboosa Tulda*, *Bamboosa Meleclona*, and Dendrocalamus Strictus is ideally suited for this application. These species have inherent structural strength and grow comparatively straight.

Bamboo is highly renewable and sustainable natural resource. It can be harvested from the same Culm (Plant) for almost 40 to 50 years. Bamboo is very strong due to its inherent construction.

Due to its unique structure Bamboo has inspired this project.

Material	Density Kg/ lit	Compressive Strength Kg/cm2	Strength to weight ratio
Bamboo	0.6 to 0.719	645	897
Teak Wood	0.604	532	880
Mild Steel	7.8	4250	544

The Bamboo has inbuilt longitudinal fibrous structure with intermediate diaphragm at the nodes.This natural construction gives Bamboo its strength. The unique combination of high strength and low weight made me to use this to create a structural module. The inherent character of bamboo was enhanced further by the use of glass fiber wound in transverse (90 deg) direction and resin.

This unique combination of naturally available renewable resource and innovative composite engineering methods gives us this Bamboo Composite Pole

Bamboo Treatment

Bamboo is easily attacked by insects and fungi due to presence of starch and sugar in abundance. Prophylactic treatment of bamboo is very essential to enhance its life, control uneven shrinkage, and avoid splitting.

Treating the bamboo properly is very critical to ensure the right kind of raw material for further processing. The bamboo will be embedded inside with glass fiber and resin layer. To ensure proper results of the Composite pole, the bamboo inside has to be treated with care.

There are two types of prophylactic treatments used.

(A) Traditional or Non-Chemical Treatment
(B) Chemical Treatment.

A. Traditional or Non-Chemical Treatment

Storage in Water:

Freshly cut bamboo is stored either in running water or in water pools for 3-4 weeks to leach out starch. This process prevents bamboo from insect attack. In case of water pool water has to be changed frequently to prevent fouling. Although traditionally treated bamboo show increased resistance to insect and fungal attack compared to freshly cut culms, these methods do not provide long term durability.

Smoking:

Smoking is carried out in chambers. This produces toxic agents and heat which destroy starch in bamboo thus making it immune to insect attack and also blackens the culms.

B. Chemical Treatment

Chemical treatment is more effective than traditional treatments. Typical chemical treatment methods uses water soluble preservatives like Gamma BHC 0.5%, Formalin 0.5% , Phenol+ 1 Copper sulphate (1: 2), sodium penta chlorophenate 0.5% and Borax 1.5%. The chemicals are dissolved in water. Bamboo or bamboo mats are either sprayed with the solution or dipped in the solution for 10 minutes. After treatment the bamboo mats are stored in shade till they are processed further.

Bamboo treated in such a way is ready to be used for further processing it into Composite Pole

Composite Pole Manufacturing Process

Filament winding using glass fiber and polyester resin. Winding of glass roving is done manually with a simple pulley arrangement. Resin is applied with a brush. The Bamboo Pole is held in a chuck as a mandrel. It is then rotated by hand.

Same process can be done on an automated Filament Winding machine. This involves high production cost, so is not considered for this project.

Glass Fiber Winding Machine (Figure 1)

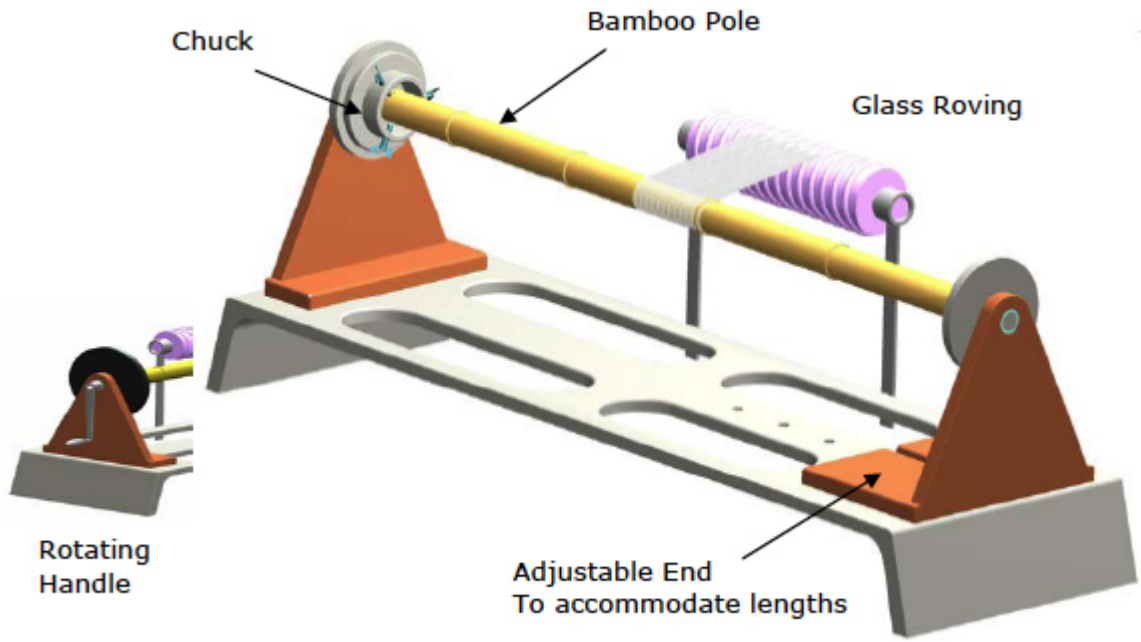

Figure 1 : Glass Fiber Winding Machine

This is a simple hand operated turntable used for winding glass fiber over the Bamboo Pole. It has a chuck to hold the bamboo at one end and an adjustable head at the other end. The chuck is fitted with a rotating handle. The harness for holding the glass roving spindle is on one side. This spindle slides along the length of the bamboo pole to ensure proper winding of the glass fiver over the Bamboo pole.

Composite Bamboo Pole Manufacturing Process:

Bamboo is held in between the circular chuck. The glass fibre rovings are tied at the starting end of the bamboo pole. Using the turn handle the roving's are wound along the entire length of the Bamboo pole. (Figure 2)

A mixture of Polyester resin with hardener (same way which is used for the Hand Lay Up process) is applied over this pole. Depending upon the length of the pole and the activation time, the glass fiber and the resin sets to form a strong hard surface over the bamboo. This is then allowed to cure for about 4-5 hours. (Figure 3)

The end of the poles is closed using glass matt and resin using hand lay-up process. In this way the bamboo pole is completely enclosed with glass and resin. This makes the bamboo pole completely safe from any degradation due to environment and due to the lateral winding of the

glass fiber it becomes extremely strong.

The Composite Bamboo Pole so formed is ready for use in various applications.

Figure 2 Figure 3

Figure 2 : Glass Fiber winding

Figure 3 : Fiber wound pole being covered with resin

Product Characteristics

The Composite Bamboo Pole manufactured has good strength in Compression and Tension. Properties of FRP and Bamboo gets enhanced multifold to give stronger product. (Figure 4)

Silent Characteristics / features

- • Cost effective – use of bamboo as core material and one layer of glass filament Winding
- • Insulating, light weight, non corrosive, long lasting poles for various applications
- • Effective use of natural, renewable, easily available material for commercial application using appropriate manufacturing technique.
- • Possibility of manufacturing at the remotest of the location by ordinary worker with no requirement of power

Table 1 : Physical Properties Comparison chart

	Natural Bamboo	Bamboo Composite Pole
Density	0.6	1.3
Modulus of Elasticity	1,59,460 kg / cm2	1,75,500 kg / cm 2
Compressive Strength	645 kg / cm 2	1350 kg / cm2
Moment of resistance	1184 kg / cm2	
Stiffness Factor	33	

Figure 4 : Bamboo Composite Pole

The cross section of the ends of this pole needs to be made of same diameter, so that it can be standardised. A fiber Glass reinforced mould was made to make the ends of the pole of uniform diameter. Using this mould the ends of the poles are casted in resin and fiber glass. (Figure 5)

Figure 5 : Uniform End Diameter

Connectors

Various connectors are developed in Glass reinforcement process to suite the end diameters of the pole. (Figure 6)

Figure 6 : L – angle Connector

Various types of connectors are developed in Glass reinforcement process to suite the end diameters of the pole.(Figure 7)

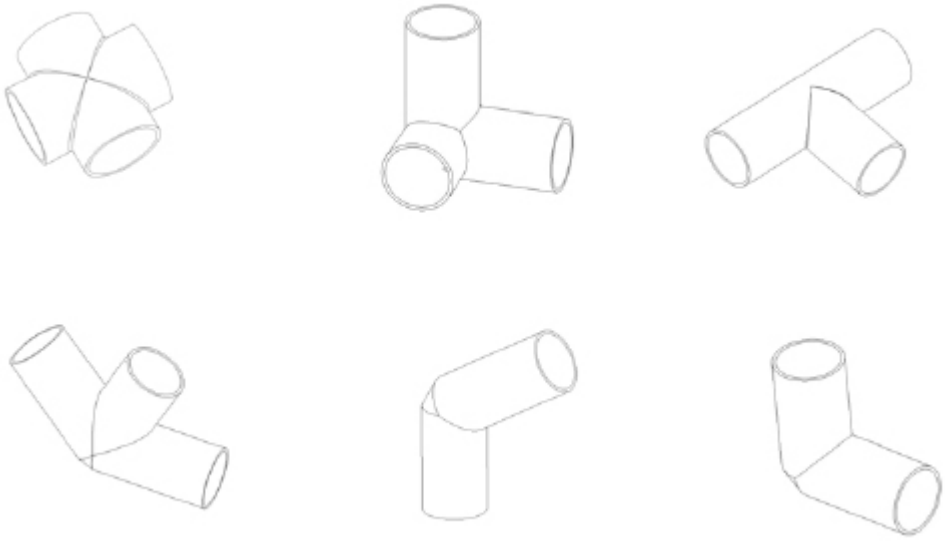

Figure 7 : FRP Connectors

Applications

Cost effective and durable solution for

(a) rural lighting poles,
(b) poles required in inaccessible areas for supporting cables for wind mills
(c) Structural members for rural , disaster housing

Rural Lighting Pole

These poles can be effectively used in Rural street lighting and in inaccessible areas where heavy poles cannot be transported. (Figure 8)

Wind Mill installations can use these poles for cable connections

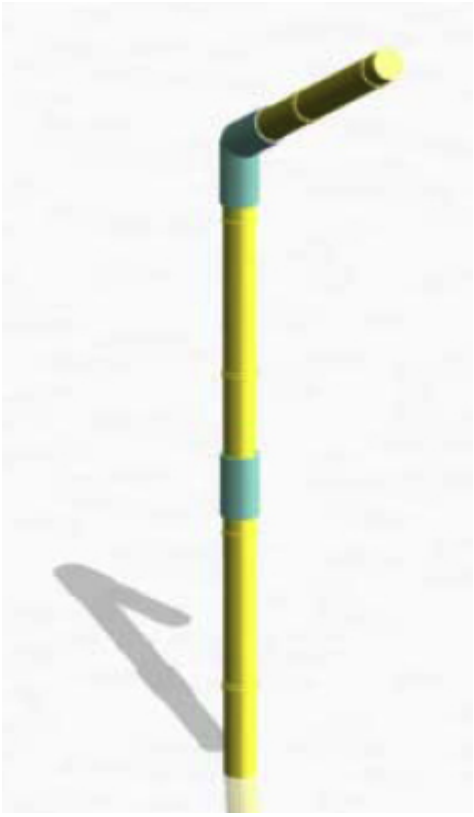

Figure 8 : Street Light Pole

Housing Structure Truss Module (figure 9)

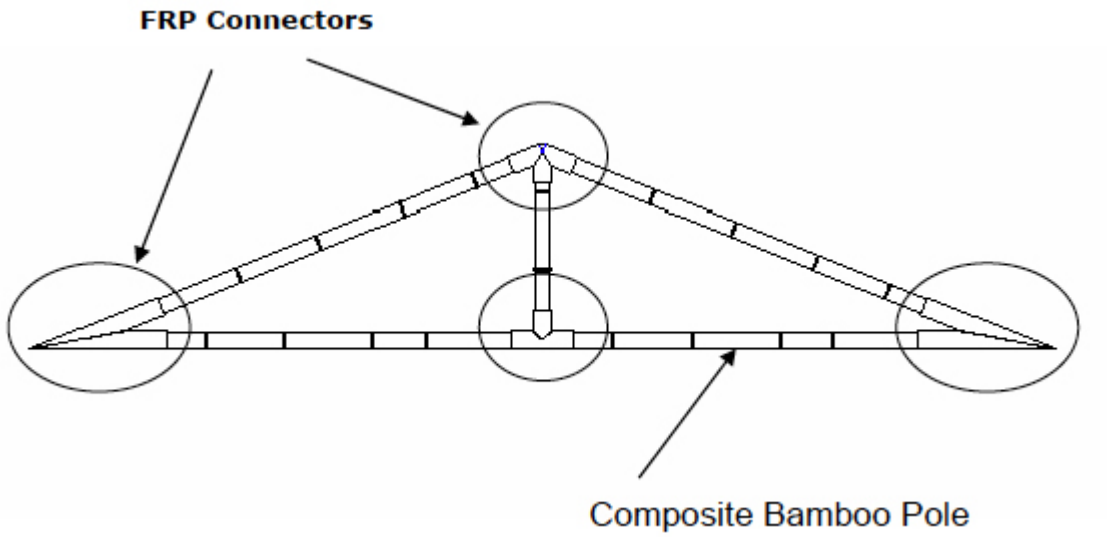

Figure 9 : Housing Structure Truss Module

Housing Structure

Using various connectors made out of reinforced glass fiber and the Bamboo composite poles a complete house structure is erected. This installation of a fully dis-mantalable system can be put in place in 2 hours (Figure 10)

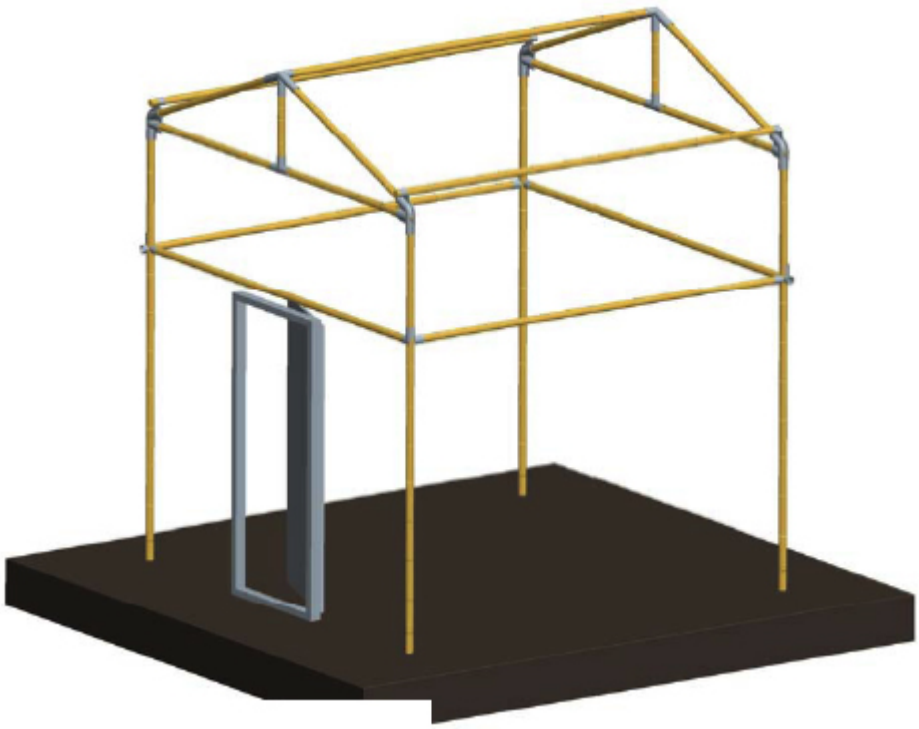

Figure 10 : Bamboo Composite Pole house structure

Connector Details (figure 11)

Figure 11 : Connector Details

Cement Reinforcement

The Composite Bamboo Pole is impregnated with Sand granules. This Sand Impregnated Bamboo Composite Pole is used as a structural reinforcement for casting the column in cement. (Figure 12 , 13, 14)

Figure 12 : Sand Impregnated Bamboo Composite

Figure 13 : Making of the Cememet Casted Bamboo Composite Pole

The Cement Casted Bamboo Composite Column is used with bare Bamboo Composite Pole to complete the structure of the house. Any method for constructing wall panels can be used. Brick, stone, mud masonry or Bamboo board panelling can be used to complete the house.

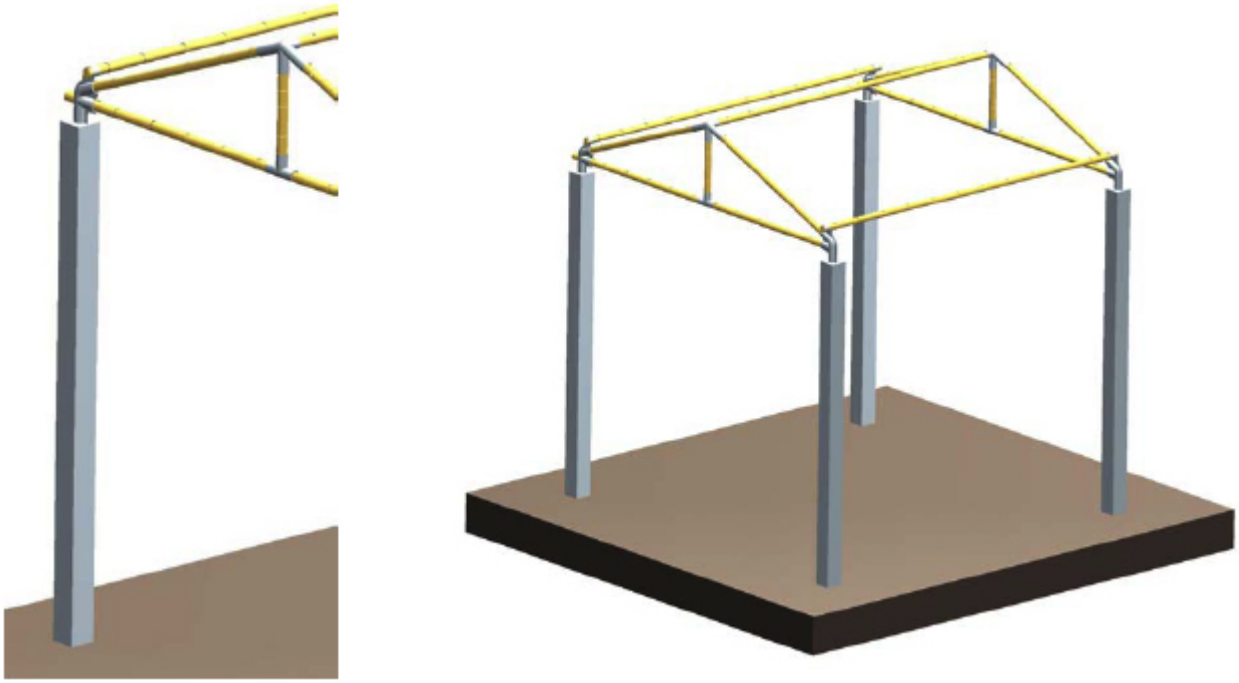

Figure 14 : Cement Casted Bamboo Composite Pole Column is grouted in the plinth

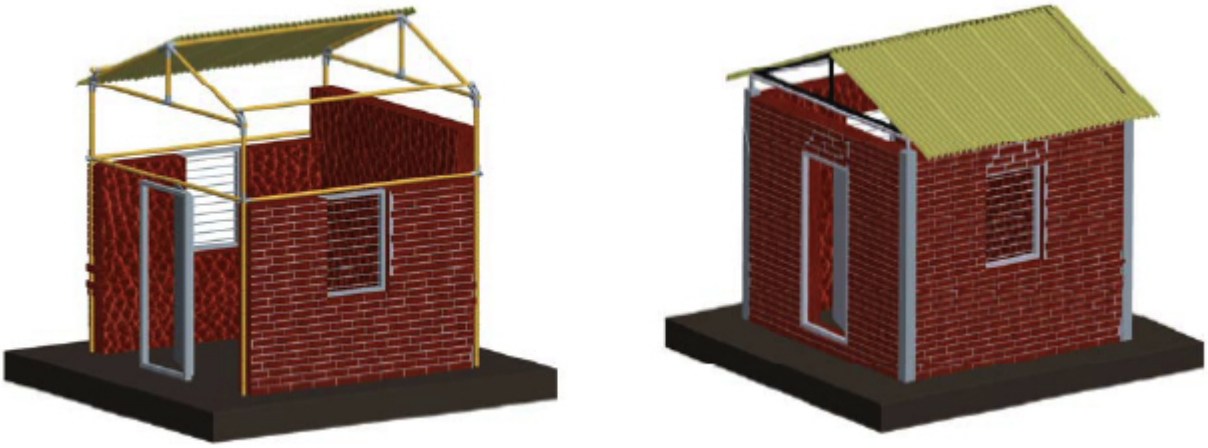

Figure 15 : A fully built house module using Bamboo Composite Pole structure

Conclusion

Bamboo Composite Pole module creates numerous innovative application possibilities.The modules so produced can be used in combination with various other materials and processes.

These modules are very light, durable, strong and cost effective. This will open up new areas of composite applications which are sustainable, long lasting and economical. The unique blend of naturally available material with optimal use of composite technology will give stimulus for overall development of product as well as the people at the grass root level.

These Bamboo Composite Poles can be used effectively for Disaster Housings in seismic zones. The unique manufacturing process also will help generate livelihood in the remotest of the areas and will also provide the much needed shelter for the needy.

Figure 16 : Bamboo Composite PoleModules & Standardisation

Sustainable Utilization of Bamboo for Pulp and Paper Manufacturing

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Abstract

This research examined the potential of bamboo utilization and qualified the bamboo pulping for pulp and paper manufacturing. The following three pulping processes were developed namely formacell, sulfate and soda processes in various conditions. The results showed that the formacell pulping from *Cephalostachyum virgatum* Kurz gave 42.88% yield, 22.6% kappa number and at 40oSR freeness, then the physical properties of bamboo paper were analyzed which were 5,702.23 m breaking length, 431.43 KPa bursting strength, 88.8cN tearing strength and 20.7% ISO brightness. On the other hand, the sulfate pulping from C. *virgatum* had a 41.18% yield with 16.91%.kappa number. After beating for a few minute; the paper properties were measured which were 5,165.29 m breaking length, 330.44 KPa bursting strength, 81.5 cN tearing strength and 27.6% ISO brightness. For the soda pulping from C. *virgatum* had a 42.30 % yield with 31.29 %, kappa number after beaten, the paper strength gave 4,449.12 m breaking length, 272.78KPa bursting strength, 74.5cN tearing strength and 32.4%ISO brightness. Then, the comparisons of soda pulp quality among 13 species of bamboos were performed. It is shown that about 5 species [*Bambusa logispiculata* Kurz,*Bambusa blumeana* Schult,*Thysostachys siamensis* Gamble,*Bambusa arundinaceus* Wild, *Cephalostachyum virgatum* Kurz] gave significantly high yield, high strength and brightness. Finally, it was possible for bamboo to perform in any process with a good result. Particularly, five species of bamboo have had high potential and good quality for pulp and paper, especially high tearing strength and high brightness.

Keywords: bamboo pulping, formacell process, sulfate process, soda process

Introduction

Bamboo is a perennial, monocotyledon plant which is necessary of life for Thai-people from the past until now. All parts of bamboo give advantage to human for food, construction and raw material for industry such as basket, chopsticks, toothpick and pulp industry and so on. So bamboo is a special plant that is important both direct and indirect utilization but there are insufficient in knowledge of the conservation and management.

Bamboo is a group of genus namely Gransineae the same as grass. Bamboo has spread widely throughout the hot zone and the southeastern Asia, there are about 45 families (genus) 750 species. (Dransfield, 1980) In Thailand we have found about 13 genus 60 species which some are not discovery because they grow in

the dense forest and lack of experts in breeding classification. Bamboo is the plant that can adapted to the new environment by exchanging phynotype for example. Often the same kind of bamboo can grow in the different geography and rainfall with different characters. Therefore, the classification of bamboo has to importantly point out some feature such as root, the leaf sheet , branching, the interval stem, stem size, roundness, color of the trunk, shoot and seed.

There are various kinds of bamboo and lots of advantages as mentioned but no specific utilization. The purpose of this study are to qualified bamboo pulping and gives result to bamboo utilization for pulp and paper manufacture by comparing the qualities some bamboos that found in the northern of Thailand. As Fiber produced by chemical processes varies in quality depending on the kind of material, method and condition during cooking. The two conventional pulping processes are soda process and the sulfate, in which the cooking liquor for the soda is a caustic soda. However, the cooking liquor for the sulfate process is essentially a mixture of caustic soda and sodium sulfide. Furthermore, the third chemical process is formacell process which employs an organic acid as the cooking liquor. In addition the important factors in cooking are temperature, time during cooking and the ratio of chemical to wood. These studies cover different cooking method of both conventional and the formacell cooking.

Materials and method

This investigation seeks to identify some bamboo species from the Northern of Thailand to be used as raw material pulping industry. Three potential pulping processes were performed in various conditions. The condition included temperature, chemical charge and wood per liquor ratio. Three pulping processes were formacell, sulfate and soda, the formacell process (Saake et al, 1995) is a chemical pulping using organic acid at 10%, formic acid, 160oC temperature, 120 min retention time, wood per liquor ratio of 1:7 and water content of 5% 10% 15% and 20% respectively. While the sulfate process is a process using mixture of caustic soda and sodium sulfide at 25% sulfidity, 170oC temperature and retention time of 2hrs. In which Soda process is a pulping of caustic soda at 150oC temperature, 90 min retention time, different wood per liquor ratio of 1:4 and 1:3 and also various sodium hydroxide concentration of 10% 15% 20%and 25%. (T1204 os-61)

Bamboo pulps from above three processes were examined a chemical testing, a sheet forming (Seiber, 1951), a physical testing and pulp evaluation relating to quality under standard test methods. Then the pulp properties of those three processes were compared. The following table is the standard method used in this paper.

Testing Method

Parameter	TAPPI and SCAN standards testing
Kappa number	T236m-60
ISO Brightness	SCAN-P3; 62
% Yield	weight
Beating Time	SCAN-C24; 67
Freeness	T227 os-68
Thickness and Apparent density	T411 os-68
Breaking Length	SCAN-P16; 65
Tear Factor	SCAN-P11; 64
Burst Factor	T403 ts-63

Results and discussion

Results of the bamboo pulping from the formacell, sulfate and soda processes and the quality of bamboo paper from three processes are shown in Figure 1-3 and Table 1-3 respectively. Then the comparison of pulp quality of 13 bamboo species from the soda is illustrated in Figure 4 and Table 4.

As can be seen in figure 1, it is found that formacell pulping from C.vergatum at 15% water content give high pulping yield and brightness.

From figure 2, it is obvious that 18% active alkali is the best condition for sulfate process.

For the soda process, it is found that 15% alkali and wood per liquor ratio of 1:3 give the highest at the brightness of 27%. However, the highest yield is found at 10% alkali.

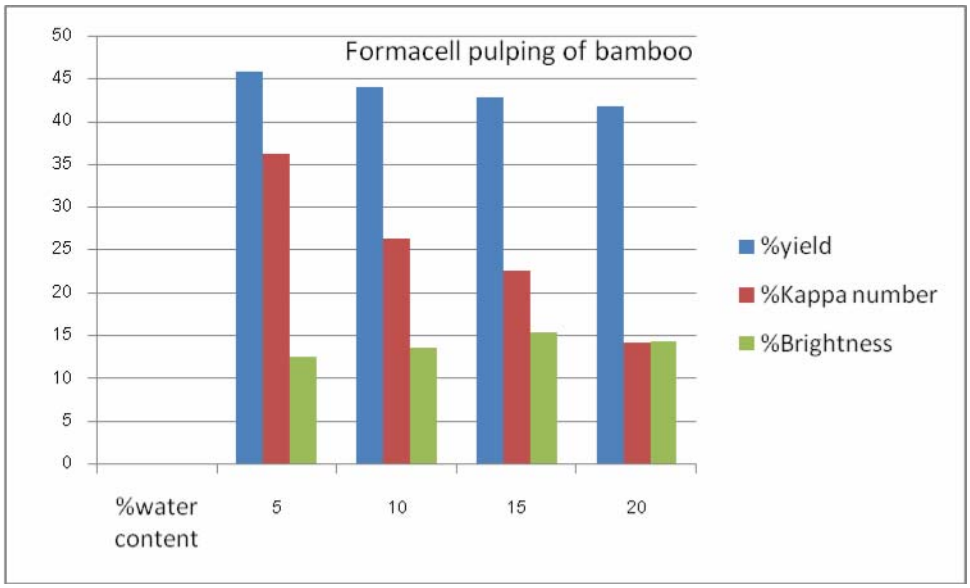


Figure1. Effect of % water content on Percentage of Yield, kappa number and brightness of formacell pulping at Formic acid of 10%, at temperature of 160oC, retention time of 120 minutes and wood per liquor ratio of 1:7

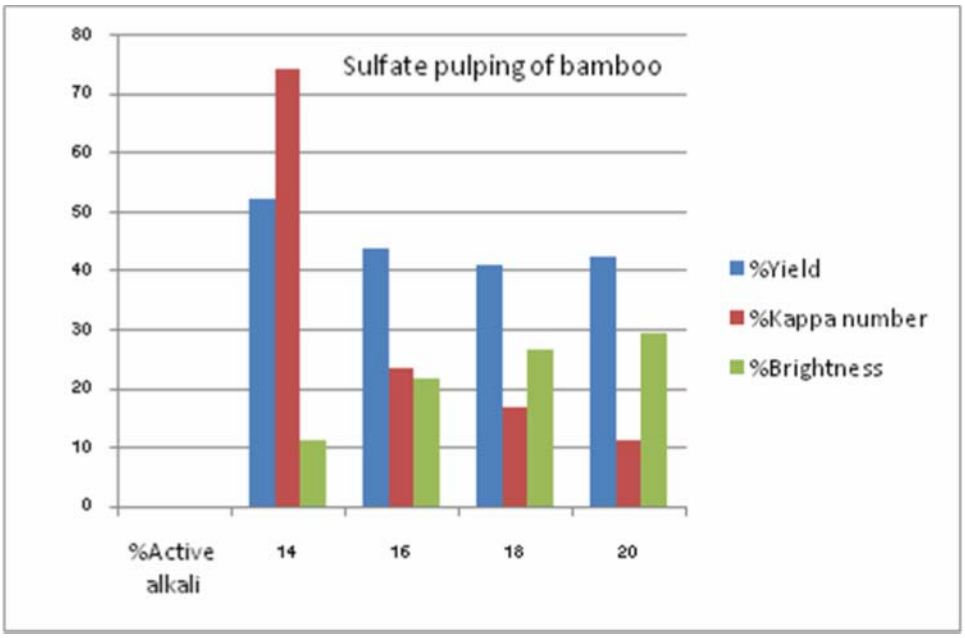
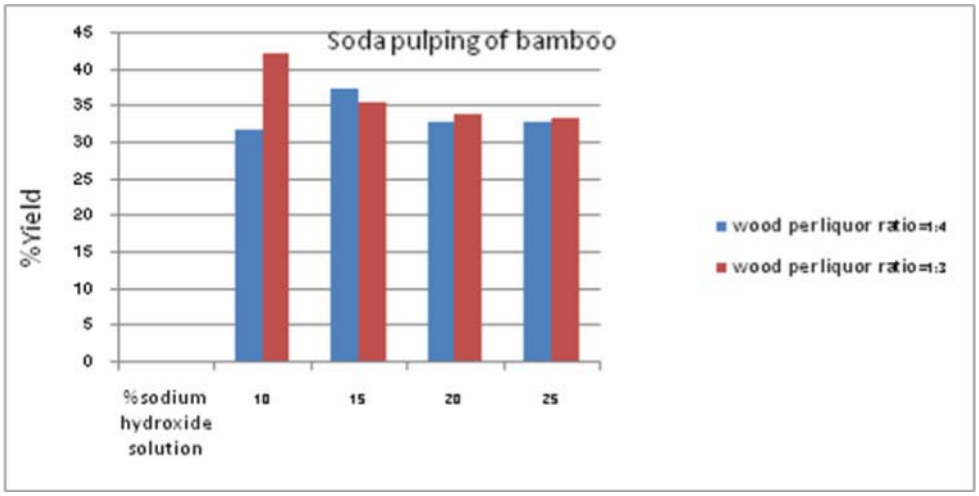
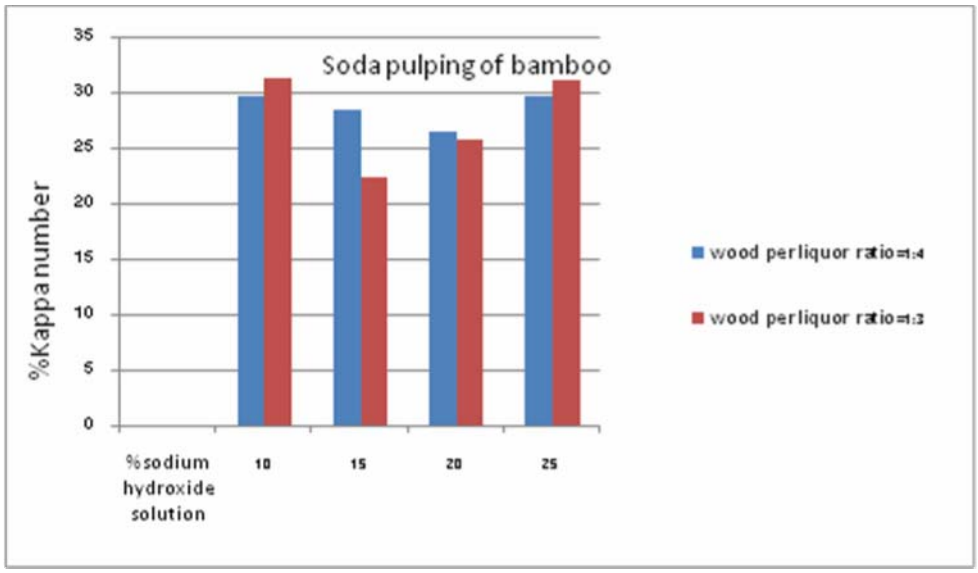


Figure2. Effect of % active alkali on Percentage of Yield, kappa number and brightness of sulfate pulping at sulfidity of 25%,temperature of 170oC,retention time of 2hrs.


Soda pulping of bamboo
%Yield
45
40
35
30
25
20
15
10
5
0
%sodium hydroxide solution
10
15
20
25
wood perliquor ratio=1:4
wood perliquor ratio=1:3


Soda pulping of bamboo
%Kappa number
35
30
25
20
15
10
5
0
%sodium hydroxide solution
10
15
20
25
wood perliquor ratio=1:4
wood perliquor ratio=1:3

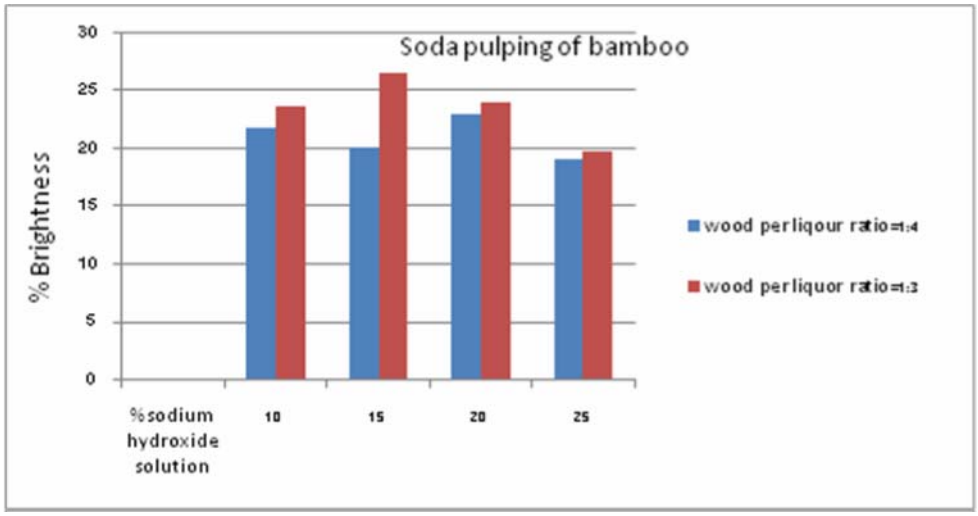


Figure3. Effect of % sodium hydroxide solution on Percentage of Yield, kappa number and brightness of soda pulping at temperature of 150oC,retention time of 90 minutes and different wood per liquor ratio of 1:4 and 1:3.

From the Table 1, a good bamboo paper quality from formacell pulping is found at 165oC, formic acid of 10% and water content of 10% with higher brightness.

It's can be seen in Table 2 the highest bamboo paper quality of sulfate pulping is given at active alkali of 18% with higher brightness.

From Table 3, a bamboo paper quality from soda pulping is given at a sodium hydroxide solution concentration of 10% and the ratio of wood to liquor 1:3 with higher brightness.

Table1 Physical properties of bamboo paper (C.vergatum) from formacell process in various conditions at different freeness

Condition	Freeness [oSR]	Tensile strength [m]	Bursting strength [KPa]	Tearing strength [cN]	Brightness [%ISO]
T=165oC FOH=10% H2O=5%	5-6 unbeat	1,905.59	53.92	56.6	16.3
	5-6 beat	2,735.93	154.38	103.7	13
	38-39	4,034.44	345.26	113.1	17
T=165oC FOH=10% H2O=10%	5-6	1,052.5	65.34	54.0	13.8
	10-11	2,435.19	81.90	65.4	18.6
	43-44	5,633.33	339.42	87.5	17.9
T=165oC FOH=10% H2O=15%	10-11	2,468.93	103.18	86.4	20.2
	40-40	5,702.23	431.43	88.8	20.7
T=165oC FOH=10% H2O=20%	9-10	2,863.21	122.84	85.7	19.8
	45-46	5,010.27	425.71	68.2	18.9

Note that T= temperature, FOH = formic acid, H2O = water content

Table 2 Physical properties of bamboo paper (C.*vergatum*) from Sulfate process in various conditions at different freeness.

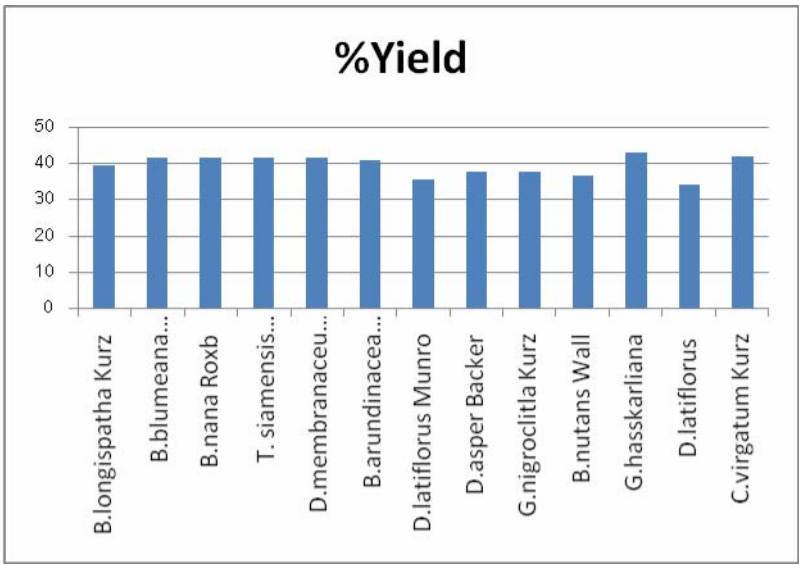
Condition	Freeness [oSR]	Tensile strength [m]	Bursting strength [KPa]	Tearing strength [cN]	Brightness [%ISO]
AA=14%	25-26	4,127	261.93	93.2	12.5
	72-72	6,086.51	418	66.6	15.3
AA=16%	11-12 unbeaten	1,792.08	95.28	61.4	23.3
	31-32	4,842.98	302.64	95.5	21.8
	36-37	5,168.55	441.67	75.8	23.4
AA=18%	11-12 unbeaten	1,091.90	91.22	52.4	30.2
	27-28	3,870.98	252.04	96.0	25.5
	44-45	4,940.60	427.05	53.1	30.6
	45-46	5,165.29	330.44	81.5	27.6
AA=20%	15-16 unbeaten	1,974.87	93.83	69.9	33.6
	20-21	3,040.54	161.86	86.3	31.6
	35-36	4,374.88	403.24	67.6	34.6
	48-48	4,530.80	248.64	61.6	32.8

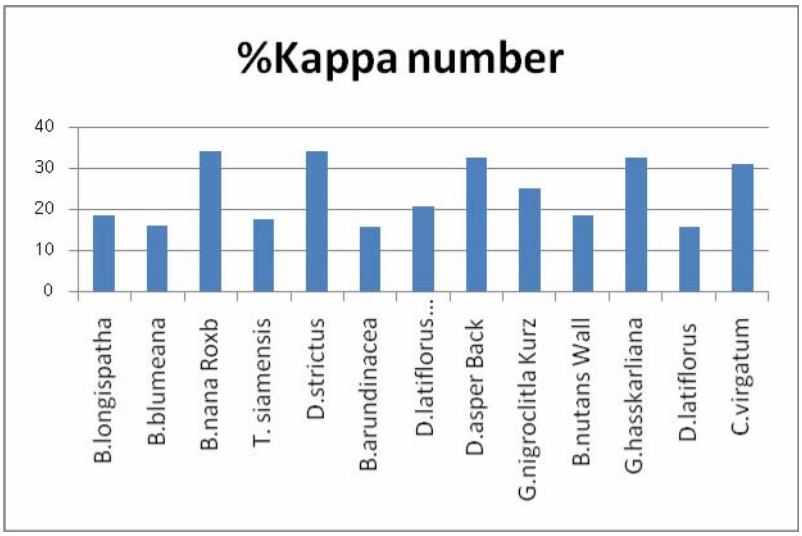
Note that: AA = Active alkali

Table 3 Physical properties of bamboo paper (C.vergatum) from Soda process in various conditions at different freeness.

Condition	Freeness [oSR]	Tensile strength [m]	Bursting strength [KPa]	Tearing strength [cN]	Brightness [%ISO]
10%NaOH aq. Wood per liquor ratio=1:4	13-14	2,036.58	105.34	54.4	28.7
	26-26	2,762.63	132.45	57.9	31.6
	38-38	2,829.10	145.18	52.5	31.8
	81-82	4,374.43	230.62	44.6	34.4
15%NaOH aq. Wood per liquor ratio=1:4	10-11	1,100.85	59.38	26.5	27
	39-40	1,260.45	69.62	14.8	30.6
20%NaOH aq. Wood per liquor ratio=1:4	4-5 unbeaten	3,80.27	37.13	25.4	26.5
	19-20	1,170.23	69.15	15.9	33.2
	38-39	1,354.28	71.26	11.1	34.8
25%NaOH aq. Wood per liquor ratio=1:4	4-5 unbeaten	160.85	31.67	20.5	22.4
	57-58	1,241.57	67.86	11.6	32.7
10%NaOH aq. Wood per liquor ratio=1:3	27-28	3,383.04	194	91.1	32.4
	51-52	4,449.12	272.78	74.5	32.4
15%NaOH aq. Wood per liquor ratio=1:3	29-30	2,090.47	100.31	27.1	34.8
	52-53	2,214.61	110.60	21.6	37.2
20%NaOH aq. Wood per liquor ratio=1:3	16-17	1,554.75	71.87	21.7	32.9
	72-72	2,407.53	123.21	19.3	35
	32-33	1,585.52	83.70	16.8	37.8
25%NaOH aq. Wood per liquor ratio=1:3	17-18	1,142.49	66.11	22.5	27.8
	39-40	1,305.74	71.92	16.3	31.5

Note that: NaOH = sodium hydroxide solution concentration


%Yield
50
40
30
20
10
0
B.longispatha Kurz
B.blumeana...
B.nana Roxb
T. siamensis...
D.membranaceu...
B.arundinacea...
D.latiflorus Munro
D.asper Backer
G.nigroclitla Kurz
B.nutans Wall
G.hasskarliana
D.latiflorus
C.virgatum Kurz


%Kappa number
40
30
20
10
0
B.longispatha
B.blumeana
B.nana Roxb
T. siamensis
D.strictus
B.arundinacea
D.latiflorus...
D.asper Back
G.nigroclitla Kurz
B.nutans Wall
G.hasskarliana
D.latiflorus
C.virgatum

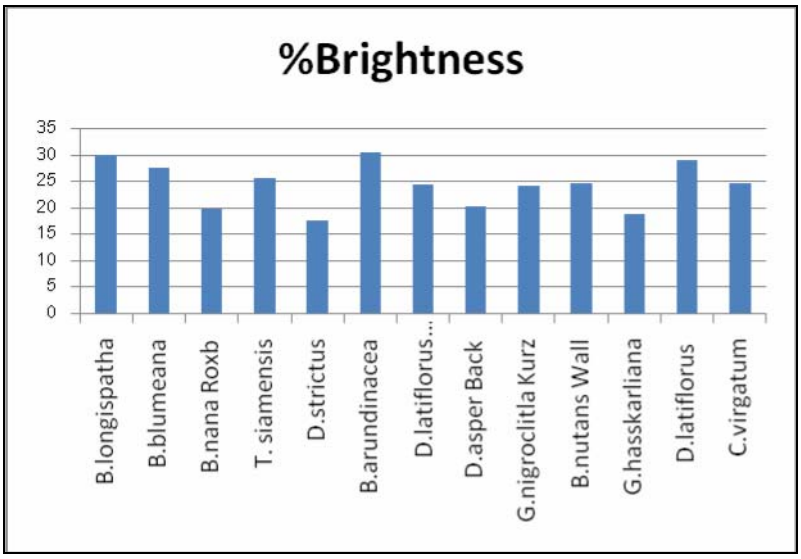


Figure 4 Comparison of soda pulping quality among 13 species of bamboo on yield, kappa number and brightness at the cooking temperature of 150oC, retention time of 90 min, 10% concentration of aqueous lime and wood per liquor ratio of 1:3

Table 4 Physical properties of paper from 13 species of bamboo with Soda process at the cooking is temperature of 150oC, retention time of 90 min, 10% concentration of aqueous lime and wood per liquor ratio of 1:3 in different freeness.

Type of bamboo	Freeness [oSR]	Tensile strength [m]	Bursting strength [KPa]	Tearing strength [mN]	Brightness [%]
Bambusa longispiculata Kurz..	2-3	1,013.97	64.34	439	30.4
	5-6	2,311.26	105.68	549	33.2
	18-18	2,405.77	123.02	531	34.9
	36-36	3,000.64	158.07	570	36.8
Bambusa blumeana Schult	3-4	707.70	47.40	323	26.4
	14-15	1,487.43	89.62	240	30.7
	21-22	2,040.2	107.99	213	32.5
	38-39	2,276.83	120.51	219	35
Bambusa nana Roxb	5-6	515.93	46.06	268	15.8
	13-14	1,843.20	101.68	296	22.5
	51-51	3,079.35	162.06	356	26.8
	61-61	3,067.80	169.45	311	27.9
Thyrsostachys siamensis Gamble	5-6	450.31	38.54	219	26.8
	15-16	2,250.50	110.71	281	32.7
	41-41	2,725.53	135.12	278	34.8
	51-51	3,218.95	167.54	297	36.4
Dendrocalamus membranaceus Munro	5-6	544.66	47.15	363	15
	3-4	1,495.80	79.95	246	20
	33-33	1,715.42	97.44	222	22.1
	41-41	1,842.78	94.35	190	23.5
Bambusa arundinacea Wild	4-5	753.45	57.42	427	29.8
	5-6	2,239.16	129.41	480	37.1
	37-38	2,583.12	146.75	419	38.6
	56-57	3,345.69	185.43	382	40.3
Dendrocalamus membranaceus Munro	5-6	846.47	58.73	401	23.5
	26-27	2,236.81	137.25	356	29.3
	53-54	2,832.25	165.0	322	31.7
Dendrocalamus asper Backer	4-5	875.19	66.57	577	20.2
	4-5	1,844.46	105.46	362	24.4
	41-41	2,212.5	118.93	260	27.3
	56-57	2,768.65	127.47	248	28.9
Bambusa affinis Mouro.	5-6	1,026.64	61.89	396	24.7
	14-15	2,169.74	111.95	388	26.3
	35-35	2,309.93	128.40	279	31.0
	46-47	2,499.33	122.66	232	30.2
Bambusa nutans Wall	5-6	476.36	51.31	518	23.8
	20-21	1,990.90	115.76	471	28.9

	42-42	2,730.50	148.24	426	32.2
	50-50	2,772.11	147.82	416	31.8
Gigantochloa hasskarliana	4-5	788.02	55.95	407	15.8
	25-26	2,046.88	113.52	395	22.7
	65-65	3,029.68	155.23	285	27.7
	65-65	3,118.01	155.27	302	27.7
Derdrocalamus Latiflorus	4-5	1,337.76	84.0	507	31.4
	35-35	3,142.88	171.59	340	35.8
	54-54	3,441.82	196.01	315	36.5
Cephalostachyum virgatum Kurz	27-28	3,383.04	194	911	32.4
	51-52	4,449.1	272.78	745	32.4

Pulp properties of the 13 species of bamboo are compared of under investigation at cooking condition [at 150oC temperature, 90 min retention time, 10% sodium hydroxide solution concentration and wood per liquor ratio of 1:3]. It was found that *B.longispiculata* Kurz, *B. blumeana* Schult, *Thyrostachys siamensis* Gamble, *Bambusa arundinacea* Wild, and *C. virgatum* Kurz provide high yield and high brightness. However, the soda pulps of *B.longispiculata* Kurz, *Thyrostachys siamensis* Gamble, *Bambusa arundinacea* Wild, *D.Latiflorus* and *C. virgatum* Kurz gave high strength.

Pulp quality of Bamboo can process by formacell pulping at 10% formic acid, 10%water content ,165oC temperature, 120 min retention time and 1:7 wood per liquor ratio. The pulp properties are 42.88 % yield , 22.60 % kappa number , the beating may produce at 40 oSR freeness, the physical properties of paper are 5,702.23 m tensile strength, 431.43 KPa bursting strength , 88.8 cN tearing strength and 20.7% ISO brightness .

Pulp quality of Bamboo can process by sulfate pulping at 25% sulfidity, 10%active alkali 170oC temperature, 120 min retention time and 1:4 wood per liquor ratio that gives 41.18 % yield, 16.91 % kappa number, the beating may produce at 45oSR freeness at this point the physical properties of paper are 5,165.29 m tensile strength, 330.44 KPa bursting strength, 81.5 cN tearing strength, and 27.6% ISO brightness.

Pulp quality of Bamboo can process by soda pulping at 10% NaOH solution, 165oC temperature, 90 min retention time and 1:7 wood per liquor ratio had provided a 42.30% yield, 31.29% kappa number, the beating may produce at 51 oSR freeness, the physical properties of paper are 4,449.12 m tensile strength, 272.78 KPa bursting strength, 74.5cN tearing strength and 32.4%ISO brightness.

Conclusion

It can be concluded that the soda process is preferable for bamboo pulping as it is known process and give the highest brightness. From 13 bamboo species investigated in this experiment, it is found that 5 species are good raw material for pulp and paper process. However, the method of cooking condition depends on the paper quality required from the end use.

Acknowledgement

I would like to thank Mr.Anirut udomkitti, Mr.Wasuthon malingun for their in wood chipping in laboratory contribution.

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Vocabulary/Parameter

- Pulp quality may represent in Yield, Kappa number, resistant, Degree of polymerization and Brightness etc.
- Physical properties of paper represent in Tensile strength, bursting strength and Tearing strength and Brightness etc.
- Brightness is the percentage reflectance of blue light only at a wavelength of 457 nm. The standards are per TAPPI T 452
- Tensile Strength is indicative of fiber strength, fiber bonding and fiber length.(TAPPI T 494)
- Bursting strength tells how much pressure paper can tolerate before rupture.(TAPPI T 403)
- Tearing Resistance/strengths is the ability of the paper to withstand any tearing force (expressed in cN, TAPPI T 414)
- Canadian Standard Freeness (CSF) is an arbitrary measure of the drainage properties of stock under specified conditions.

Bamboo Design Dialogue

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Assistant Professor, Indian Institute of Technology Guwahati, Assam, India

Abstract

Bamboo is known for its tensile strength that has been compared with the steel. Moreover the various applications of bamboo from housing to handicrafts, using traditionally or in a contemporary way, and the role of industrialisation into bamboo sector tell us the story of its characteristic evolution through exploration.

Bamboo design dialogue reflects on various critical experiments done while design and development of processed bamboo furniture at Department of Design, Indian Institute of Technology Guwahati, India. It also established the dialogues by highlighting the application of philosophical thoughts, which helps to create new values in terms of functionality and aesthetic by understanding the real nature of bamboo.

The paper ends with the sharing of the experience of training workshop to the entrepreneur for fabricating processed bamboo furniture.

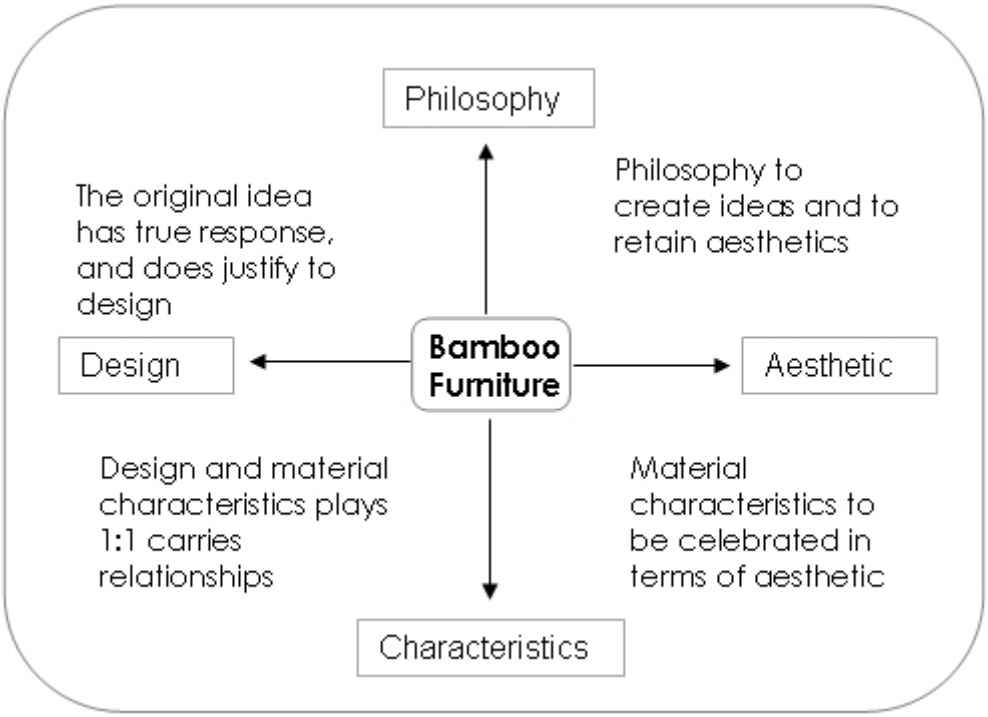
Keywords: Design, characteristics, joineries, jigs and fixtures, training

Introduction

Bamboo is the fastest growing grass, abundantly available in North Eastern India, more than 130 species of bamboo occurs in India. It has been diversely used traditionally for daily usages from bamboo shoots as diet to basket weaving or utilizing in construction.

Very recently in Indi, bamboo is being taken seriously to rethink as a potential material resource for the industrial products, which contributes towards the positive side of the society in terms of eco system and economy.

In general bamboo is being explored to a considerable level, whereas it is yet to explored in design per se. However, understanding the characteristics of bamboo and the process of the manufacturing of the industrial bamboo products opens up the door for creativity to convert bamboo in realisation of day to day products. Here is a trial of using bamboo board, flooring tiles and sticks to convert into furniture.



Bamboo Design Geography

Furniture 1: Mother Chair

Concept

'Mother' stands for 'Nature', who behaves/ reacts same with every creature and gives everything without expecting anything in returns.

This chair is designed with absolute natural (eco-friendly) material that is bamboo, in the form of bamboo board and bamboo sticks. The backrest of the chair is made of raw bamboo sticks, which is exposed to adjust as per the user's back profile. The number of layers of loosed bamboo sticks for backrest was estimated optimistically to fit between comfort and durability.

Material

Bamboo

Mother Chair

Furniture 2: Ekatra - Modular Stool

Concept

”Ekatra” means “Together” in Marathi (a local language of Maharashtra State in India). The concept is inspired by a fact shared by Frijtof Capra in his book “Web of Life” - the multi-cellular organism, where each cell is separate but interconnected and interdependent to each other. A fertilized egg”new cell” undergoes multiple cell divisions repeatedly in the growth and development of a multi-cellular organism. Similarly in Ekatra Stool, the multi-pieces of board are derived from a single board.

They are separate but interconnected and interdependent to each other through the joints, and arranged as such to see in the form of a live product altogether.

Material

Bamboo
Spring Steel

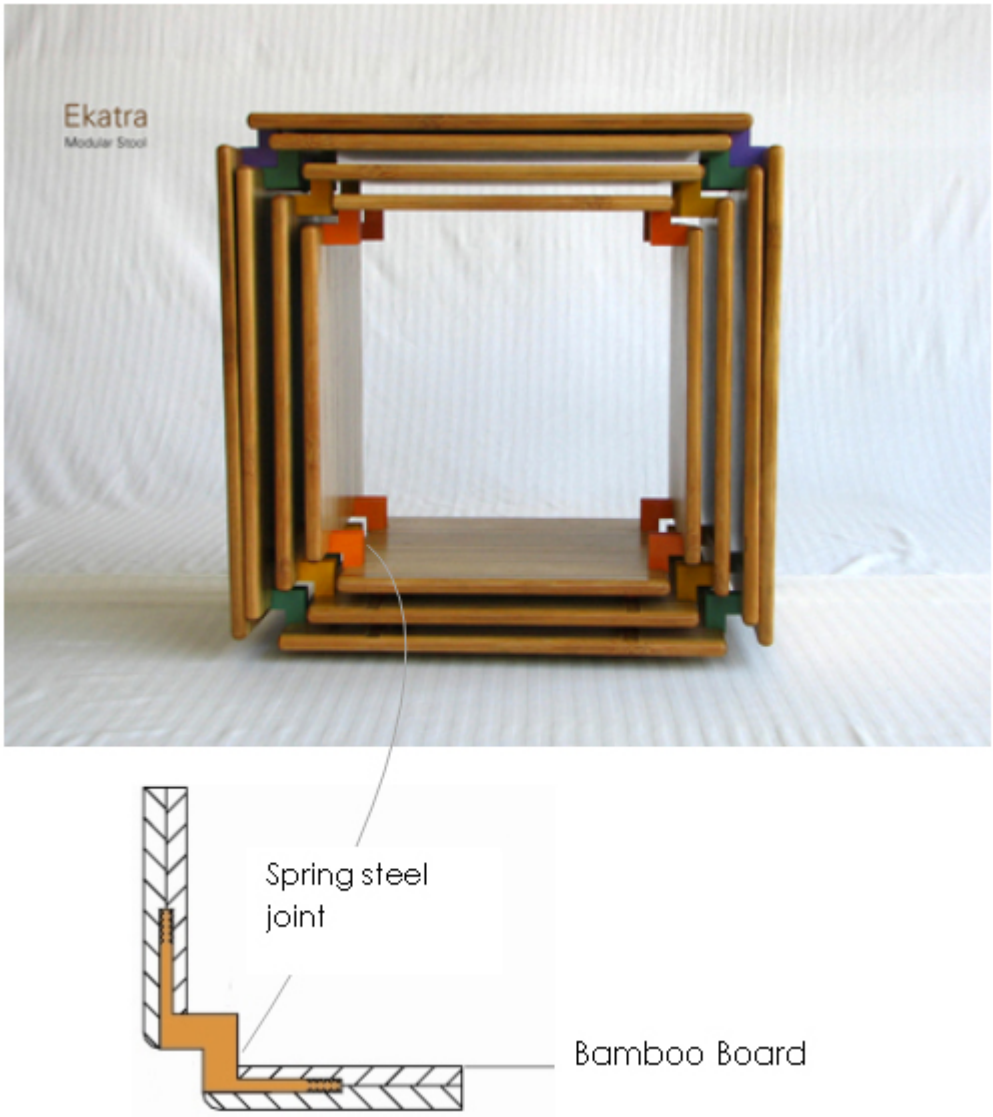


Illustration 1

Joint Detail

Laser cut spring steel joints are incorporated to interconnect the boards to each other.

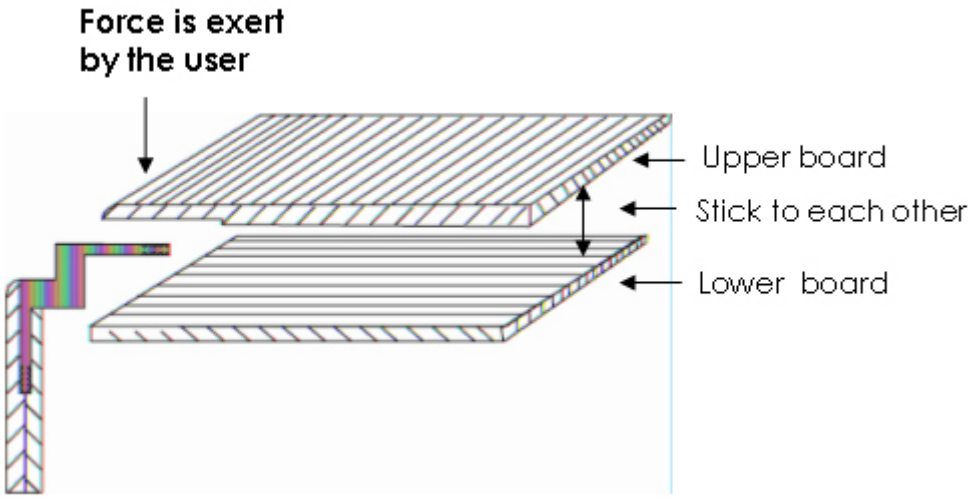


Illustration 2

This design is critical in two ways

1. Each plank consists of two separate bamboo boards, upper board (where the grains of the bamboo are perpendicular to the joints) and lower board (where the grains are perpendicular to the grains of the upper board). The manipulation of the grains "as said above" is important to withstand the force exerted by the user from the top that is distributed through the joint.
2. Spring steel Joinery element, which is very innovative and effective. A precise slot on the inner surfaces of the boards where the joinery element slips inside with the glue. The teeth profile on the joinery element doesn't allow the joints to come out.

The joints were given powder coat finish (rust proof) of different colour, chosen from the VIBGYOR colour pallets. Blue - Green - Yellow – Orange

Furniture 3: Bakda

Concept

Bakda stands for bench. The concept is inspired by the bench occurs in the local tea stall in India. It is solely made of bamboo flooring tiles (natural and carbonised). The two inclined legs are easy to slip from the two ends of the horizontal plank through the slots. The legs are designed to hold the plank stable and contribute to the feature of anti bending while sitting at the centre of the bench.

Material

Bamboo
Spring Steel

Furniture 4: Elephant Bench

Concept

The elephant bench is merely stands out for its surface finish. The water based stain and polyurethane coating used.

Material

Bamboo

Furniture 5: Foldable rack

Concept

The concept was generated with two factors

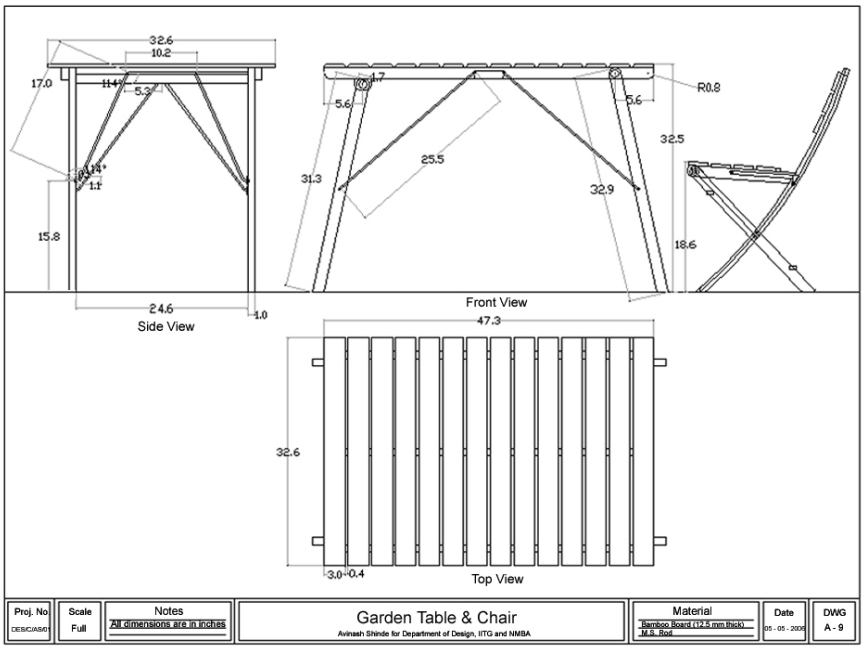
1. Compact packing while transportation, till the consumer end.
2. Short time to open and easy to unfold and use.

Such design is appreciated in the studio, hostels, offices and where the space is the prime constraint.

Furniture 6: Garden Furniture

Concept

Again the concept was generated for ease of transport and less Consumption of the space while storage.


32.6
10.2
17.0
5.3
15.8
24.6
1.0
Side View
1.7
5.6
5.6
R0.8
32.5
25.5
31.3
32.9
18.6
Front View
47.3
32.6
3.0
0.4
Top View
Proj. No
DESIGIAS01
Scale
Full
Notes
All dimensions are in inches
Garden Table & Chair
Avinash Shinde for Department of Design, IITG and NMBA
Material
Bamboo Board (12.5 mm thick)
M.S. Rod
Date
05 - 05 - 2006
DWG
A - 9


Garden
Furniture

The shape of curved leg of the chair was formed by using a cost effective spring steel jig. The different parts of jig are made of using laser cut technology and they are designed to fit each other to form a jig, without using any other fittings like nut bolts and screw (as shown below).

A defined bamboo strips come together with the glue and clamped inside the jig to get the required shape of the chair member. Such cost effective moulds could be thought of for making big furniture by using bamboo mats as shown in illustration 3.

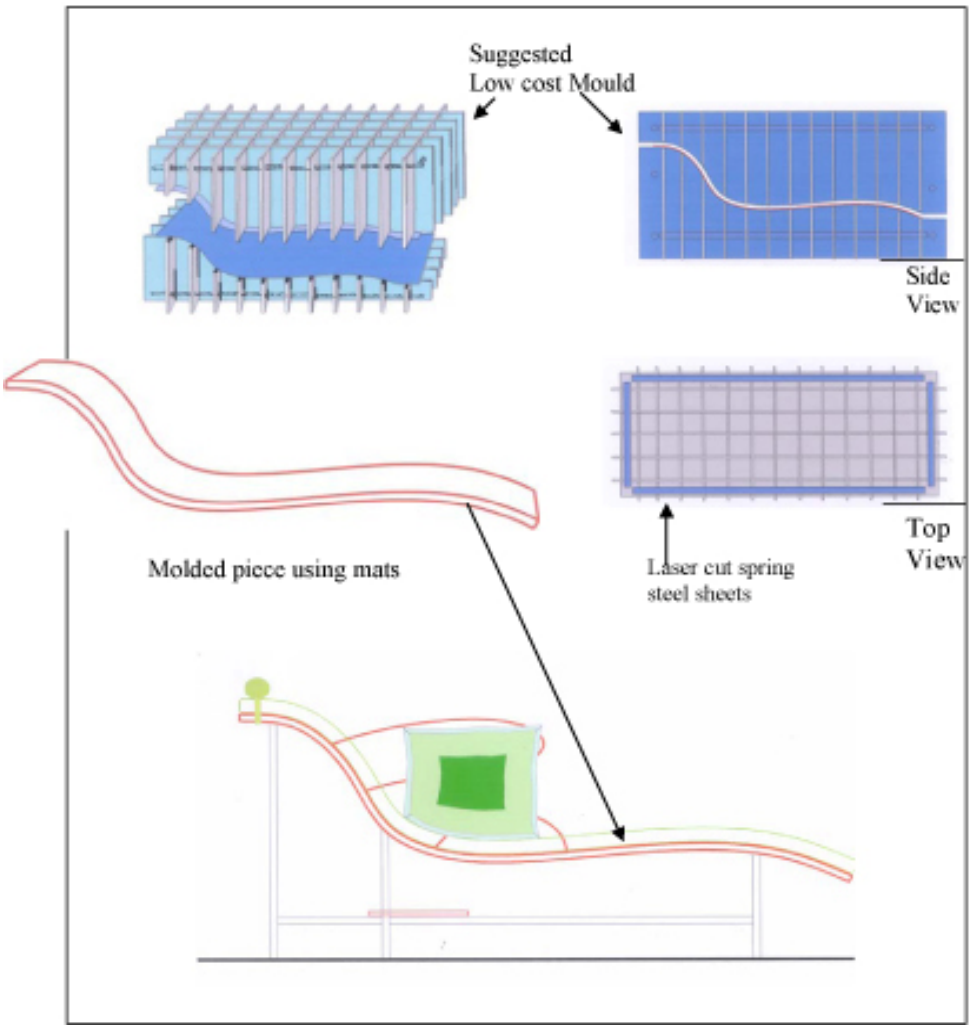


Illustration 3: Mould made with laser cut spring steel sheets and welded M.S. sheet

Furniture 7: Tree Book Shelve with Book Stopper

Concept

Design is an experiment as combination of material, which inspired by tree; a tree is organized by its own way, which provides space and shelters to birds and many living beings.
Similarly, Tree Book shelve can make even a single book to stand anywhere on the shelf. It gives user the liberty to think creatively while arranging the books as per mood or liking and help to generate different patterns. Tree book rack can also act as a room partition. The laser cut pattern incorporated in the stainless steel panels, depicts tree leaves.

Material

Bamboo
Stainless Steel

Workshop

10 days training Workshop to the entrepreneur on design and development of Bamboo Furniture

The workshop was started with understanding the design drawings of the furniture, followed by hands on training of using machineries, jigs and fixture. The key factors of starting of bamboo furniture were discussed as mentioned below.

1. ***Mass production of the various parts of furniture separately.***

Each furniture is different from the others. The manufacturing of the different parts of furniture should happen in batches. Similarly the joineries details should also take place in batches for mass production. There are standard wooden joineries like dove tail, finger joint and so on, for that the machines are readily available. Whereas for special joineries special customised jig and guides could be practised.

2. *Assembly line of the furniture*

Special clamps could be made for assembly of the furniture. It is important to retain the desire shape and to avoid the post hurdle of matching of one part to another part of the furniture.

3. *Storage and Packaging*

Proper tagging is needed while storage and packaging.

Conclusion

Bamboo has an immense potential to explore into furniture sector. New surface finishes and new texture provide a new flavour to the environment. This age is looking for new sensorial pleasure through either by concept of design or by the new material invention. The new material can be invented by mixing bamboo dust and bamboo charcoal with Polyurethane and silicon or with rubber or with different plastics. The furniture could be mould as similar as moulding done in plastics.

The new unconventional methods of experiments is needed which will help us to take bamboo into very new direction in new age.

Production of Manually-Oriented Strand-Cement Board from Bamboo

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Abstract

Recently, it was found that the strength properties of wood wool cement board (WWCB) can be significantly improved by aligning the strands in a cross-ply manner within boards. In this study, the technical and economic feasibility of manufacturing oriented bamboo strand-cement board using manual strand orientation were assessed. Three-layer commercial-size oriented bamboo strand-cement boards (12 x 610 x 2440 mm) from kauayan tinik (*Bambusa blumeana* J.A. & J.H. Schultes) were manufactured wherein the strands at the surface layers were manually aligned along the length of the board while the strands at the core layer were randomly oriented. The properties of such boards were compared to the boards manufactured using the conventional method of manufacturing strand cement boards wherein single-layer boards contain randomly oriented strands.

The modulus of elasticity (MOE) and modulus of rupture (MOR) improved by 1.8 and 1.6 times, respectively as a result of aligning the strands within boards. The MOE and MOR of oriented bamboo strand cement boards that where tested wet had comparable properties to those of boards containing randomly oriented strands that were tested dry. The strength properties of bamboo strand cement boards were higher than boards made from yemane (*Gmelina arborea* Roxb.). On the other hand, thickness swelling (TS) and water absorption (WA) properties of boards were unaffected by strand orientation irrespective of species used to manufacture such boards.

The profitability analysis showed that the manufacture of oriented bamboo strand cement composite is economically viable with a return on investment (ROI) of 36% at a yearly production of 66,500 boards (250 boards per day).

This study signifies that manual strand orientation as a technique to improve the strength properties of strand-cement composites is technically and economically feasible in the Philippines. Manufacture of oriented bamboo strand-cement boards is also suitable to the socio-economic conditions of the country.

Introduction

The combination of long, thin strands of wood (wood wool) and Portland cement to produce a building material known as wood wool cement board (WWCB) dates back from the early 1900s (Kollman 1963). Since then, WWCBs have been used for non-structural applications such as for insulation and acoustical purposes and where the ingress of moisture is unavoidable. There has been limited research on improving the strength properties of WWCBs and extending their use for non-structural applications. Recently however, it was found that by aligning wood strands within boards in certain direction, a 100% increase in flexural strength of boards can be achieved (Cabangon and Evans 2001; Cabangon *et al*. 2002).

At present, there is no machinery available to orient wood wool strands. Meanwhile, in the Philippines, WWCBs are manufactured in small to medium scale plants using labor-intensive process. The mat-forming process is done by hand (Figure 1), and therefore, such technique may be used in aligning the strands in boards to improve their strength properties. Such strength improvement is important particularly in the Philippines because WWCBs are used for general-purpose construction.

Figure 1. Manual mat-forming of cement-coated wood wool strands in a commercial WWCB plant in the Philippines

It is known that bamboos have extremely high bending strength and stiffness properties. For example, Espinosa (1930) reported that *Bambusa blumeana* (30 cm circumference) can support a 500 kg load when loaded at the center of 1.5 m span. In addition, bamboo strands may be easier to align manually because of its stiffness

compared to the curly nature of wood wool strands. Thus, the utilization of bamboo for the manufacture of oriented strand cement composite has great potentials to improve the strength properties of strand-cement boards. This study examined the feasibility of using bamboo as raw material for the production of oriented strand cement composite. It aims to (1) determine the flexural strength and water resistance properties of oriented bamboo strand-cement board; (2) compare the properties of boards manufactured from aligned and randomly oriented strands from bamboo and wood; (3) determine the economic viability of producing oriented bamboo strand cement board.

Materials and Methods

Materials

Three-year old plantation-grown kauayan tinik (*Bambusa blumeana* J.A. & J.H. Schultes) poles were collected from Pililia, Rizal. This bamboo species was chosen because of its widespread availability in the Philippines and posses a considerable culm wall thickness. On the other hand, five-year old yemane (*Gmelina arborea* Roxb.) was collected from a private plantation in Alaminos, Laguna. Type I Portland cement was used as binder during board manufacture.

Board Manufacture

The bamboo poles and yemane were cross-cut into 400 mm long billets and then shredded using a horizontal type reciprocating shredding machine in a WWCB plant in Bay, Laguna. The resulting bamboo strands measuring 0.4 x 4 x 400 mm were soaked in tap water, to remove water-soluble extractives that inhibit cement setting, in a soaking tank (1 [depth] x 2 [width] x 3 [length] m). The strands were air-dried by spreading on a concrete floor for two days to equilibrium moisture content of approximately 18 percent. The air-dried strands, Portland cement, and water were mixed in a drum-type mixer. The strand/cement ratio and water/cement ratio used were 0.8/1 and 1/1, respectively. Two types of boards were manufactured. The first board type contains strands with random orientation. The second has a three-layer structure wherein the strands at the surface layers were oriented parallel to board length while the strands at the core layer were randomly oriented (Cabangon and Evans 2002). Boards measuring 610 x 2440 mm with 12 mm thickness were manufactured at the WWCB pilot plant at the Forest Products Research and Development Institute (FPRDI) in Los Baños, Laguna.

Bamboo strands, cement, and water were mixed for a period of 3 to 5 minutes or until the strands are thoroughly coated with cement. Mats were formed by hand by evenly distributing the cement-coated strands into a detachable rectangular forming box placed on top of plywood caul plates lined with plastic sheets. In the case of three-layer oriented WWCBs, cement-coated strands of adjacent layers were manually formed into a mat one layer at a time. Formed mats were pre-pressed, followed by the careful removal of the forming box. The resulting mats on caul plates were placed on top of each other to form a batch of boards. Wood thickness stoppers, corresponding to the desired thickness of boards (12 mm), were placed at the long ends and in-between the caul plates. The resulting batch of boards was compacted in a 60-ton capacity hydraulic press by applying a pressure of 3000 psi or until the thickness stoppers have met the caul plates. The pressure was maintained for 24 h for the setting of cement to take place.

Board Conditioning and Property Tests

Each manufactured board was allowed to stand vertically on one of its longer sides in between wood stickers (12 mm thick) at ambient temperature and humidity for a period of 28 days. Conditioned boards were tested for their modulus of rupture (MOR), modulus of elasticity (MOE), thickness swelling (TS), and water absorption (WA). Test specimens were cut from each board parallel and perpendicular to board length. The dimensions of the test specimens were 50 x 230 mm. Specimens tested wet were soaked in water for 24 h, excess water wiped with a clean cloth, and then immediately tested for bending properties. TS and WA tests were conducted by measuring the respective thickness and weight of the 'wet' test specimens before and after soaking in water.

Experimental Design and Statistical Analysis

The two board types (random and oriented) were manufactured using bamboo and yemane with three replications. A total of 12 boards were manufactured over a period of six days. Boards from the two species with random strand orientation were manufactured on the first, third and fifth day while boards with a three-layer structure were manufactured on the second, fourth and sixth day. The order in which boards were manufactured was randomized.

Results of tests were subjected to an analysis of variance (ANOVA) appropriate for the design described above. A least significant difference bar was used to compare differences between means.

Results and Discussion

Board Properties

The effect of strand orientation, test condition, species, and their interactions on the MOE and MOR of boards are shown in Tables 1 and 2, respectively. Strand orientation, species and test condition significantly affected the MOE of boards (Table 1). Similar ANOVA was obtained for MOR except that the species did not affect the bending strength of boards (Table 2). The MOE (Figure 2a) and MOR (Figure 2b) of boards containing strands oriented parallel to the span were significantly higher than boards containing randomly oriented strands and the above board types were significantly higher than boards containing strands oriented perpendicular to the span. These results were in accord with the results of Cabangon and Evans (2001) and Cabangon *et al*. (2002).

Table 1. Analysis of variance on the effect of strand orientation (board type), test condition, species, and their interactions on the MOE of boards

Source of Variation	Df	Sum of Squares	Mean Square	F Value	Pr > F
Orientation (O)	2	9599601252	4799800626	273.58	0.0001 **
Test Condition (T)	1	2893829876	2893829876	164.94	0.0001 **
Species (S)	1	414734981	414734981	23.64	0.0001 **
O x T	2	750209160	375104580	21.38	0.0001 **
O x S	2	1699808920	849904460	48.44	0.0001 **
T x S	1	46815649	46815649	2.67	0.1029 ns
O x T x S	2	169397125	84698562	4.83	0.0083 **

** significant at the 0.01 level of probability

Table 2. Analysis of variance on the effect of strand orientation (board type), test condition, species, and their interactions on the modulus of rupture of boards

Source of Variation	Df	Sum of Squares	Mean Square	F Value	Pr > F
Orientation (O)	2	216386	108193	250.98	0.0001 **
Test Condition (T)	1	93208	93208	216.22	0.0001 **
Species (S)	1	228	228	0.53	0.4673 ns
O x T	2	13860	6930	16.08	0.0001 **
O x S	2	17416	8708	20.20	0.0001 **
T x S	1	1133	1133	2.63	0.1055 ns
O x T x S	2	2899	1449	3.36	0.0352 *

** significant at the 0.01 level of probability

* significant at the 0.05 level of probability

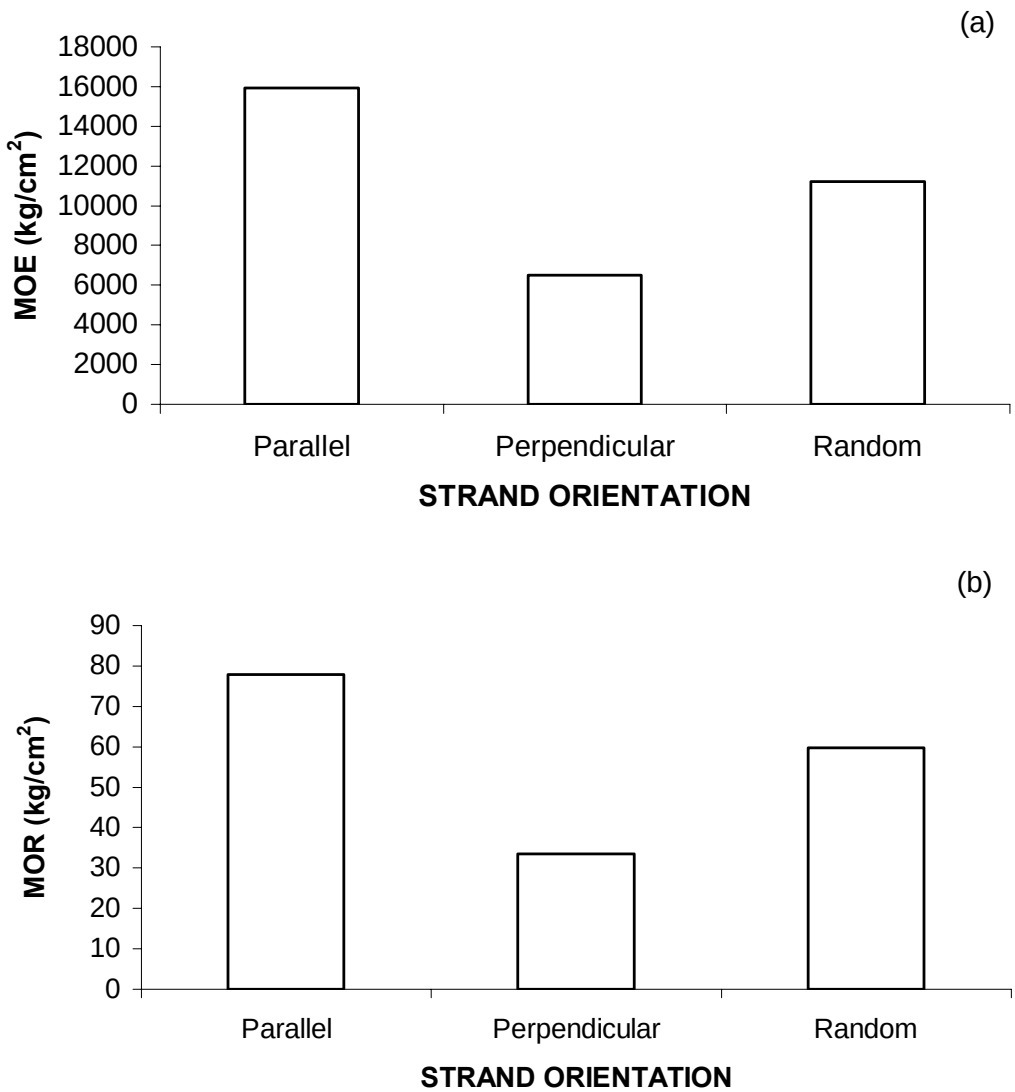

Figure 2. Influence of strand orientation on the MOE (a) and MOR (b) of boards

The MOE (Fig. 3a) and MOR (Fig. 3b) of boards tested wet were significantly lower than those boards that were tested dry, as expected. The overall reduction in MOE and MOR was 32 and 35 percent, respectively. On the other hand, only the MOE of boards was significantly influenced by species. The MOE of boards made from bamboo were 1.15 times higher than boards made from yemane (Fig. 4). This effect may be attributable to the high tensile strength of bamboo than wood in the longitudinal direction.

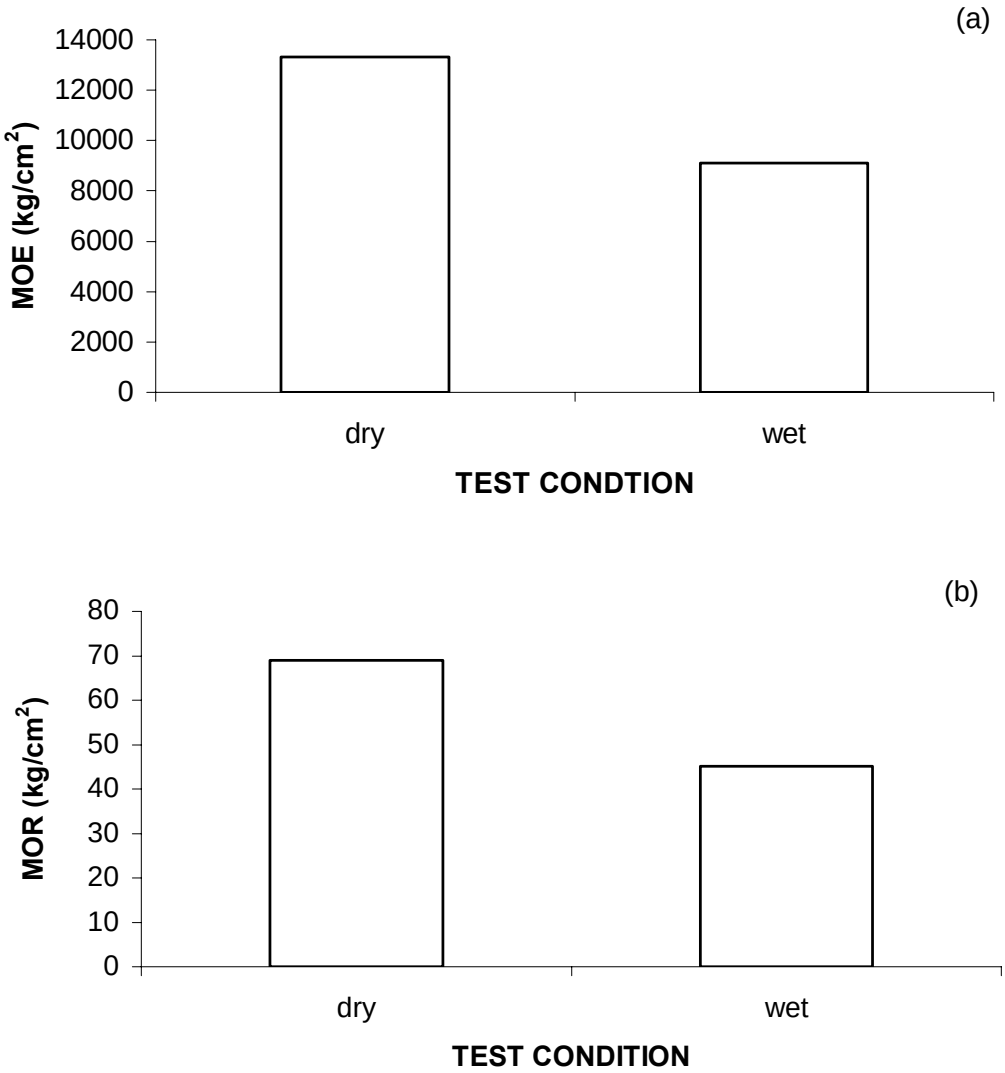

Figure 3. Influence of test condition on the MOE (a) and MOR (b) of boards

There was a significant interaction between the variables used in the study. Both MOE (Table 1) and MOR (Table 2) were affected by the interaction between strand orientation and test condition, orientation and species, and the interaction between strand orientation, species and test condition. On the other hand, the interaction between test condition and species was found to be insignificant suggesting that the MOE and MOR of boards made from bamboo and yemane did not differ in terms of reduction in strength when tested wet.

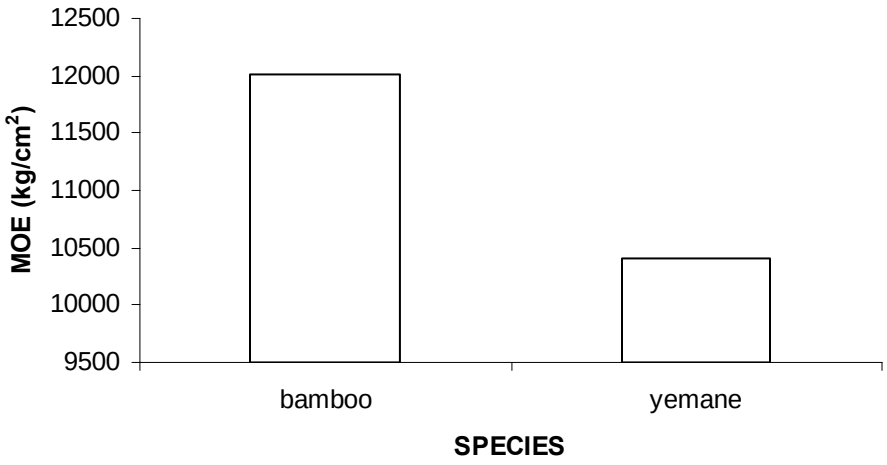

Figure 4. Influence of species on the MOE of boards

The interactive effect of strand orientation, species and test condition on the MOE and MOR of boards are shown in Figs. 5a and 5b, respectively. A least significance difference (LSD) bar is included in each graph to facilitate comparison of means. Boards made from bamboo exhibited the highest MOE and MOR. The dry MOE and MOR of boards from bamboo containing oriented strands were significantly higher than those of boards containing randomly oriented strands. The respective MOE and MOR of boards containing bamboo strands oriented parallel to the span was 1.8 times and 1.6 times higher than boards containing randomly oriented strands. The increase in board stiffness was comparable, while the increase in bending strength was lower, than those obtained by Cabangon *et al.* (2002). On the other hand, the increase in MOE and MOR of boards (compared to boards with random strand orientation) manufactured from yemane was only 1.27 and 1.2 times, respectively.

In Fig. 5, the dry strength properties of boards from yemane and bamboo containing randomly oriented strands did not differ. However, when, the strands were oriented in the preferred direction, higher increase in strength was exhibited by boards made from bamboo. During the manufacture of boards, yemane strands tend to break during mixing with cement resulting to increased difficulty in aligning the strands within boards. This could have been the reason for the lower increase in strength properties of boards from yemane. Such suggestion can also be supported by the lower dry strength parallel/perpendicular ratio of boards made from yemane compared to boards made from bamboo strands. The MOE and MOR parallel/perpendicular ratios were 3.5 and 3.1, respectively. Comparable figures for yemane, were 1.7 and 1.8, for MOE and MOR, respectively. The higher dry strength ratios from bamboo suggest higher strand alignment that could have been the reason for the higher strength increase.

In general, the wet flexural strength of boards was lower than those that were tested dry (Figs. 3 & 5). However, the strength of boards containing bamboo strands aligned to the preferred direction and tested wet did not differ

to that of boards from yemane containing randomly oriented strands that were tested dry. This confirms the high strength properties of boards from aligned bamboo strands.

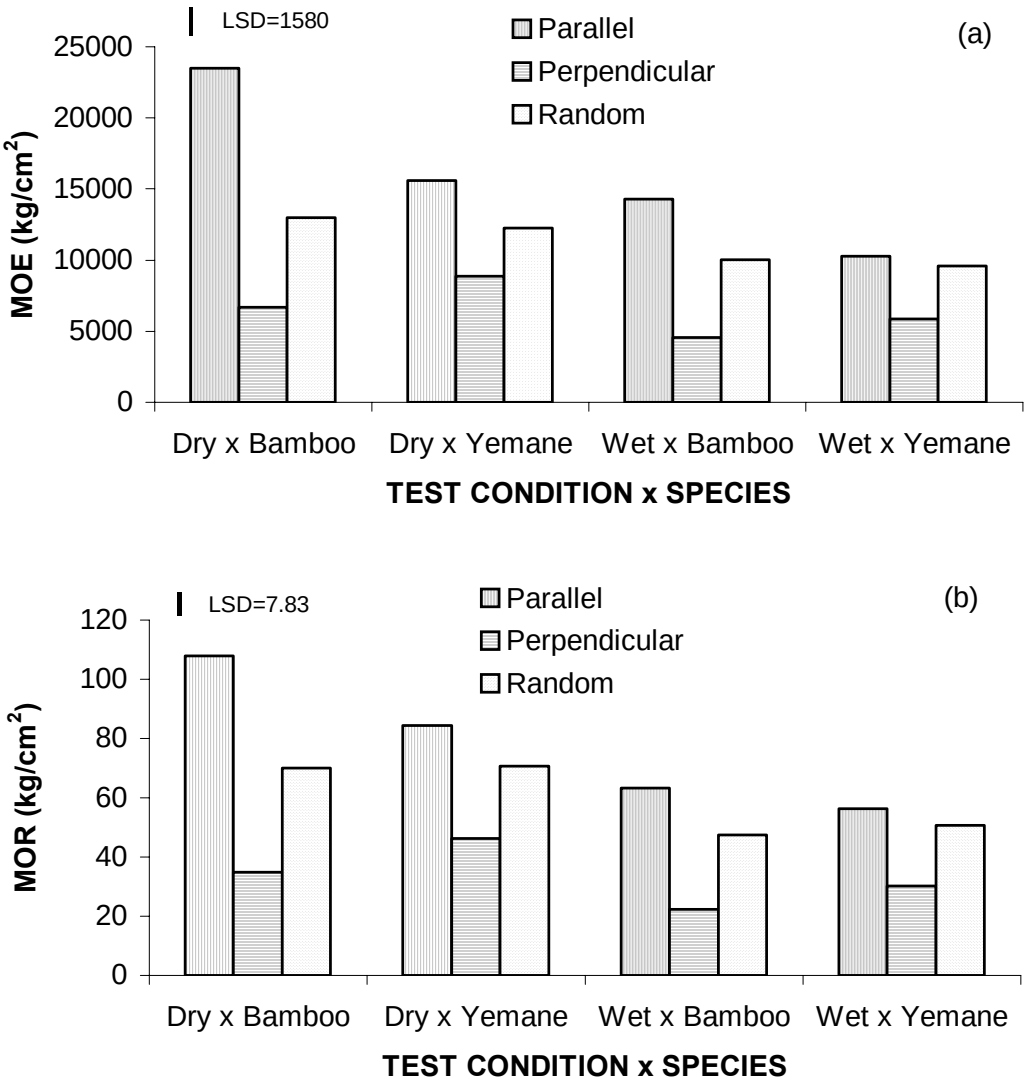

Figure 5. Interactive effect between strand orientation, species, and test condition on the MOE (a) and MOR (b) of boards

In order to examine whether the boards met the minimum strength specifications, the maximum breakage loads of test specimens were compared to the Philippine National Standard for Wood Wool Cement Board (PNS/CTP 07: 1990) (Table 3). PNS specifies a minimum failure of 180 N. Generally, all the manufactured boards passed the PNS specifications except those boards that were aligned perpendicular to the span. The strength properties of boards containing aligned and randomly oriented strands significantly exceeded (particularly boards made from bamboo) the minimum PNS specifications irrespective of test condition. This suggests that both bamboo and yemane are suitable for strand-cement board manufacture. However, where high flexural strength is required, oriented bamboo strands may be preferred.

Table 3. The maximum breaking load of boards compared to PNS (1990) for WWCB

Strand Orientation	Min. Breakage Load (N) (PNS 1990)	Max. Load (N)			
		Bamboo		Yemane	
		Dry	Wet	Dry	Wet
Parallel	180	423.4	247.7	331.0	221.0
Perpendicular		136.9	87.7	181.3	118.8
Random		274.6	186.1	277.5	198.9

The water resistance (TS and WA) properties of boards are shown in Fig. 6. TS (Fig. 6a) and WA (Fig. 6b) of boards were unaffected by species and strand orientation. The water resistance properties of WWCBs are highly dependent on the wood/cement ratio of boards (Cabangon 2003). Thus, the result obtained here may be attributable, in part, to the similarity in strand/cement ratio of 0.75/1 used in the study for both species and strand orientation.

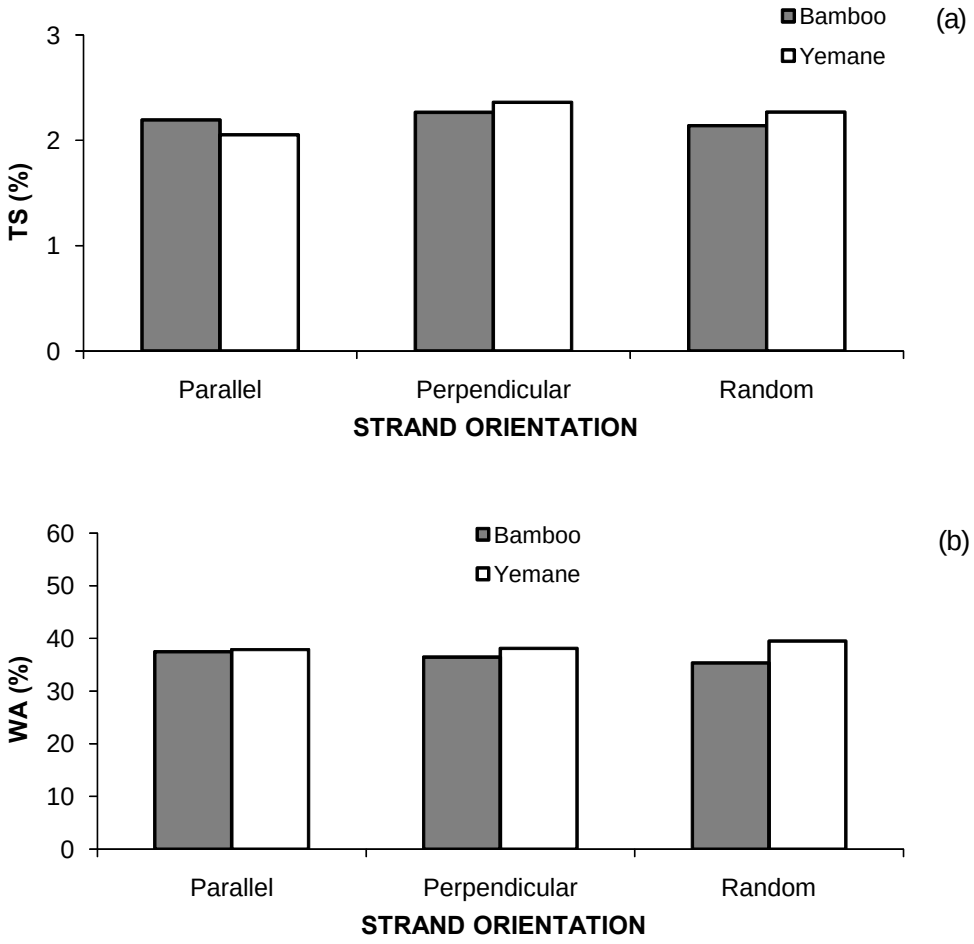

Figure 6. TS (a) and WA (b) of boards from yemane and bamboo

Profitability Analysis

The initial investment cost in putting up a plant is PhP 7.3 M excluding land acquisition. Initial investment includes machineries (e.g. shredding machine, mixer, hydraulic press, etc.), building, labor, materials, and pre-operating expenses. The plant is targeted to produce 66,500 panels per year operating at 22 days a month. The plant will employ 6 skilled workers, 10 laborers and one plant supervisor.

It is assumed in the financial evaluation that a market exists and that the outright sale of boards can be made. The average cost of producing a panel is PhP 109.45 and the selling price is about PhP 164.18 obtained by adding a 50% mark-up to the production cost per panel. The income statement indicates that the project will yield an average return on investment (ROI) of 36% Sales revenue is PhP 10.92M per year and the average net income after tax is PhP 2.6M. The cash flow from operations shows the result of the discounted cash flow

analysis, which measures the benefit-cost ratio (BCR) and net present value (NPV) of the project. The flow of benefits in accord with the net cash flow was positive indicating a viable undertaking in producing oriented bamboo strand cement composite. The operation is acceptable as shown by the NPV of PhP 9.11 M.

Conclusion

The flexural strength of boards particularly MOE was significantly increased as a result of orienting the bamboo strands within boards. MOE of boards containing strands oriented parallel to the span was 2306 MPa while the MOE of boards containing randomly oriented strands was 1272 MPa. Boards containing bamboo strands oriented parallel to the span and tested wet were comparable to those of boards from yemane containing randomly oriented strands. The MOE of boards from bamboo was significantly higher than the MOE of boards from yemane. However, all boards manufactured using aligned (in the preferred direction) and randomly oriented strands met the minimum strength specifications of the Philippine National Standards for WWCB. TS and WA was unaffected by species and strand orientation.

In addition to enhancing the strength of boards, strand alignment provides a means of better utilizing raw materials for the manufacture of cement-bonded stand boards. For example, if strands are aligned in the prefereed direction, lower amounts of bamboo strands and cement will be required to make boards of a certain strength. This reduces the pressure on the resource base and provides raw materials savings. Moreover, manual strand alignment required no additional equipment or significant modification of the process currently used to manufacture boards in the Philippines. More importantly, the socio-economic conditions in certain countries, for example in the Philippines, permit the employment of hand-forming of cement-coated strands in a production situation.

Results of the study indicate that it is technically and economically feasible to manufacture oriented bamboo strand cement composite using manual strand orientation technique. It therefore appears possible to adopt manual manipulation of board structure to improve properties in commercial WWCB plants.

Acknowledgement

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Development of Oriented Strand Lumber made from *Dendrocalamus asper* Backer

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Abstract

The study was conducted to evaluate the suitability of using Sweet bamboo (*Dendrocalamus asper* Backer) for Oriented Strand Lumber (OSL) manufacturing. The boards were manufactured from bamboo-strands using four resin types (MUPF, MF, PF and pMDI) and three levels of resin content (7, 10 and 13%). The physical and mechanical properties of lab manufactured OSL were evaluated by ASTM 1037, ASTM 5456 and EN 300. It was found that OSL made from bamboo strands exhibit acceptable strength properties compared to the commercial products (i.e., Oriented Strand Board) and the engineered products (i.e., zephyr and Parallel Strand Lumber) made from bamboo and wood. The resin type and content have a significant effect on its properties. Regarding the internal bond, bamboo-based OSL shows less strength than others. Further improvements in the internal bond and thickness swelling may lead to OSL industrial for structural use. The best results were obtained by using 13% pMDI content at 750 kg/m³ density.

Introduction

Wood has distinct advantages over other construction materials because it is a renewable raw materials and also friendly to the environment. Moreover, wood has unique characteristics of being superior in strength-to-weight ratio, shock absorbance, vibration, and aesthetically appealing as well as warm touchable. Then, it has been used by humans for the varied requirement, especially for constructions. The availability of timber for the production of large size solid-sawn lumber has declined, while the demand for high quality wood has increased because of the increasing of the world population and restrictive harvesting regulation from natural forest. Thus, this has led to continuous efforts to find new resources as an alternative to wood. Bamboo can be a potentially usable alternative raw material.

Bamboo is one of the promising raw materials that can be used for wood composite manufacturing, because it is a fast-growing, short-rotation life and has similar ligno-cellulosic structure. It has better mechanical properties compared to some wood species. Bamboo has been used since thousands of years for building, especially in the Asia and Pacific region. Thailand is one of the richest areas of bamboo in Asia. There are 13 genera and 60 species. *Dendrocalamus asper* is one of the most popular bamboo species of Thailand planted in more than 60 provinces (Pungbun 2000). The utilization of *Dendrocalamus asper* can be divided into two fields, i.e. young

bamboo shoots and bamboo culms. The young shoots are widely consumed as a vegetable. The culms are strong and durable and used as building material and for houses and bridges, also in furniture, musical instruments, chopsticks, household utensils and handicrafts (Dransfield and Widijaja 1995; Rao et al 1998). In many countries, the interest for bamboo utilization has increased after several studies have evaluated bamboo's properties and its potential as an alternative resource for wood composites industry, and regarded the effective use of bamboo for engineered products such as plywood (Chen 1985), oriented strand board (OSB) (Lee et al 1996 and 1997; Sumardi et al 2007 and 2008), waferboard (Zhang 2001), zephyr board (Nugroho and Ando 2000) and laminated bamboo lumber (Nugroho and Ando 2001). They confirmed that bamboo is able to provide high quality engineered wood products. At the same time, several researches in Thailand were carried out to use this species as raw material for fiberboard, pulp and paper (Kamthai 2003; Laemsak and Kungsuwan 2000). However, none of these studies researched bamboo as raw material for the Oriented Strand Lumber (OSL).

The primary objective of this study was to determine the physical and mechanical properties of OSL made from *Dendrocalamus asper* with the respect to the two processing parameters (resin type and resin content), and to compared its properties to standard requirements and previous researches.

Materials and methods

Materials

Three-year-old bamboo culms, with an average culm length of 19 m, and a culm-wall thickness in the range of 6-27 mm, were collected from bamboo plantations located in Nakorn Sri Thammarat, South of Thailand. They were used as raw material for the prototype bamboo-based OSL. Four exterior used resins were used in this research: Melamine Urea Phenol Formaldehyde (MUPF), Melamine Formaldehyde (MF), Phenol Formaldehyde (PF) and Isocyanate (pMDI). The MF resin (Prefere13H560, Liquid) was supplied by Dynea. The MUPF resin (KML 534, Liquid) was obtained from BASF. The PF resin (Bakelite 1279 HW, Liquid) was supplied by Hexion. The pMDI resin (Suprasec® 5025, Liquid) was provided by Huntsman. Their properties are presented in Table 1.

Table 1 Resin properties and manufacturing parameters of bamboo-based OSL

Resin types	Resin properties			Manufacturing parameters			
	Solid content (%)	pH at 20°C	Viscosity (mPa∗s)	Hardener	Mat moisture content (%)	Pressing temperature (^{0}C)	Pressing time (s/mm)
MUPF	64±1	9.3-9.8	150-400	NH_4NO_3	9	210	16
MF	62.5	9.73	100-150	NH_4NO_3	9	190	12
PF	48	8.5-10.5	650-700	K_2CO_3	14	190	12
pMDI	-	-	180-240	-	6	220	10

Preparation of strands

Bamboo strands were prepared from green-state culms, with the moisture content in the range of 80-100%, having a culm-wall thickness more than 12.5 mm. The culms were crosscut to 140 mm long pieces and spited into half. Stranding was carried out on a CAE 6/36 Laboratory Disc Flaker. The average dimensions of bamboo strands were 140 mm long, 0.7 mm thick, and 12.5-20 mm wide. Strands were then graded by a Gilson Screen (Model TM-4) through meshes of 12.5 mm. Strands that passed through the 12.5 mm screen-mash and remained in the pan were considered as fine fractions. After these processes, all strands were dried with a laboratory-made rotary dryer to 2% final moisture content.

Lab manufacture of bamboo-based OSL

Uni-directional oriented strand boards with the dimension of 800 mm x 300 mm x 16 mm and 750 kg/m³ in target density were manufactured using laboratory equipment using four resin types and three levels of resin content. All commercial liquid resins were applied to strands using an inhouse-made paddle-type blender. No waxes or other additives were used. Hand-formed mats were transferred to a single-opening hydraulic lab hot press (Siempelkamp press) and pressed into boards. In this study, 36 boards were produced by using a pressing temperature and time following the suggestion of glue supplier, as presented in Table 1.

Properties evaluation of bamboo-based OSL

The lab boards were trimmed and cut into specimens for physical and mechanical properties testing. All specimens were conditioned for several weeks at 65% relative air humidity (RH) and 20°C until constant weight was attained. The property tests for Specific gravity (SG), Thickness swelling (TS), Water absorption (WA), Modulus of rupture (MOR), Modulus of elasticity (MOE) and Internal bond (IB) were conducted in accordance with the ASTM D 5456, ASTM D 1037 and EN 300. All data from the tests were statistically analyzed. A factorial analysis of variance was conducted to test level of significance in difference between factors and the test values.

Results and discussion

The results of the of resin type and resin content influence on bamboo-based OSL are graphically presented in this part. Table 2 shows the results of multifactor analysis variance for bamboo-based OSL properties based on two chosen parameters.

Table 2 Multifactor analyses of variance of resin type and resin content influence on the physical and mechanical properties of bamboo-based OSL

OSL properties	Source of variation	F-value	Significance level
	Resin type	84.75	**
Thickness swelling	Resin content	30.80	**
	Interaction	6.10	**
	Resin type	55.03	**
Water absorption	Resin content	13.17	**
	Interaction	4.30	**
	Resin type	6.52	**
Modulus of rupture	Resin content	41.49	**
	Interaction	0.86	NS
	Resin type	68.69	**
Modulus of elasticity	Resin content	50.57	**
	Interaction	3.17	*
	Resin type	87.70	**
Internal bond	Resin content	65.37	**
	Interaction	2.10	NS

Note:** indicates significance at the 1% level of probability.

* indicates significance at the 5% level of probability.

NS indicates not significant.

Specific gravity

The target specific gravity of the bamboo-based OSL is 0.75, while an average specific gravity is 0.72 at an average moisture content level of 6.64%. This result suggests that the average board specific gravity is lower than the target one (board specific gravity). It may provide an explanation as a spring-back phenomenon of the board after pressing, since the internal board strength cannot resist the internal stress due to excess steam pressure which could not escape from the mat during hot pressing. In this case, the board thickness after pressing increases around 11.92% and 6.50% for bamboo-based OSL bonded with 7% MUPF and 10% MUPF, respectively.

Thickness swelling

The result suggests that the thickness swelling (TS) value ranges from 2.3-26.4 % which is shown in Figure 1. It can be seen that pMDI-bonded board shows less thickness change than those of other boards. Moreover, board made with higher resin content results in improved dimensional stability similar to the findings of previous works (Lee et al 1996; Nugroho and Ando 2000). These results are further confirmed with the statistical analysis, as presented in Table 2. The result shows that the different resin type and resin content have a significant effect on TS value. Notable, the MUPF-bonded OSL shows a significant higher TS value than those of others. It can be explained as a result of the higher hydrolysis sensitivity of the MUPF resin. The lack of

resistance to high moisture content is attributed to the presence of hydrolysable group between carbon of the methylene linkage and nitrogen of urea (Pizzi 1994).

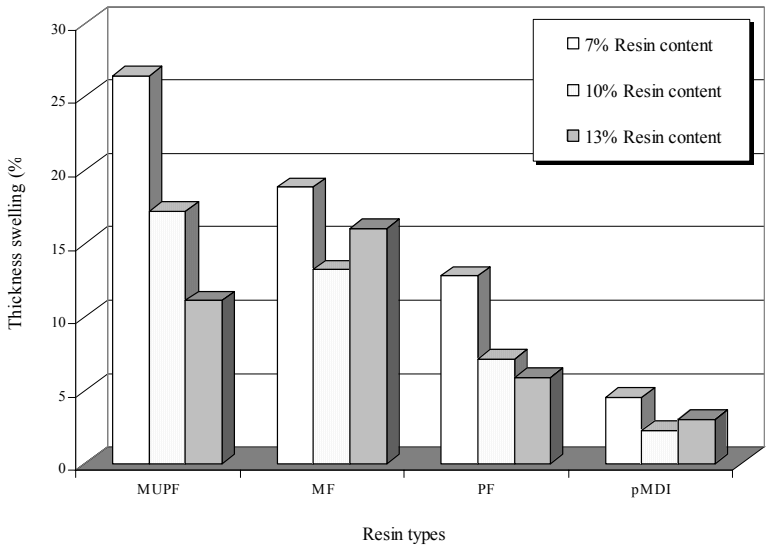

Figure 1 Effect of resin type and content on thickness swelling after 24h water soaking (20°C) of bamboo-based OSL

In accordance with the requirement of OSB/3 type by EN 300 standard, the allowed maximum TS value (24 hours water soaking) is 15%. The MUPF-bonded OSL does not achieve this requirement. It can be explained by no wax or other treatments were done. Accordingly, it requires the wax adding or additional strands pretreatments to improve the dimensional stability of bamboo-based OSL.

Water absorption

The WA of bamboo-based OSL is shown in Figure 2. The value ranges from 16.9 to 40.5%. Analysis variance based on resin type and content is presented in the Table 2. From these data, it may be concluded that the resin type and resin content have a significant effect on this property. The results suggest that OSL made with 13% pMDI resin shows the significant lowest WA, as presented in Fig. 3. A distinctly increase in hydrophobic characteristic observed for pMDI-bonded OSL can be explained by the highly strong bonds between NCO groups of resin and -OH groups of the bamboo cellulose. Furthermore, the obtained values show a slight decreasing trend along with the increase in their resin content in boards.

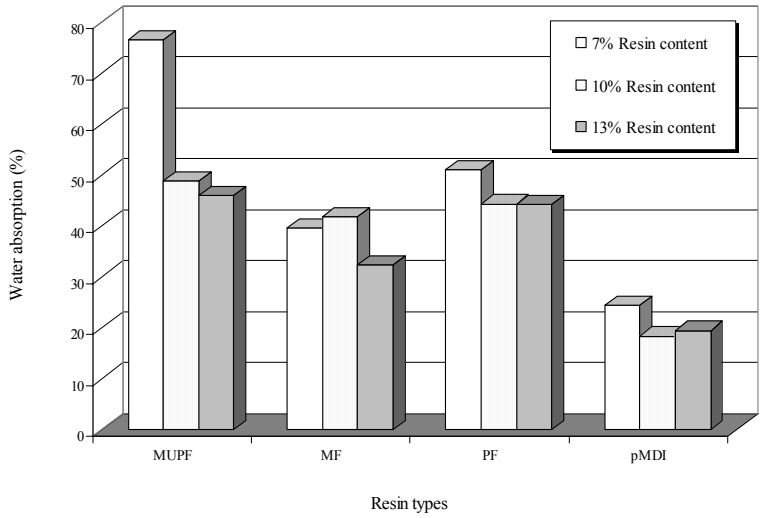

Figure 2 Effect of resin type and content on water absorption after 24h soaking of bamboo-based OSL

This result is consistent with the TS, 7% MUPF-bonded OSL shows a higher WA value than the others. This might be due to its lower specific gravity. Then, more water can be absorbed. Moreover, MUPF resin is low hydrolysis resistance. In distinct contrast to the TS, the WA for PF-bonded OSL is higher than that of MF-bonded OSL. This phenomenon can be suggested by the hydroscopic behavior of the alkali in the PF resin. Thus, a greater amount of water is absorbed without affecting the TS (Pizzi 1994).

Compared to previous reports, the bamboo-based OSL made from pMDI resin show a quit similar WA value to that of bamboo-zephyr (Nugroho and Ando, 2000), while bamboo-based OSL bonded with MUPF and PF resins show smaller values than those of other bamboo-strand based boards (Lee et al. 1996) and Scots pine-based OSB (Paul et al. 2006). The reason of this circumstance has not been addressed.

Static bending

The static bending strengths of bamboo-based OSL are illustrated Figure 3 and 4. The MOR and MOE values are in the range of 29.1 to 65.2 MPa and 3,280 to 11,109 MPa, respectively. The analysis of variance testing conducted on the effect of the two factors and their interaction (Table 2), confirms here that the resin type and resin content significantly influence on both of MOR and MOE.

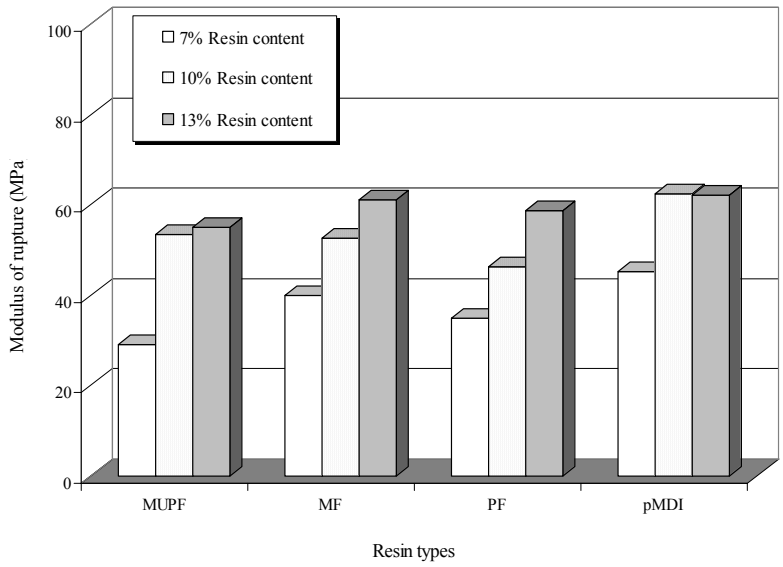

Figure 3 Effect of resin type and content on modulus of rupture of bamboo-based OSL

From Figure 3, it can be seen that the MOR value of pMDI-bonded OSL is highest, while those of MF and PF-bonded OSL are quit similar, and that of MUPF-bonded OSL is lowest. One explanation may lie in the high bonding strength of the cross linked polyurea network of pMDI resin, as mentioned earlier. As well, the resin content contributes to improve board strength and stiffness. In basic knowledge, it can be described the relationship between resin content and product strength that with the increasing of resin content, the product strength will improve by the increase of the intimate contact area between adjacent bamboo strands in the board. These results are also in agreement with the result of Barnes (2000) and Post (1958) who show that with higher resin content of composite board, the physical and mechanical properties of board increase.

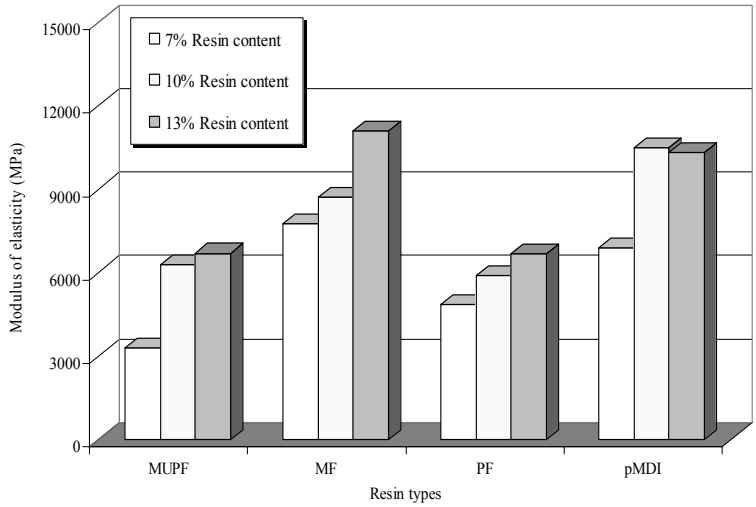

Figure 4 Effect of resin type and content on modulus of elasticity of bamboo-based OSL

From Figure 4, the result suggests that MOE of bamboo-based OSL are mainly influenced by the resin type. The strengths increase in the order MUPF, PF, pMDI and MF bonded OSL. Moreover, they also increase with the resin level. The maximum value is 11,109 MPa for MF at 13% resin content, while the minimum value is 3,290 MPa for MUPF at 7% resin content at the target density of 750 kg/m³. It is impossible to distinguish the difference between MF- and pMDI-bonded OSL and they are approximately 35% higher value than MUPF and PF bonded board at the same level of resin content.

The comparison of MOR and MOE values between bamboo-based OSL and several engineered wood products in the previous researches (Liu and Lee 2003; Malanit et al. 2005; Nugroho and Ando 2000). The average MOR of bamboo-based OSL is quit similar to bamboo-zephyr, but slightly lower than those of wood-based boards. The MOE of bamboo-based OSL is also quit similar to bamboo-zephyr, but approximately 50 to 75% lower than wood-based boards, while the average specific gravity of all products are quit similar. Although bamboo-based OSL was found to be less rigid, but it exhibits acceptable strength property, as indicated by its high MOR value.

Internal bond

The internal bond strength (IB) of bamboo-based OSL made with different resin types and content is shown in Figure 5. The minimum value is 0.06 MPa for the board made with 7% MUPF resin content which shows lower density than those of other and occurs the blisters inside the board., while the maximum value is 0.67 MPa for the board made with 13% pMDI resin content. The analysis of variance result (Table 2) conducted on the effect of two factors and their interaction shows that the resin type and resin content significantly influences the internal bond. The IB of the MF-bonded OSL is quite similar to PF-bonded OSL. Their values are

approximately 35% lower than pMDI-bonded OSL because of the high strength of covalent bonds between strands, as mentioned above.

Compare to other engineered composite products (Liu and Lee 2003; Nugroho and Ando 2000; Malanit et al. 2005), PF-bonded bamboo-based OSL shows approximate 3 to 9 time smaller IB value than Rubberwood-OSL. The average IB value of bamboo-based OSL made from pMDI resin is approximate 2 times smaller than those of bamboo-zephyr and Rubberwood-OSL. A possible explanation might rest for this situation. The bamboo specific gravity varies within the horizontal and vertical of culm (Liese 1985). This variation could influence the glue penetration and bonding.

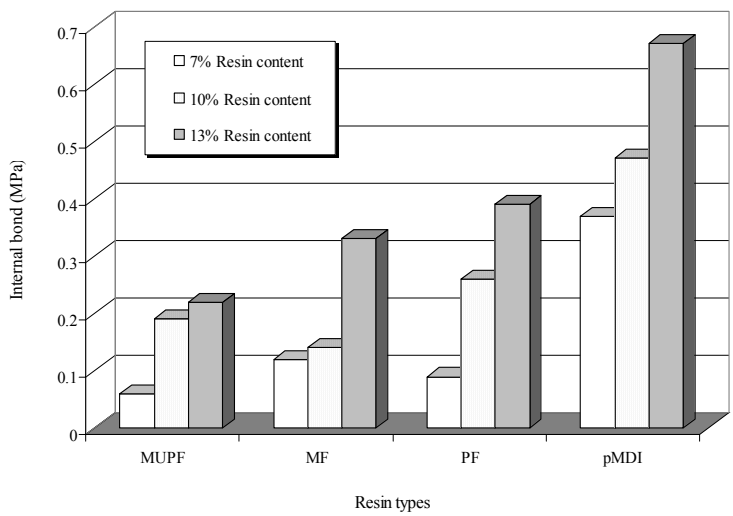

Figure 5 Effect of resin type and content on internal bond of bamboo-based OSL

The minimum IB required by the EN 300 standard for OSB/3 is 0.35 MPa. The result demonstrates that, only the IB value obtained from pMDI-bonded OSL is higher than that of the standard requirement (EN300). It seems likely that the OSL made from *Dendrocalamus asper* shows low internal bond strength. Further experiments to improve of board with special consideration in strands preparation are necessary.

Conclusions

From the results of this study on the physical and mechanical properties of OSL made from *Dendrocalamus asper* conclusions are drawn as follows:

1. Resin type and content are dominant parameters controlling physical and mechanical properties of OSL. The pMDI-bonded OSL show better physical and mechanical properties than MF, MUPF and PF-bonded one. All properties are improving with the increase of resin content.
2. The best parameters of this study are achieved for 13% pMDI resin content.
3. Compare to the commercial products and other engineered wood products, bamboo-base OSL exhibit acceptable strength properties. Then, bamboo-based OSL can be used for structural purposes.
4. *Dendrocalamus asper* can be promoted as an alternative raw material for OSL manufactures, but the special improvements like strand pretreatment and equipment adaptation/pressing optimization are necessary.

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Study on Manufacture and Properties of Bamboo-Chip Binderless Board

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Abstract:

The development of bamboo utilization as renewable alternative raw material as well as bamboo-chip binderless board manufacturing was explored. In this study, the manufacture of bamboo-chip binderless board was described and the investigation of board performances was presented. Board performances were assessed for different pressing temperatures, 160°C, 180°C and 200°C, with fine (designated by F, 0.5mm) and coarse (C, 2.0mm) chips mixed in ratios of 0:100, 50:50 or 100:0. The increase in pressing temperature led to the increased internal bonding (IB) and IB retention in boards after wet conditions. Increase in F and C mixing ratios also increased IB but hardly affected on IB retention. Bending properties including modulus of rupture (MOR) and elasticity (MOE), thickness swelling (TS), and water absorption (WA) of boards were increased as a result of the increasing bond strength. Even though these boards met the requirements for mechanical properties of type 8 JIS A 5908-1994 (Particleboards) the TS and WA were observed rather high.

Keywords: bamboo, bamboo-chip binderless board, pressing temperature

Introduction

The increasing trend of enormous wood-based composites consumption leads to a worldwide interest, especially in many developing countries where the progress towards the infrastructure build-up and massive building construction has been accelerated significantly. Wood-based composites such as wood-based panels are being continuously enhanced to satisfy the high demands imposed by the mobilized construction. However, this enhancement in both quantity and quality has been marked by the production technology as well as many new trends concerning with the environmental aspects, i.e., the attention to renewable alternative raw materials sources for manufacturing, the increasing environmental requirements and the utilization of technology with reduced wastes. Bamboo, a fast growing plant, has attracted a growing attention as the interesting resources for wood substitution in the wood industry. Bamboo is considered as an abundant resource and could be used as substitute raw materials in the wood industry, especially in Asian countries which have limitation in wood supply but enormous agricultural wastes. In Thailand, bamboo is an important economic crop as bamboo shoot utilized for food commodities is increasing the export share in the world market. Consequently, bamboo

plantations are expanding rapidly in order to serve the high demands of bamboo shoots[1]. These plantations produce culm as waste from pruning and thinning operations. The bamboo which is considered as waste from plantation might be a potential raw material in the wood industry.

Currently, bamboo was used to produce panel composites at an industrial scale, i.e., bamboo composites boards and laminates[1]. The technology such as bamboo mat laminates is still being developed and scaled-up, and some studies concerned with bamboo products are still under progress[2].

These studies have been stressed mainly to investigate the feasibility of producing bamboo boards with adhesives such as bamboo strand boards bonded with phenol formaldehyde[3] and bamboo particleboard bonded with urea formaldehyde[4]. The study[5] also confirmed that bamboo could be used as a substitute raw material in place of wood species due to its compatibility with commonly available adhesives.

Despite intensive attention repeatedly emphasized on producing adhesive-bonded boards, the high cost of synthetic adhesive, health and environment concerns and formaldehyde emission are regarded as the major issues for developing the wood industry technology. Bamboo-chip binderless board could be one way to develop bamboo utilization as well as wood technology which will allow the production without the dependence on synthetic adhesives and will also be the alternative technology for wood industry. This manufacturing has several potential advantages, i.e., reduction in adhesive costs and also a suitable technology for any country that has petroleum resource limitations. Several researchers have been dealt with binderless boards as well. Study[6] suggested that lignin-fufural linkages of steam exploded-fiber, generating during hot pressing, was the main bonding strength of board. One study[7] confirmed that binderless panels made from softwood pretreated by steam explosion had better mechanical properties than panels made from non-pretreated materials. Moreover, steam-injection press was used for developing kenaf core binderless board[8]. In another recent study[9], kenaf binderless board was produced from kenaf core flour. To date, even though there have been many studies about binderless board, the processing conditions reported in these different raw materials may not be suitable for bamboo. In order to use bamboo effectively to produce bamboo-chip binderless board further research is needed. This study was aimed to explore the possibility of producing bamboo-chip binderless board. Ground chip were selected to produce bamboo-chip binderless board as they were small chip that might provide large surface area. Consequently, the chemical components of chip with large exposed-surface area may be activated easily during hot pressing without pretreatment.

The objective was to investigate the possibility of manufacturing bamboo-chip binderless board concerned with the effects of manufacturing conditions including pressing temperature during hot pressing and the mixing ratio in different size of chip on the basic performance of binderless board.

Materials and Methods

Materials

Four years old bamboo culm, Madake (*Phyllostachys reticulate*) collected from Chiba prefecture, Japan, with specific gravity 0.7, was used as the raw material. The bamboo culms were cut to 50 mm in length, and then

sliced by cutter into coarse particle of approximately 5 mm thickness. These coarse particles were ground to pass through the sieve in a willey mill to obtain fine chip with grain size 0.5 mm (F) and coarse chip with grain size 2.0 mm (C). The mixing ratios of F and C (F/C) at 100:0, 50:50, and 0: 100 were prepared for producing boards. The moisture content of these particles was around 10-12%.

Board Manufacturing and Testing

The F/C mixtures were manually formed into homogeneous single-layered mats of 300 mm × 300 mm × 6 mm (using a forming box and covering the top and bottom surface of the mats with aluminum foil) with a target board density of 0.8 g cm^{-3}. Afterward the mats were pre-pressed by hand and were then pressed for 10min at the pressing pressure of 4.7 MPa by a hot press with various pressing temperatures (PT) of 160, 180, 200 and 220°C. Four replications of boards were made for each manufacturing condition.

Before testing the properties, the boards were conditioned at room temperature for about 2 weeks during which time they reached a moisture content of 7-8%. After that, the boards were cut into various test specimens and were tested for mechanical (internal bonding, IB and bending strength including modulus of rupture, MOR and modulus of elasticity, MOE) and physical (thickness swelling, TS and water absorption, WA) properties. In each condition, five specimens with the size of 50 mm × 200 mm were tested for MOR and MOE. Eight specimens with the size of 50 mm × 50 mm were tested IB. Twelve specimens with the size of 50 mm × 50 mm were tested for TS and WA. The procedure of testing was done according to JIS A 5908-1994 (Particleboards)[10]. In each condition, bending strength and IB values were measured additionally from five and eight specimens, respectively, after the wet conditions. The wet conditions were performed firstly by soaking the specimens in water at 70°C for 2 h and then water at 20°C for 1 h.

Results and Discussion

Board Appearance

Most of the binderless boards made from given manufacturing conditions were successfully manufactured except board pressed with pressing temperature of 220 ^{o}C. The specimens of boards pressed with 220 ^{o}C could not be obtained as the board exploded during pressing. Boards pressed with higher platen temperature were more darkly colored. These indicated a greater degree of hydrolysis of the chemical components during hot pressing process. All boards had odor, smooth and glossy surface, and tight edges.

Internal Bonding

Fig 1 shows the effect of PT on IB and IB retention with the different F/C mixing ratios. On the whole, IB values had a trend to increase with the increasing PT. This increasing trend is similar to those reported in studies[7,9]. These IBs were improved because the increasing PT might be contributed well to activate the chemical components in board constitute and then would be brought about the increasing IB. In this study, the result suggested that at PT of 200°C, IB was higher than using PTs of 160 and 180°C. This indicated that the favorable PT for developing the highest IB in this study was at 200°C. This PT of 200°C corresponded to the

glass transition (Tg) values, in dry state, of cellulose (around 220°C), hemicellulose (around 170°C) and native lignin (around 200°C)[11]. Therefore, PT of 200°C may be the temperature that could make bamboo soften and develop bond area which provided the highest IB. This phenomenon could possibly be interpreted from the explanations given in the previous study[11]. They suggested that at temperature above the Tg of wood polymers, viscosity of wood would drop and present the flow characteristic, then the diffusion would take place and promote the bonding area, especially under the pressure applied. Furthermore, the increase in PT also had trend to increase the percentages of IB retention and at PT of 200°C it also showed the higher retention than other PT conditions as well. From this result, the increasing PT could improve some extent of the water resistant properties of board which were indicated by the increase in IB retention. The residual bonding strength in boards after wet condition could be assumed as the bond type that could resist the water. As in the report[11] the bond that would resist the water was thought to be the covalent bond forming between the wood polymer chains to some extent during hot pressing, and they suggested that lignin appeared to be the most reactive in this type of autocrosslinking. Therefore, this reaction of lignin might improve the water resistant property of boards. Nevertheless, the highest IB retention obtained in this study remained somewhat low, only about 30%. A similar result was also observed in binderless board made from kenaf in one study[9].

Fig 1 also shows IB values in different F/C mixing ratios. Board made from F/C mixing ratio = 100:0 provided the highest IBs. These highest IBs were observed due to the greater amount of fine chip in mixing ratio of boards. The fine chip might provide more bonding contact between chips due to its greater surface area compared to that of coarse chip. Therefore, the fine chip could improve IBs and could also lead to the higher IB retentions. In addition, at the same PT, IB retentions were nearly similar in all mixing ratios. This indicated that F/C mixing ratio hardly affected the development of water resistant properties in boards. This suggested that using chip with more surface area could develop IB values but hardly induce the bond that could resist the water. The reason may be attributed to the property of bond, which is sensitive to the water. The exact property of this bond occurring when particles were activated under heat is not known clearly. However, these potential interparticle-bonding might predominately be the secondary bond which is sensitive to water as suggested by one study[11]

Thickness Swelling and Water Absorption

Fig 2 shows the effect of PT on TS and WA in different F/C mixing ratios. At higher PT, less TS values were noted as a result of an increase in IB retention. Furthermore, TS values were improved due to two possible reasons. First, increasing PT might make bamboo more soften and boards could produce less stress, and thus less stress relaxation might be occurred. Another, as in one study[12], increasing PT could degraded hygroscopic hemicellulose in greater extent which decreased the hygroscopic components in boards. The WA values had also the similar trend as TS values which were related to an increase in IB values of the boards. Again, when bamboo becomes more soften and diffusive flow characteristics occurs due to the increasing PT, the contact area would be developed. This made the boards to possess few porosity inside, and this could explain the reason of less water absorbed in boards due to the increasing PT.

It could be observed that, at higher PT, the effect of F/C mixing ratio on TS values was not distinctly observed. This might be because the F/C mixing ratios had a slight effect on the improvement of the water resistant

property of boards. For WA values in each F/C mixing ratio, there seemed to be a slight difference. Boards made from greater coarse chip in F/C ratio showed little greater WA values since the coarse chip provided lower IB in boards and hence there would be more porosity inside the boards.

Bending Strength

Figs 3-4 show the effect of PT on bending strength (MOR and MOE) and on their retention after wet conditions, respectively. The bending strength had the same trend as IB. The PT of 200°C provided higher MOR and MOE than other PT conditions. MOR and MOE retentions also tended to increase with the increasing PT. However, boards were rather low in bending properties when compared to the requirements of the JIS A 5908-1994 (Particleboards) standard[10]. This was probably caused by the small grain-shape of chip that did not contribute to bending strength. If the chip does not create the bond sufficiently well, boards made from these chip type might not then develop sufficient bending strength.

The F/C mixing ratios also had effect on bending strength. Boards made from the higher coarse chip in F/C ratio showed higher MOR values and MOE values because the coarse chip could provide the larger length of contact among the chips. Thereby coarse chips could favorably withstand the shear stress and create the continuous contacts among the chips. A little difference of retention among various F/C mixing ratios was observed and this might be caused by almost same IB retention in all cases of F/C mixing ratios. From these results, coarse chip could support the strength. Further research should be done for developing the particle types, which is contributed to bending strength as well as this particle could also develop the sufficient bond strength.

Conclusions

The following conclusions could be drawn from the study:

1. There is the possibility to develop the bamboo utilization for manufacturing bamboo-chip binderless board. Under the given conditions, pressing temperature of 200°C and fine and coarse chips mixing ratio of 0:100 provide board properties, which achieve the required mechanical properties of type 8 JIS A 5908-1994 (Particleboards). However, the low strength retention in wet conditions as well as the high values of TS and WA may indicate the low water resistant properties, suggesting that bamboo-chip binderless boards are suitable for nonstructural application with service in indoor not exposed to wet condition. The results suggest that the further development related to the water resistant properties needs to be considered.

2. The increasing in pressing temperature would develop the bonding strength of boards. Improved bonding strength retention also implicates that pressing temperature may be an important parameter to induce the bond that resists water.

3. Using the greater extent of coarse chip could improve the bending properties although bonding strength appears lower than using fine chip. This suggests that further research for development of shape and/or type of particle in inducing bending properties should be considered.

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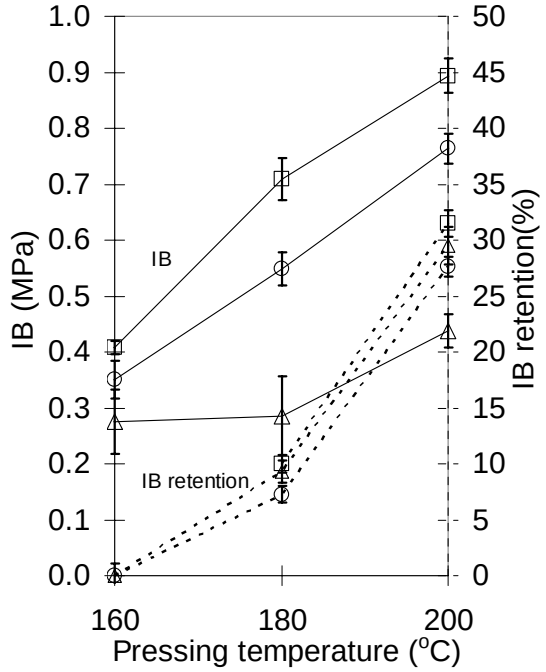

Fig 1. Effect of pressing temperature (PT) on the internal bonding (IB, symbols with full line) and IB retention (symbols with dash line) of boards with different fine (size 0.5 mm) and coarse (size 2.0 mm) chips mixing ratios.

□ 100:0, O 50:50, Δ 0:100, vertical lines with the bars represent the standard deviation from the mean

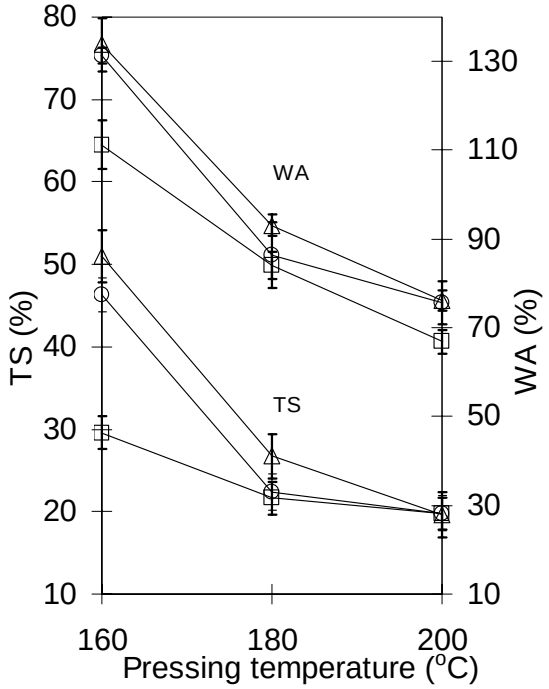

Fig 2. Effect of PT on the thickness swelling (TS) and water absorption (WA) of bamboo binderless board with different fine (size 0.5 mm) and coarse (size 2.0 mm) chips mixing ratios.

□ 100:0, O 50:50, Δ 0:100, vertical lines with the bars represent the standard deviation from the mean

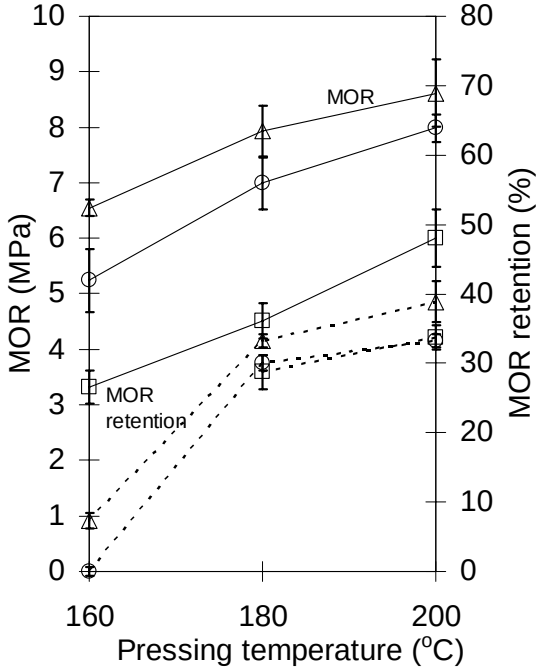

Fig 3. Effect of PT on the modulus of rupture (MOR, symbols with full line) and MOR retention (symbols with dash line) of boards with different fine (size 0.5 mm) and coarse (size 2.0 mm) chips mixing ratios.

□ 100:0, O 50:50, Δ 0:100, vertical lines with the bars represent the standard deviation from the mean

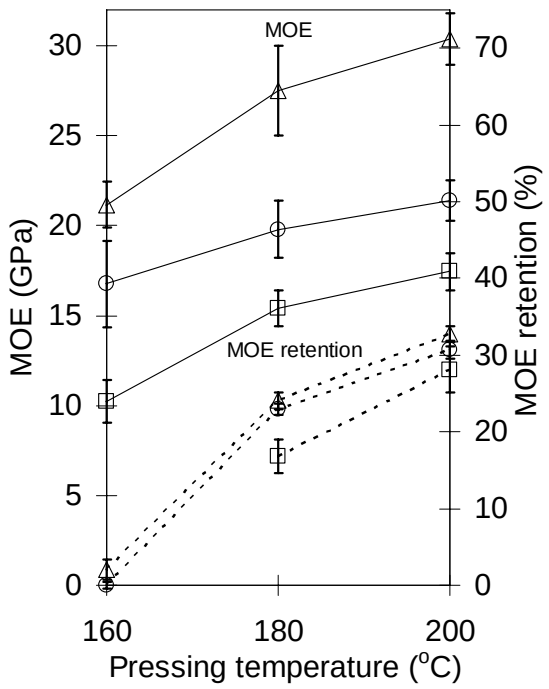

Fig 4. Effect of PT on the modulus of elasticity (MOE, symbols with full line) and MOE retention (symbols with dash line) of boards with different fine (size 0.5 mm) and coarse (size 2.0 mm) chips mixing ratios.

□ 100:0, O 50:50, Δ 0:100, vertical lines with the bars represent the standard deviation from the mean

Bambu Project:
Mechanical Characteristics of the Glued Laminated Bamboo

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Abstract

With the growing of forest deforestation it is becoming necessary to search alternative materials and solutions that can help reduce this process. The bamboo culture is millenary in many regions of the planet but it has its utilization and research restrict mainly to oriental countries. The bamboo is a tropical culture renew resource, with fast growing, annual production and hundreds of species and thousands of applications sprayed around the world. The bamboo is considered a great carbon sequester and with physical and mechanical characteristics that makes possible to use it as products usually made with wood, as to: civil construction components, furniture, tools, panels, etc. This work intended to determine some mechanical characteristics of resistance and elasticity of the glued laminated bamboo using mature culms from clumps locally cultivated in the Universidade Estadual Paulista-UNESP, campus of Bauru, São Paulo state. The specie used was the giant bamboo (*Dendrocalamus giganteus*) that has good characteristics and dimensions to strips confection. The culms were processed to obtain the laminated bamboo strip nearest possible to the skin part. These strips were glued to specimens confection and study. The specimens were made according to Brazilian wood standard -NBR 7190/1997. The results showed that the glued laminated bamboo has good resistance and elasticity characteristics that make possible the use of this material for many purposes, like some objects and furniture confection. Thus, some glued laminated bamboo products were made to show some possibilities of the material.

Keywords: bamboo strips, glued laminated bamboo, mechanical characteristics, products.

Introduction

Historically, the bamboo has accompanied the human being providing food, shelter, tools, utensils and an infinity of other items. Nowadays, it contributes to the livelihoods of more than one billion people. Equally important alongside the traditional practices, it has been the development of industrial uses of bamboo (Sastry, 1999).

With the increasing deforestation and pressure on tropical forests, as well as on the areas of reforestation, makes it increasingly necessary to search for renewable materials and alternative solutions capable of partially alleviate

this process. Today, few people doubt that the ecological problems will be a necessary condition for industrial processes, human settlements and development, and the 21st century can be considered as the century of the environment. Thus, the search for non conventional materials and renewable energy sources has been converted into a global priority at the beginning of this century (Saleme & Viruel, 1995).

In accordance with Zhou (2000), in the past 50 years the devastation of the forests got to 24.9 million ha/year, or the equivalent to 47.41 ha/minute, a condition which must also contribute to the increase in the area for cultivating bamboo in world that today is about 22 million hectares. Newspaper Folha de São Paulo (09 /08/2000) mentions the FAO data where for the period between 1990 and 1997 a speed of deforestation equivalent to 12.17 ha/minute is presented. Another newspaper reportage (Newspaper Folha de São Paulo, 09-09-2002), showed data supplied by the Secretary of State for Agriculture and the Brazilian Society of Forestry, where a fall of 5% in the reforested area of the Sao Paulo state was reported and indicates the necessity of the duplication of the annual wood reforestation planting in the country.

Pauli (1996 ; 2001), highlights the bamboo as an efficient carbon fixer, converting the carbon-via photosynthetic in cellulose, hemi-cellulose and lignin, with rapid growth and harvests, long fibers and strong and high mechanical strength using minimum energy, and also, an entire industrial conglomerate around the bamboo can really be developed.

Bamboo is the natural resource that needs less time to be renewed, as there are no forest species that can compete in growth rate and utilization per area (Jaramillo, 1992). The decreasing of the quantity and quality of forest resources has increased the interest to low cost and renewed materials like bamboo, with applications involving composite bamboo panels and wood/bamboo panels, as well as glued laminated bamboo, bamboo mats; bamboo plates made by mold pressure, compounds of bamboo-epoxy and bamboo-polymer, bamboo particles and others. However, to maximize the use of bamboo, it is necessary that their physical and mechanical properties be better understood (Lee et al, 1994).

Products made with glued laminated bamboo such as floors, boards, panels, handle tools, plywood, furniture, construction components, among others, can be explored by the culms processing. Although we do not think bamboo as an exclusive solution to problems related to the environment and/or the sharp decrease of our forest resources, it may be considered and studied as an alternate and low cost material to be explored. The culms production is very fast, without the need of replant, its culture and exploitation in the field may be quickly implemented (Pereira, 2001)

Even though the bamboo has been used and studied for centuries in oriental countries, China Bamboo Research Center (CBRC, 2001), underlines that since the 1980s the use of bamboo has been intensified in several industrial areas, highlighting food, paper, engineering, chemicals and products based on processed bamboo (wood of bamboo) which may replace/prevent the cutting and use of tropical forests, highlighting among others, products such as coal, activated charcoal, sticks, sheets, panels, glued laminated bamboo products, mats, composite, plates of oriented fiber (OSB), components for construction/housing and furniture industry, among others. In China many bamboo products are investigated and produced (industrialized) such as: floors, ceilings, sidings, furniture, strips plates and parquet, curtains, concrete forms (ply bamboo). (Qisheng & Shenxue , 2001).

The bamboo project has been developed since the year 1994 when the first species were planted in the Unesp campus. Since the year 1998 bamboo culms have been harvested and used for research purposes (Pereira & Beraldo, 2007). Studies with bamboo as a laminated material are still incipient in Brazil, and even in terms of world its study is fairly recent. Laboratory data, concerning the determination of physical and mechanical resistance, are important for assessing the quality of the material and its technological potential, aiming later use in applications. As the data on bamboo management, development and production as well as physical and mechanical characteristics are scarce in Brazil, the determination of these characteristics for future uses and bamboo development is very important.

The mechanical characteristics determination is important not only for quality of the material but also for a future standardization of the tests.

The main objective of this work was to determine such mechanical characteristics as the compressive, tensile and bending strength together with the elasticity modulus, using for this the wood Brazilian standard – NBR 7190/97 (ABNT, 1997).

Experimental procedure

The bamboo is a different material from wood in terms of its anatomy, morphology, growth and properties of resistance, having significant variations in their properties both in the vertical-height direction (from the base of culms toward its tip), as well as toward horizontal thickness direction (through the wall of the culms). Variations that occur also in despite of species studied, the local conditions of cultivation and especially also in relation with of the age of culms. Thus, in this work, some parameters were fixed, to standardize the obtaining of the specimens in relation to the culms age, culms location along the height and its position through the wall of the culms.

2.1 Research location

The work is being developed in Bauru city (23°S, 48°W), São Paulo state, where the clumps are cultivated and managed. The laboratory studies are carried out in the Laboratory of Wood Processing, of the Mechanical Engineering Department and in the Laboratory of Construction Materials, of the Civil Engineering Department, in the São Paulo State University-Unesp/ School of Engineering

2.2 Bamboo specie

The laboratory, has a collection with approximately 23 bamboo species, being 13 of them priority (INBAR, 1985). The specie used in this work is the giant bamboo (*Dendrocalamus giganteus*), which is relatively common in the Brazilian rural environment. The clumps of this specie were cultivated in the summer of the years 1994-1995, and since the year 1998 have produced culms with adequate dimensions for processing. Figure 1 shows a clump of this specie.

Figure 1 - Clump of giant bamboo.

Age of Culm

It was fixed the culms age of 3 years old because this age is cited by many authors (Liese, 1998; Hidalgo Lopez 2003; Beraldo et al., 2004; Janssen, 2000; Zhou, 2000 and CNBRC, 2001), as that in which the culms are mature in terms of their mechanical strength characteristics. Figure 2 shows the letter system adopted to make the age of the culms known.

Figure 2 - Age identification of the culms.

Useful height of culms

Defined as one where the wall thickness is at least 10 mm. maximizing this way the use of culms in terms of its height. The thickness of 10 mm is the minimum necessary for the processing and obtaining of the final strips that are used in the specimen composition, with a final thickness between 5 and 6 mm, in accordance with the preliminary experience developed (Pereira & Beraldo, 2007). All the specimens were made using strips with the presence of nodes.

Culms processing

After the harvest in the field the culms were processed to obtain the strips, as follows (shown in the figures 3 and 4):

- Transversal cutting in a ripsaw machine getting sections with 90 cm in length.

- Longitudinal cutting in a double ripsaw for the strips obtaining

- Removal of the protuberance caused by the presence of the nodes using a ripsaw

- Air drying the strips up to the equilibrium humidity

- Processing using a four faces shaper machine for laminated strips obtaining

- Gluing of the strips for a specimens obtaining

Figure 3 - Transversal cutting and longitudinal cutting.

Figure 4 - Nodes removal and four face shaper

Dimensions of the strips

The thickness of the strips defined at the moment as being between 5 and 6 mm, so as to maximize the use in height of the culms. The width of the strips defined at the moment as being 20 mm (for this kind of bamboo and their physical characteristics of diameter and wall thickness), and this way getting the strips as close as possible to the most external region of the wall.

Strips position through the culms wall

The specimens were made using strips from positions as close as possible to the skin, seeking the richest region in fibers and theoretically more resistant along the wall, being discarded at this time the material from regions more internal of the wall, richest in parenchyma and theoretically less resistant. The most external wall of culms (peel) was also removed in order to make the gluing process easier. Figure 5 shows the position where the strips were removed.

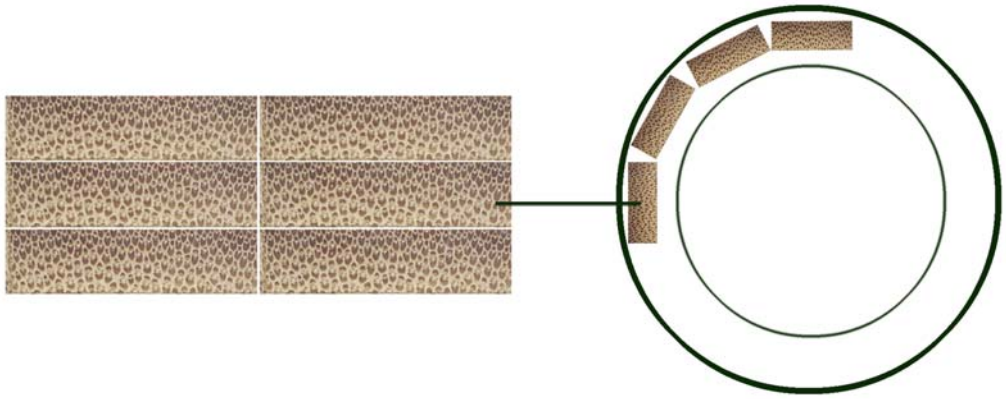

Figure 5 – Position of the strips through the culms wall

Mechanical Tests performed, specimens dimensions and moisture

The mechanical characterization was done by the resistance and longitudinal elasticity modulus, obtained from three tests that are: fiber parallel compression, fiber parallel tension and simple bending; all performed according to Brazilian wood standard NBR 7190/97 (ABNT, 1997), because there aren't Brazilian standards to the bamboo.

The specimens and the samples were made according to the standard dimensions. The cross section dimensions for the parallel compressive test are 5 cm x 5 cm and 15 cm length. For the simple bending test, 5 cm x 5 cm at cross section and 115 cm length (with 105cm at distance between supports). The cross section for the parallel tensile test is 5cm x 0.7 cm and 42 cm length, as shown in figure 10. All specimens were made with the bamboos in the equilibrium moisture.

Results and discussion

In this section the main results of the mechanical characterization tests are presented, besides illustrations that can show the shape of the adopted specimens.

Resistance and elasticity in the parallel compressive test

The specimen appearance and the deformation measure instrument are shown in figure 6.

Figure 7 shows the two patterns of severing observed in specimens of parallel compressive test. The image on the left shows a pattern of diagonal severing (angle of 45º, more or less) observed in most specimens and similar to that observed in tests with solid wood. The image on the right shows a severing without a well defined diagonal and that occurred in some specimens. In terms of safety it shows a rupture which may be considered ductile.

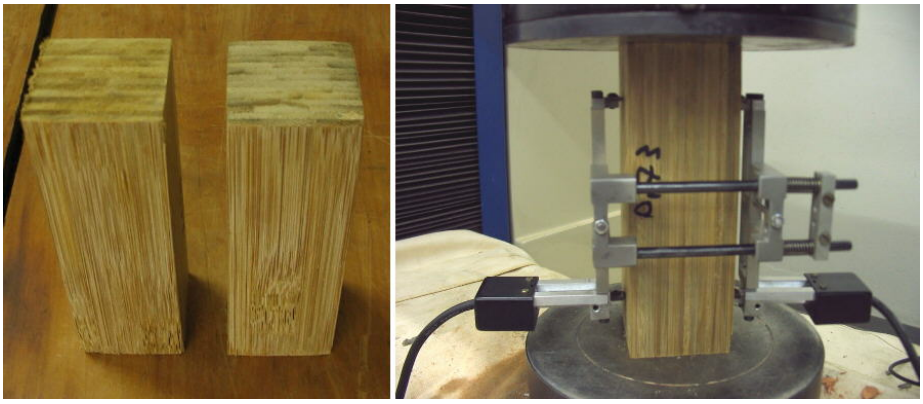

Figure 6 – Specimens in parallel compressive test, with the deformation measure instrument.

Figure 7 – Specimens after the test.

Table 1 shows the results obtained to strength (f_{co}) and longitudinal modulus of elasticity (E_{co}), in parallel compressive test, using the adhesive cascorez 2590 (PVA), at the rate of moisture U.

Table 1 – Results of the parallel compressive tests, in glued laminated bamboo.

Specimens	f_{co} (MPa)	E_{co} (GPa)	U (%)
1	67	17.0	11.2
2	62	17.8	11.1
3	64	17.2	11.1
4	68	18.6	10.8
5	63	19.8	10.9
6	61	22.5	11.4
7	63	16.2	10.9
8	64	17.2	10.9
9	65	17.7	11.3
10	67	17.9	11.4
11	66	18.1	10.9
12	73	19.4	11.4
13	63	15.2	11.2
14	75	20.6	11.4
15	61	20.0	11.5
16	64	15.2	11.3
average	65.5	18.1	11.2
standard deviation	3.9	1.9	0.2
variation coefficient (%)	5.9	10.7	2.1

Table 1 shows the variation range of resistance obtained in parallel compressive tests with values ranging between 61 and 75 MPa, with an average of 65.5 MPa. The average modulus of elasticity in the compression was of the order of 18.1 GPa, with variations between 15.6 and 22.5 GPa. The resistance values obtained are above native or reforestation coniferous wood, as for example, Pine of the Paraná (*Angustifólia Araucária*) with 40.9 MPa or *Pinus elliottii* with 40.4 MPa or superior to some native or reforestation dicotyledon wood species, as for example *Eucalyptus saligna* with 46.8 MPa, *Eucalyptus grandis* with 40.3 MPa, Cupiúba (*Goupia glabra*) with 54.4 MPa or Angelim Rock (*Hymenolobium petraeum*) with 59.8 or still comparable to *Eucalyptis citriodora* with 62.2 MPa.

Resistance and elasticity in the simple bending test

The specimen appearance and the test set are shown in figure 8 and figure 9 shows the pattern of severing observed in specimens of bending. The image on the left shows the usual pattern of severing observed (shearing between the bamboo strips near to neutral line). The image on the right also shows an usual severing with shearing of bamboo strips and nodes break for tension (below the neutral line). In terms of safety it shows a rupture which may be considered ductile.

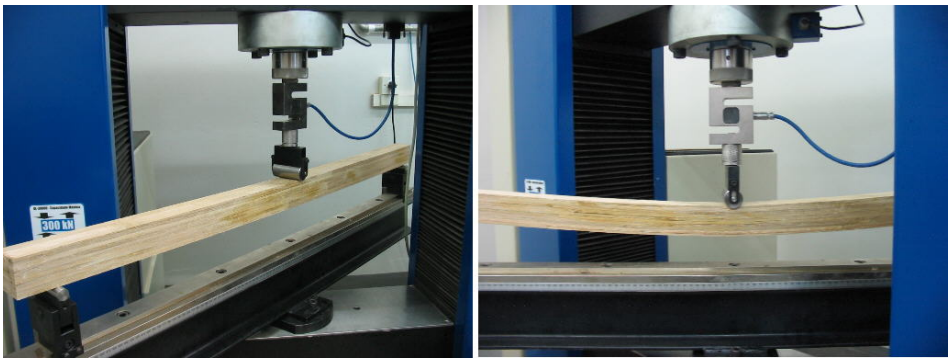

Figure 8 – Specimen in the simple bending test.

Figure 9 – Specimens after the simple bending test

Table 2 shows the results obtained for strength ($f_f o$) and longitudinal modulus of elasticity ($E_f o$), in simple bending test, using the adhesive cascorez 2590 (PVA), at the rate of moisture U.

Table 2 – Results of the simple bending tests in glued laminated bamboo.

Specimens	f_{fo} (MPa)	E_{fo} (GPa)	U (%)
1	112	16.4	11.3
2	95	14.4	11.0
3	107	14.8	11.4
4	104	14.2	11.4
5	108	15.1	11.4
6	105	14.2	11.2
7	104	12.8	10.9
8	105	12.3	11.1
9	89	12.7	11.3
10	96	12.4	11.5
11	105	14.2	11.2
12	83	12.4	11.4
13	89	13.0	11.2
14	84	11.9	11.4
15	97	13.0	11.5
average	98.9	13.6	11.3
standard deviation	9.2	1.3	0.2
variation coefficient (%)	9.3	9.4	1.6

Table 2 shows the variation range of resistance obtained in simple bending tests with values ranged between 83 and 112 MPa, with an average of 98.9 MPa. The average modulus of elasticity in the bending was of the order of 13.6 GPa, with variations between 11.9 e 16.4 GPa. The resistance values obtained are above native or reforestation coniferous wood, as for example, *Pinus elliottii* with 69.6 MPa or superior to some native or reforestation dicotyledon wood species, as for example *Eucalyptus grantis with* 7.6 MPa or Cedrinho (*Dipteryx odorata*) with 80.2 MPa.

Resistance and elasticity in the parallel tensile test

Figure 10 shows the tests performed and figure 11 shows the pattern of severing observed in specimens of parallel tensile test. The image on the left and the right (figure 11) shows the usual pattern of severing observed, in all specimens the disruption was observed on nodes and on fibers.

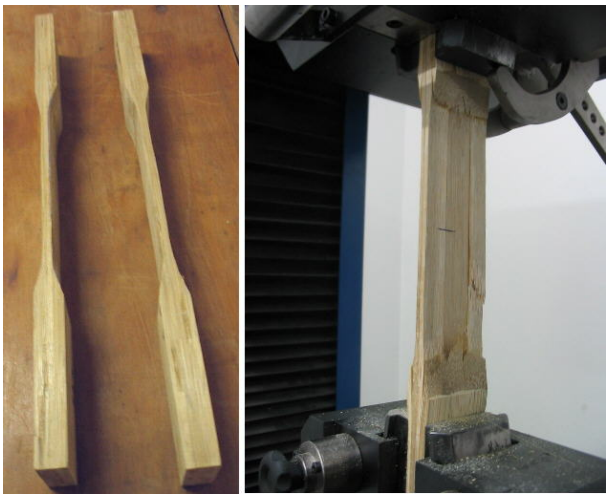

Figure 10 - Specimens in parallel tensile test

Figure 11 – Specimens after the test

Table 3 shows the results obtained for parallel tensile strength (fto) and longitudinal modulus of elasticity (E_{to}), using the adhesive cascorez 2590 (PVA), at the rate of moisture U

Table 3 – Results of the parallel tensile tests in glued laminated bamboo.

Specimens	f_{to} (MPa)	E_{to} (GPa)	U (%)
1	142	21.8	11.0
2	147	19.9	11.4
3	143	21.4	11.0
4	147	17.9	10.9
5	130	20.7	11.2
6	147	18.6	11.3
7	152	21.0	10.9
8	200	20.1	11.3
9	147	21.1	11.1
10	117	20.3	11.3
11	120	21.2	11.1
12	141	22.8	11.5
13	166	21.6	11.3
14	132	22.3	11.2
15	128	19.2	11.4
16	142	18.1	11.1
average	143.7	20.6	11.2
standard deviation	19.4	1.4	0.2
variation coefficient (%)	13.5	7.1	1.6

Table 3 shows the variation range of strength obtained in parallel tensile tests with values ranged between 130 and 200 MPa, with an average of 143.9 MPa. The average modulus of elasticity in the tension was of the order of 20.6 GPa, with variations between 18 and 22 GPa. The resistance values obtained are above native or reforestation coniferous wood, as for example, Pinho do Paraná (*Araucária angustifólia*) with 93.1 MPa or *Pinus elliottii* with 66 MPa or superior to some native or reforestation dicotyledon wood species, as for example *Eucalyptus saligna* with 95.5 MPa, *Eucalyptus grandis* with 70.2 MPa, *Eucalyptus citriodora* with 123.6 MPa, or Ipê (*Tabebuia serratifolia*) with 96.8 MPa or still comparable to Maçaranduba (*Manilkara spp*) with 138.5 MPa.

Table 4 summarizes the mechanical characteristics of the glued laminated bamboo, presenting the average values in the compressive, bending and tensile tests, also showing the absolute density (ρ**)**

Table 4 – Average values of the mechanical characteristics of the glued laminated bamboo (ρ = 0.79 g/cm^3).

	Strength (MPa)	Elasticity modulus (GPa)	U (%)
Tensile	f_{t0} = 143.7	E_{t0} = 20.6	11.2
Simple bending	f_f = 98.9	E_f = 13.6	11.3
Compressive	f_{c0} = 65.5	E_{c0} = 18.1	11.2

Example of some bamboo products developed

Figure 12 shows some glued laminated bamboo products produced by the first author together with students of the design course.

Figure 12 - Some prototype of glued laminated bamboo products.

Conclusions

In accordance to the conditions where the work was developed it can be considered that:

- The Brazilian wood standard was revealed satisfactory for the bamboo mechanical characterization;

- The specie *Dendrocalamus giganteus* used in this work revealed satisfactory for the confection of the laminated strips.

- The limit established for the useful height of the culms (wall with at least 10 mm of thickness) was satisfactory for the processing and maximum exploitation in height of the culms. The 4 face planer used for the final processing of the strips revealed adequate for this use.

- The adhesive (PVA) used for the strips glue presented a very good performance.

- The mechanical characteristics obtained in this work are good enough for a confection of the glued laminated bamboo products, as furniture, tools, etc.

Gratefulness

To Fundação de Amparo a Pesquisa do Estado de São Paulo – Fapesp, for the financial support in this work development.

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Bamboo (*Dendrocalamus asper*) as Raw Material for Interior Composite Panel Manufacture in Thailand

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Abstract

This study reviews some of the findings of various past and ongoing research projects carried out to manufacture composite panels from bamboo (*Denrocalamus asper*) in Thailand. Experimental panels including particleboard, medium density fiberboard (MDF), and sandwich type panels having fibers on the face layers and particles in the core layer were made. Both physical and mechanical properties of above boards were evaluated. Average values of modulus of elasticity and modulus of rupture of particleboard and MDF samples were determined as 2,424 MPa, 22.57 MPa, 2,200 MPa, and 22.70 MPa, respectively. In the case of sandwich type panels such values were 1,840 MPa and 20.91 MPa. In addition to the bending properties, internal bond strength and physical properties including thickness swelling, water absorption of all types of samples resulted in satisfactory values based on Japanese Industrial Standards (JIS) for panels use for interior purposes. Surface roughness of MDF and sandwich type panels was also determined using a stylus type equipment. It appears that bamboo which is considered as under-utilized specie may provide profitable and marketable panels products in Thailand. Such panels are not only environmentally friendly but also one of the alternative ways to convert bamboo in a value-added product.

Introduction

Non-wood material based resources such as bamboo and agricultural fibers including wheat straw, kenaf, rice husk, and rice straw are getting more important as raw material to manufacture composite panels. Thailand has

rich natural biological resources and diverse ecosystems that contain many non-wood materials. Unfortunately similar to many developing Asian countries deforestation and over harvesting in Thailand also created environmental awareness which focused exploratory research using non-wood renewable resources in composite panel production.

Bamboo is one of the most diverse groups of plants in the grass family which belongs to the sub-family of Bambusoidae (Zheng and Guo 2003). It is widely recognized as an important non-wood forest resource due to not only its excellent mechanical properties but also its high socioeconomic benefits. Housing, packaging and transportation are only few examples its common utilization for many years in Asian countries (Zhang and Yonglan 1988; Xuhe 2005;Sumardi et al.2005; Wang and Joe 1983). Currently, bamboo is still considered as under-utilized non-wood species, although it has additional limited use as scaffolding, furniture units, plywood, and flooring in Thai constructional industries (Ye 1991; Ganapathy et al. 1992). Its fast growth rate and better characteristics than many other wood species makes this resource an alternative raw material for various composite panel manufacture. One of the first bamboo composite panels developed was in 1940's in China and since then, at least 28 different types of bamboo composite products have been developed (Ganapathy et al.1992). Also there have been several attempts to explore the possibility to produce panel products including particleboard, oriented standboard, plywood, and laminated composite panels from bamboo at commercial level (Bai 1996 ; Hiziroglu et al. 2005; Lee et al. 1996, Li et al. 1994; Li 2004; Chow et al. 1993, Chew et al. 1994, Chen and Hua; 1991).

Although particleboard is also used as substrate for overlays its rough surface may create certain problems resulting show through the thin films or direct finishing applications. Medium density fiberboard which is prime substrate product for furniture and cabinet manufacture is the most widely used interior type of panel in many countries including Thailand. However overall cost of MDF is more expensive and has more complicated manufacturing process than that of particleboard. Combination of fibers and particle in the form of sandwich type of panel would possibly solve this cost problem. Experimental panels with a sandwich configuration were also manufactured from bamboo. Since fibers were used on the face layers it is expected such panels had not only smooth surface with thin layer of fibers on board faces but also their overall properties were enhanced.

The main objective of this study was to explore potential suitability of bamboo to develop value-added interior panel products, namely particleboard, medium density fiberboard (MDF), and sandwich type panels having fibers on the face layers and the coarse particles in the core layer. Both basic physical and mechanical properties of experimental panels made from bamboo were tested to find if bamboo could be used to produce experimental panels with accepted properties.

Materials and Methods

Bamboo (*Dendrocalamus asper*) samples were harvested in Khon Khen, Prachin Buri bamboo plantation in Thailand. The specimens were reduced into chips using a commercial chipper before they were hammermilled for particle production. Figure 1 shows particle and fibers of bamboo used in this study. A laboratory type defibrator illustrated in Figure 2 was employed for disintegration of bamboo chips into the fibers using a pressure of 0.75 MPa, at a temperature of 160 ^{o}C for 1.5 min. before particles and fibers were dried in a kiln at a

temperature of 80 ^{o}C until the furnish reached to 4 % moisture content. Later dried fibers were mixed for 4 min with 9 % urea-formaldehyde resin with a specific gravity of 1.27 and solid content of 84.8% in a rotating drum type mixer fitted with a pneumatic spray gun. Half percent wax was also added during resin spraying for the furnish. Twenty and 50% rice straw fibers and particles were also added into the various types of panels to evaluate interaction between two types of materials. Table 1 displays experimental schedule of the study involved with MDF manufacture.

The sandwich type samples with fibers on the face layers and the particles in the core layer were also manufactured using the above set-up. The core of the panels had homogeneous mix of 95% bamboo and 5% rice straw as filler using a 8% urea formaldehyde resin. Fibers of both type of raw material were used at the same ratios for the face layer of the panels using 10 % urea formaldehyde. Particles and fibers were mixed with the adhesive and 0.5% wax in the rotating mixer equipped with pressurized spray gun. Ten replicas for each type of panel in 35 cm by 35 cm by 1.0 cm were manually formed in a plexiglass box and pressed in a hot-press at a temperature of 165 ^{o}C using a pressure of 5.2 MPa for 5 min. Average target density of the panels ranged from 0.65 g/cm^3 to 0.80 g/cm^3. Panels were conditioned in a climate room with a temperature of 20 ^{o}C and a relative humidity of 65% for about two weeks before any tests were carried out. Modulus of elasticity, modulus of rupture, and internal bond strength properties were tested on an Instron Testing Machine Model-22, 5500-R equipped with a load cell capacity of 5,000 kg. Two and six samples were cut from each panel for bending and internal bond strength tests, respectively. Figures 3 and 4 illustrate unpressed MDF and sandwich type mats. Density profile samples were then determined on Quintek Density Profilometer, Model QDP-01X. This instrument can be set to a minimum linear increment of 0.25 mm depending on the sample thickness. Four samples with a size of 15.2 cm by 15.2 cm were used to determine thickness swelling of the panels. Thickness of each sample was measured at four-point midway along each side 2.5 cm from the edge of the specimen. Later samples were submerged in distilled water for 2-h and 24-h before thickness measurements were taken from the same location to calculate thickness swelling (TS) values. Table 2 shows experimental design of sandwich type panels.

Surface roughness of the samples was evaluated using portable stylus type equipment, Hommel T-500 profilometer as shown in Figure 5. Eight specimens with a size of 5 cm by 5 cm were randomly taken from each type of panel for roughness measurements. The profilometer equipment consisted of a main unit with a pick-up drive which has a skid-type diamond stylus with a 5-µm tip radius and 90° tip angle. The stylus traverses the surface at a constant speed of

1 mm/sec over a 12.0-mm tracing length. The vertical displacement of the stylus is converted into electrical signals by a linear displacement detector before the signal is amplified and converted into digital information. Various roughness parameters such as average roughness (R_a), mean peak-to- valley height (R_z), and maximum roughness (R_{max}) can be calculated from the digital information. Typical roughness profiles of samples from four types of panels are shown in Figure 6. Definition of these parameters is discussed in detail in previous studies (ANSI 1985; Hiziroglu et al. 1996, 2004; Mummery 1993). Four random measurements were taken from each side of the samples to evaluate their roughness characteristics. Analysis of variance was used for statistical analysis of the data from the tests.

Results

Results of physical and mechanical properties of different types of panels made from bamboo are displayed in Tables 3 and 4. Medium density fiberboard samples had an average MOE and MOR values of 2273 MPa and 28.66 MPa, respectively. A previous study showed that experimental bamboo particleboard panels had 2,424 MPa and 22.57 MPa for above tests (Hiziroglu et al. 2005). In the case of sandwich type panels MOE and MOR values of the samples ranged from 1,287 MPa to 1,910 MPa and 13.77 MPa to 26.30 MPa depending on panels density as displayed in Table 4. Based on the Japanese Industrial Standard (JIS-A 5905) 13.0 MPa is the minimum requirement for interior particleboard. Based on American National Standards (ANSI-A 208) minimum MOE and MOR requirement for grade 110 MDF for interior applications are 1,400 MPa and 14 MPa. It seems that panels manufactured in such studies, including sandwich type panels satisfied MOR strength requirements for general used based on both standards. Panel type-A with sandwich cross section had the lowest strength properties which can be related to its very low density of 0.65 g/cm^3.

Internal bond strength of the samples followed the similar trend of bending properties of the panels. Overall IB strength values of sandwich type panels ranged from 0.51 MPa to 0.84 MPa satisfying the IB strength requirements based on the JIS for general use of particleboard. Thickness swelling values of both types of samples were found to be acceptable based on the standards. The panels made from 100% bamboo fibers had 7.84% thickness swelling as a result of 2-hr water soaking. Corresponding value for sandwich type panels was 10.25 MPa with 0.75 g/cm^3 density level. Using rice straw furnish as filler in the panels reduced both strength and dimensional properties of the samples.

In general single-layer particleboard with rough surface are not used for thin overlays as substrate for cabinet and furniture manufacture. Average roughness value of bamboo particleboard was within the range of 19 µm. However both MDF and sandwich type panels resulted in much smoother surface with and average R_a values ranging from 5.08 µm to 7.50 µm. It appears that having only 5% rice straw fiber on face layers of three-layers panels did not influence significantly their surface characteristics. Panel density was found to be one of the important parameter controlling surface quality. Samples had better surface roughness with their increasing density which can be related to compactness of face layers. Based on the roughness measurement it is expected that both types of panels having fibers on the face layers can be used as substrate for even ultra thin overlay papers without having any telegraphing effect .

Conclusions

This study briefly reviewed some of the findings of several experimental works related to manufacture different types of composite panels from bamboo. In the light of preliminary results of such studies bamboo which is an under-utilized non-wood resource can be used to produce interior composite panels with accepted physical and mechanical properties. It appears that manufacturing composites from bamboo would provide a profitable and marketable interior panel products in Thailand. Such panels are not environmentally friendly but also provide an alternative way to convert this resource into panel products for furniture manufacture.

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Table 1. Sampling schedule of MDF panel manufacture.

Panel Type	Raw material	Number of panels	Test Samples				
			MOE and MOR	IB Strength	TS	Density Profiles	Surface roughness
A	100% Bamboo	5	10	30	10	10	10
B	80% Bamboo-20% Rice straw	5	10	30	10	10	10
C	50% Bamboo-50% Rice straw	5	10	30	10	10	10

Table 2. Sampling schedule of sandwich type panels.

Panel Type	Face/Core Ratio	Density (g/cm^3)	Number of panels	Bending (MOE&MOR)	IB	TS	Roughness
A	10/80/10	0.65	8	40	35	40	80
B	10/80/10	0.75	8	40	35	40	80
C	25/50/25	0.70	8	40	35	40	80
D	25/50/25	0.80	8	40	35	40	80

Table 3. Results of the physical and mechanical properties of MDF samples.

Panel Type	MOE (MPa)	MOR (MPa)	IB (MPa)	Thickness swelling (%)		Density g/cm^3	Roughness parameters (µm)		
				2-h	24-h		R_a	R_z	R_{max}
(A) 100% Bamboo	2273	28.66	0.71	7.84	19.96	0.73	5.50	40.73	49.02
(B) 100% Rice straw	1484	15.65	0.23	33.03	40.95	0.74	5.20	39.23	46.65
(C) 80 % Bamboo 20 %Rice straw	1936	23.29	0.52	18.52	24.40	0.73	4.88	36.10	43.61
(D) 50 % Bamboo 50 % Rice straw	1850	22.23	0.38	22.26	27.46	0.72	5.20	39.23	46.64

Table 4. Results of the physical and mechanical properties of sandwich type samples.

Panel type	Density (g/cm^3)	MOE MPa	MOR MPa	IB MPa	TS (%)	WA (%)	Roughness (µm)		
							R_a	R_z	R_{max}
A	0.65	1,325	13.77	0.68	9.98	38.35	7.5	39.31	54.50
B	0.75	1,840	20.91	0.84	10.25	33.90	6.25	36.82	40.81
C	0.70	1,287	17.17	0.51	23.39	90.11	6.57	38.33	43.62
D	0.85	1,910	26.30	0.73	24.78	72.53	5.08	25.34	36.53

Figure 1. Bamboo and rice straw particles and fibers

Figure 2. Laboratory type defibrator.

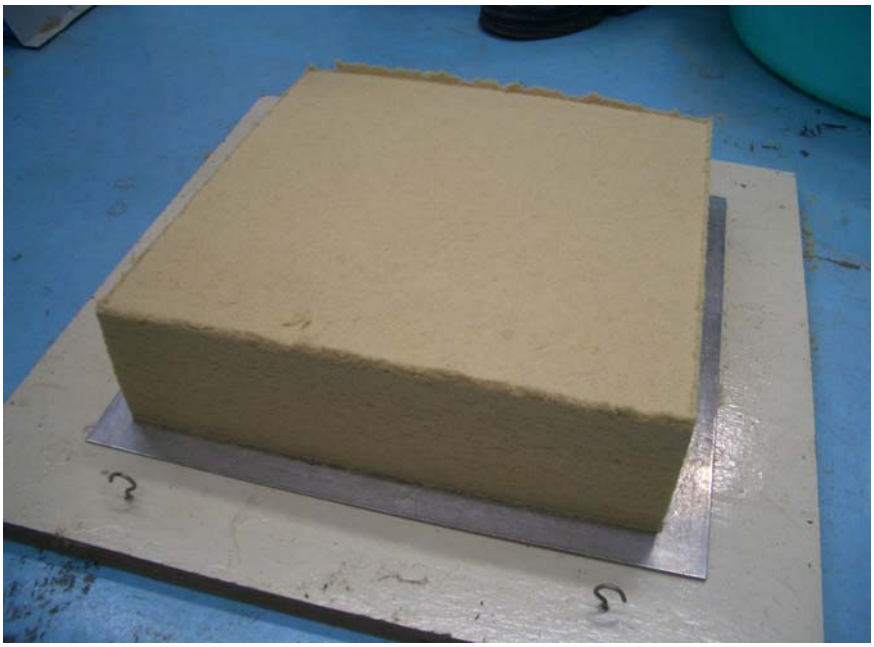

Figure 3. Unpressed MDF mat.

Figure 4. Unpressed sandwich type mat.

Figure 5. Stylus type roughness profilometer.

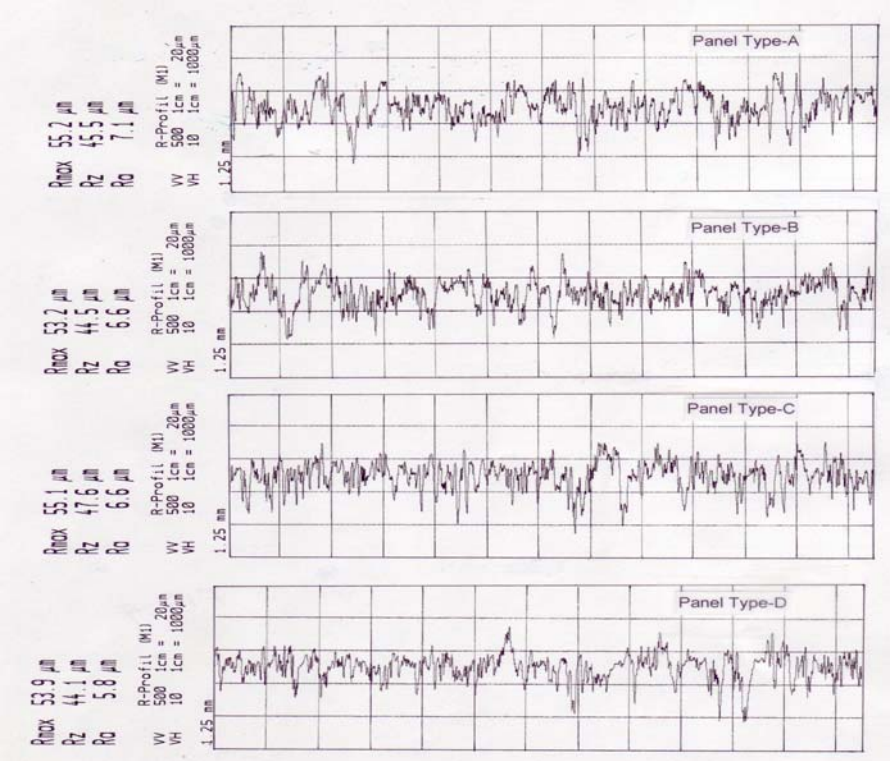

Figure 6. Typical roughness profiles of MDF samples.

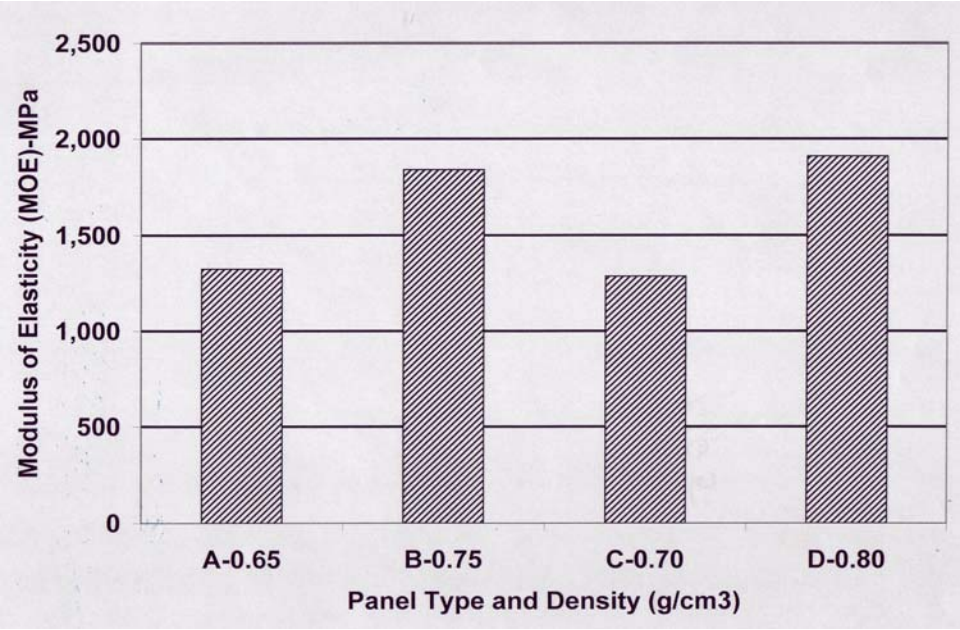

Figure 7. Modulus of elasticity of the sandwich type of samples.

VOLUME 9

Material Properties of Bamboo

Table of Contents

Preface

Robert Gretton
Chair

Bamboo is a fast growing plant with many advantages, both in its cultivation and in the physical attributes of its timber. It is used as an alternative to wood in many applications, and has further potential as a substitute for wood and other raw materials.

Modern construction methods, design, and industrial uses require certainty that the physical parameters of materials are well understood. The durability of materials is often a key parameter.

The first paper presented in Session 9 takes a detailed look at the anatomical and chemical properties of *Bambusa vulgaris* from three sites in Ghana, whilst the second looks at developing improved methods of identification of superior genetic material as an aid to exploitation of their superior traits. This work focused on *Bambusa balcooa.*

Papers three to six look at methods of enhancing the durability and characteristics of bamboo timber with a variety of chemicals and treatments. Paper three looks at heat treatments and consequent changes in physical and mechanical properties. Paper four focuses on improving durability with chemical and botanical treatments, and paper five looks at the performance of *Dendrocalamus strictus* treated with a combination of fire retardants and preservatives. Paper six documents experiments using environmentally-friendly chemicals to enhance resistance to moulds.

Identification of Superior Fiber-Trait-Yielding Genetic Resources of *Bambusa balcooa*: Analysis of Physico-Chemical Properties of Fibers

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Abstract

Rapid depletion of forest trees has considerably reduced the availability of wood fibers for paper and pulp industries, while bamboo fibers have replenished the demand partially. Fibers of *Bambusa balcooa* was preferred among non-wood raw materials for paper and pulp making primarily because of its mechanical strength attributable to the high specific gravity. Therefore, an attempt was undertaken to identify superior fiber yielding genetic resources of *B. balcooa*. Extensive analysis of physical (slenderness ratio, Runkel ratio, flexibility coefficient) and chemical (α-cellulose, lignin) characteristics of fibers among 7500 samples from 12 distant locations revealed accessions of two locations exhibiting unambiguous superiority. A SCAR marker ($Balco_{1128}$, DQ9005800) has been identified that discriminates the elite genotype from the others. Furthermore, presence of an open reading frame within the marker sequence was found in these elite genotypes and also in other bamboo species that yield fibers suitable for use in paper and pulp industry. This strategy of molecular differentiation of elite genotypes within a species could advance the efficient commercial utilization of the available superior germplasm resources.

Introduction

The indiscriminate exploitation of forest resources at global scale has considerably reduced the availability of the wood fibers for paper and pulp production (Ganapathy 1997). Consequently, the non-wood fiber resources are gaining increased attention to fulfill the ever-increasing gap between the demand and the supply in an environmentally sustainable manner. Bamboos constitute a major non-wood forest-fiber source for the paper and pulp production worldwide and a number of species have been identified as more useful (Ganapathy 1997). For instance, *Bambusa balcooa* Roxb. is preferred due to its mechanical strength, attributable to the high specific gravity and long fibers (Kabir et al. 1991; Bhatt et al. 2003). However, the physical and chemical fiber characteristics determine the suitability of traits to produce superior quality paper/pulp at low costs.

B. balcooa is native to North-East India and distributed across the states of Nagaland, Meghalaya, Tripura, Assam, West-Bengal, Bihar and Eastern Uttar Pradesh (Seethalakshmi and Kumar 1998). It is also cultivated in many other Asian countries, tropical Africa and Australia (Ohrnberger 2002). The rich local vegetation of *B. balcooa* prompted us to make an attempt towards selection of elite genotype/s across the available natural genetic resources with respect to their fiber characteristics that are directly correlated with their downstream processing to produce better quality paper and pulp at the same time maintaining the economic and environmental benefits protected.

During this investigation two natural genotypic-resources of *B. balcooa* with superior physico-chemical fiber characteristics were identified that led further studies to develop a molecular marker through which such elite genotype could be discriminated for efficient commercial utilization. A sequence characterized amplified region (SCAR) marker has been developed and was amplified from all the accessions of *B. balcooa* collected from two locations (Bb3 and Bb4) that generated superior fibers, but not from rest of the locations surveyed. In woody bamboo, lack of regular sexual events limits the study on QTL and application of breeding based segregation to test the genetic linkage between a marker and the particular trait of interest; therefore, allelic polymorphisms based selection has been adapted.

Development and judicious application of modern molecular technologies in assessment and enhancement of available forest genetic resources for their successful exploitation have often been emphasized (Burley, 2001). In the past, molecular markers have been successfully employed to study population level genetic diversity in bamboos (Suyama et al. 2000; Isagi et al. 2004; Shrestha et al. 2005; Das et al. 2008). However, their further practical application to identify commercially desirable, elite accessions/genotypes are not available in the literature. This could only be achieved when a pool of morphologically and/or chemically well-characterized bamboo accessions would be available for further characterization by genotyping.

The present study was aimed to define a strategy using selected fiber characteristics as the reference to test if molecular markers could be utilized for elite genotype screening in a plant group that predominately lacks a regular sexual event. Attempts were made to search for the presence/absence of the marker in superior/inferior fiber-yielding bamboo species/genotypes, in order to confirm the unambiguous association of the marker with better fiber yielding genotypes.

This strategy of marker-assisted molecular differentiation of elite genotypes within a species could advance the efficient commercial utilization of the available superior germplasm resources.

Materials and Methods

Plant materials

Stands of *Bambusa balcooa* Roxb. growing in wild habitats across 12 distant locations of West-Bengal, India were surveyed (Table 1). Each of these locations was represented by five randomly selected clumps (culms growing together). Five adult culms from each clump (altogether 25 accessions) of all the selected locations were independently sampled (25x12= 300 samples) for fiber isolation. The middle segments of the 5th

internodes of the secondary branches were used as the starting biological samples, since it represents the average length of all the internodes in a branch (Ververis et al. 2004).

Isolation of fibers from the internodes of Bambusa balcooa

Small slivers prepared by macerating internodes with 10 ml of 67% nitric acid, boiled in a water bath for 10 min and subsequently washed in distilled water (Ogbonnaya et al. 1997). Individual fibers were mechanically isolated from the macerated fiber bundles by using a plastic churner. Care was taken to avoid breakage of intact fibers to facilitate measurement of total length. The fibers were then stained with methylene blue solution (0.5%) and glycerine (1:1 v/v) prior to study in light microscope (Han et al. 1999).

Measurement of physical characteristics of fibers

Measurements of fiber length and diameter; cell wall thickness and lumen diameter (fiber

diameter- cell wall thickness) for 25 fibers, independently isolated from each internode were taken. Therefore altogether 625 individual fiber (25 replications X 5 culms X 5 clumps) from each of 12 locations (25 fibers/accession; 25 accessions/location = 25X25X12= 7500 samples) were characterized by 3 physical parameters. Slenderness ratio, flexibility coefficient and Runkel ratio were the three physical characteristics studied to evaluate the quality of the fibers and their suitability to be used as raw material for paper and pulp production. Equations used to derive these physical traits were as follows: slenderness ratio=fiber length/fiber diameter, flexibility coefficient= (fiber lumen diameter/ fiber diameter) X100 and Runkel ratio=2X fiber cell wall thickness /lumen diameter (Ogbonnaya et al. 1997, Saikia et al.1997).

Estimation of α-cellulose and lignin contents from B. balcooa accessions

Cellulose and acid insoluble lignin contents are the two important chemical indicators for fiber strength and durability. The α-cellulose content was estimated following the colorimetric method based on anthrone reagent (Updegraff 1969). One gram of internodal tissues were ground, mixed with 3 ml of nitric acid and acetic acid solution (1:8 v/v) and refluxed in boiling water for 30 min. Lignin, hemicellulose and xylosans were removed through successive washing followed by centrifugation. The resultant pellet was dissolved in 67% sulphuric acid (v/v), mixed with chilled anthrone reagent (Merck, Germany), incubated for 20 min in boiling water followed by a quick chilling on ice and then kept at room temperature for 10 min prior to assay at 620 nm in a spectrophotometer (Beckman-Coulter, DU-520). The α-cellulose content was quantified based on the obtained OD readings and the standard curve prepared with known concentrations of authentic sample and was expressed as gram percentage of the fiber dry weight. Acid insoluble lignin content (Klason) was determined according to the standard ASTM D-1106- 96 protocol (ASTM, 1996).

Statistical analysis of the fiber characteristics

One-way analysis of variance (ANOVA, $P < 0.05$) for each fiber characteristics (three physical and two chemical) were performed separately using SPSS 10.0 statistical software (SPSS Inc., USA) by applying accessions as the source of variations. Duncan's multiple range test (DMRT) was performed to analyze the

accession proximity with respect to each fiber characteristics. SPSS 10.0 software was employed to analyze the linear correlation coefficient (r) between cellulose and lignin contents from fibers of *B. balcooa* samples from different locations.

Sampling of plant materials

Healthy leaves representing 5 accessions of *B. balcooa* from each locations were collected for genomic DNA isolation (Table 1). Five randomly selected accessions from each location were sampled to study genetic variability among these accessions. In addition leaves from 19 other bamboo species: *Bambusa affinis* Munro, *B. atra* Lindl., *B. auriculata* Kurz., *B. bambos* Voss, *B. burmanica* Gamble, *B. multiplex* 'Riviereorum' R. Maire, *B. multiplex* 'Variegata' R. Maire, *B. oliveriana* Gamble, *B. nutans* Wall. ex Munro, *B. polymorpha* Munro, *B. striata* Lodd. ex Wendl., *B. tulda*, Roxb., *B. vulgaris* Schrad. ex Wendl., *B. wamin* Camus, *Dendrocalamus giganteus* Munro, *D. strictus* (Roxb.) Nees, *Gigantochloa atroviolacea* Widjaja, *Oxytenanthera abyssinica* (A. Rich) Munro and *Pseudobambusa kurzii* (Munro) Ohrnberger were also collected from the germplasms stock maintained at the Botanical Survey of India, Howrah, West Bengal, India.

PCR-compatible genomic DNA isolation and authentication of B. balcooa using species- specific marker

Surface sterilized bamboo leaf tissues weighing 0.1 gm, were sliced into small pieces and homogenized in liquid nitrogen using mortar and pestle. DNA was extracted using 2.5 ml warm CTAB extraction buffer following the method of Doyle and Doyle (1987). After removal of RNA by RNaseA (Sigma, USA) treatment, the concentrations of DNA samples were estimated by using an UV spectrometer (Beckman-Coulter, DU-520) and purity of DNA was checked at A260 and A280.

Plant samples were initially identified as *B. balcooa* based on vegetative characters and subsequently authenticated by the presence of species-specific molecular marker, $Balco_{836}$ (Accession no. AY653073, Das et al. 2005).

Cloning and sequencing of the polymorphic DNA fragment

During an investigation on genotypic diversity among 25 different bamboo species, we found a polymorphic, genotype-specific DNA fragment in *B. balcooa*, which is neither present in other bamboo species nor in all bamboo accessions studied during this investigation (Das et al. 2008).

Approximately 1150bp polymorphic DNA fragment was excised from 1.5% agarose gel and purified by using the MinElute Gel Extraction kit (QIAGEN, USA). The eluted fragment was ligated into pGEM-T Easy Vector (Promega, USA), transformed into competent *Escherichia coli* strain DH5 α and the plasmid DNA was purified from the unambiguous white colonies according to Sambrook *et al.* (1989). Colony screening was performed by PCR amplification and the size of the insert was confirmed by *Eco*RI (Roche, Germany) restriction digestion before sequencing the fragment in ABI Prism 3100 automated DNA sequencer.

Marker specificity assay of PCR products by hybridization analysis

The PCR products of the random decamer primer from the genomic DNA of 20 bamboo species and representative accessions of *B. balcooa* from 12 locations were transferred to two positively charged nylon membranes (Roche) and probed with αP^{32} labelled *Eco*RI excised $Balco_{1128}$ marker. Probe labelling was performed using the Prime-a-gene labelling kit (Promega). Approximately 25 ng of probe DNA was labelled with αP32 dCTP (BARC, India). Transfer of DNA to a nylon membrane, UV cross-linking, prehybridization and hybridization at 68°C followed by repeated washing for min each at 25°C, 55°C and 65°C were performed following the methods of Sambrook et al. (1989). Signals were detected by exposing the membranes to X-ray film (Kodak). The marker fragment was used as a positive control. The objective of the first hybridization experiment was to check the species specificity of the $Balco_{1128}$ marker, and that of the second experiment was to check the genotype specificity of the $Balco_{1128}$ marker as well as to validate the homology of the co-migrating marker band amplified from respective samples of *B. balcooa* collected from 2 specific locations, Bb3 and Bb4.

DNA hybridization analysis was carried-out to authenticate the genotype specificity of the polymorphic fragment following the methods adapted by us (Das et al. 2005).

Designing SCAR primers and amplification of target sequence

The 20 bp long primer pairs (Bb_{1128}F 5'-ACCCCCGAAGATCAGAACCA-3' and Bb_{1128}R 5' -ACCCCCGAAGCCTTAGTGTT-3') were designed from the marker sequence. The genomic DNAs extracted from representative accessions of *B. balcooa* from 12 locations and 19 additional bamboo species were screened with this primer pair. PCR amplifications were carried out with Perkin Elmer Cetus 2400 thermal cycler in 50 µl reaction mixture containing 100 ng of genomic DNA; 1.0 µM of primer; 1X PCR buffer comprising of 10 mM Tris-Cl (pH 8.3), 50 mM KCl, 1.5 mM $MgCl_2$; 250 µM of each dNTPs and 1unit of Taq polymerase (Bangalore Genei, India). Amplification cycle started with 4 min denaturation at 95°C followed by 35 amplification cycles with 45 s denaturation at 94°C, 45 s primer annealing at 62°C, 1 min elongation at 72°C and finally 10 min at 72°C for elongation of PCR products.

Results

Study of physical and chemical characteristics to evaluate fiber quality

In the current investigation, fibers of *B. balcooa* from each location were characterized by 3 physical (slenderness ratio, Runkel ratio, flexibility coefficient) and 2 chemical (α-cellulose, acid insoluble lignin content) parameters. Standardized maceration technique proved useful in isolating intact, individual fibers from the internodal tissues of secondary branches of adult bamboo culms for the measurement of fiber length and diameter; cell wall thickness and lumen diameter. To minimize plant to plant variability due to variable developmental stages, sampling was done from the 5th internodes (Ververis et al. 2004).

The ANOVA revealed that the slenderness ratio was significantly higher ($P<0.05$) for the fibers isolated from locations Bb3 and Bb4 than that of the other locations studied (Table 2). On the contrary, Runkel ratio was

found lowest in Bb3 followed by Bb4, while highest in Bb5. Flexibility coefficient was highest in Bb3 followed by Bb4 and Bb11 (Table 2).The α-cellulose content was highest in the Bb3 and Bb4 (Table 2) and lowest in Bb2. The lignin content was lowest in Bb4 followed by Bb3, while relatively higher in samples of Bb5, Bb6 and Bb7 locations.

Study of genetic variability to identify B. balcooa genotype-specific marker

Species authentication for *B. balcooa* was confirmed by detecting species-specific SCAR marker $Balco_{836}$ (AY653073). A subsequent genotyping revealed presence of an approximately 1150 bp polymorphic DNA fragment in all the accessions of Bb3 and Bb4 locations (Fig. 1a).

Homology assay of PCR products with marker by hybridization analysis

The cloned marker fragment (1128 bp) was probed to the blot containing PCR amplified DNA from the representative samples of *B. balcooa* from 12 locations. Unambiguous hybridization signals were obtained only from the representatives of Bb3 and Bb4 along with the positive control (Fig. 1b). The absence of any signal in the remaining samples from 10 other locations excluded the possibility of presence of the marker, undetected by ethidium bromide staining, or its homologous sequence in other genotypes studied. The marker fragment was successfully cloned into pGEM-T Easy vector and sequenced (Fig. 2).

Genotype-specific SCAR marker development

The SCAR primer pair, designed from the 1128bp marker sequence (Fig. 2), was employed to screen 20 bamboo species (Fig. 3a) and 60 samples of *B. balcooa* from 12 locations. A single, distinct and brightly resolved band of similar size was observed only in samples from Bb3 and Bb4,, but absent in all other bamboo species (Fig. 3b). This genotype-specific SCAR marker was designated as $Balco_{1128}$ and submitted to NCBI GenBank, Accession. DQ900580.

Discussion

Physical and chemical characteristics to evaluate fiber quality

Slenderness ratio, Runkel ratio and flexibility coefficient are the three essential physical parameters to evaluate fiber quality. Slenderness ratio or felting power of the fiber is the physical indicator for the durability of the product (Rydholm 1965); whereas, fibers with low Runkel ratio (<1.0) are preferred for producing high quality papers (Saikia 1997). The magnitude of fiber strength is usually proportional to the flexibility coefficient.

Fibers collected from different samples of Bb3 and Bb4 locations were predicted to be more durable by having higher slenderness ratio while, samples of other locations, except for Bb2 and Bb5, yield fibers that have preferred Runkel ratio for pulp and paper production. Thus, evaluation of these three key physical characteristics indicates that the members of the Bb3 possess best fiber quality followed by Bb4.

Estimation of the chemical characteristics is equally important for fiber quality assessment. It was found that non-wood source could be pulped in one-third time than that of the woody counterparts due to their lower lignin contents (Ververis *et al.* 2004). Additionally, pulping from low lignin plant materials reduces 30% costs for chemicals and power consumption (Young 1997) and thus preferred by the industries. In contrast, higher cellulose content ensures improved fiber strength. Hu *et al*. (1999) have demonstrated that lignin and cellulose contents could be regulated in a compensatory manner. Expression of *Pt4CL1* gene in transgenic *Populus* resulted in 45% reduction in lignin content, and 15% increase in cellulose content. In the present study, a natural compensation with reduced lignin (38% decrease from the average value of all samples assayed) and higher cellulose content (10% increase) in the Bb4 was evident and supported by a high negative correlation (-0.645) between the cellulose and lignin content (data not shown). The correlated physical and chemical characteristics of the fibers derived from accessions of Bb3 and Bb4 unambiguously demonstrated their suitability for superior paper and pulp production and also indicates cost efficacy. The combined use of the aforesaid parameters could reliably be extrapolated to other non-wood timbers to evaluate fiber quality.

Development of a molecular marker for the screening of superior genotype

Bamboos, despite being an economically important plant group, has been neglected over the years to study genetic diversity within a species by developing molecular marker/s associated with important traits like fiber quality, disease resistance etc. SCAR markers have been applied to the woody trees for diverse purposes that include identification of olive varieties (Hernandez *et al.* 2001); sex determination in papaya (Deputy *et al*. 2002) and Salix (Gunter *et al.* 2003); mildew resistance in apple (Evans and James 2003); species identification in bamboo (Das *et al*. 2005) and in *Pinus* (Mehes *et al*, 2007). Previous studies have reported intra-species phenotypic variations for many bamboo species that include *B. tulda, B. pallida* and *D. hamiltonii* (Kondas 1982; Soderstrom and Young 1983; Kochhar *et al.* 1990). However, no further efforts have been made to associate these phenotypes with genomic variations. Here we report the identification of a SCAR marker, $Balco_{1128}$ (Accession No. DQ900580) that has been successfully employed for identifying *B. balcooa* genotypes possessing superior fiber quality. SCAR markers linked to a major QTL for high fiber strength have been developed in upland cotton (Guo *et al*, 2003). However, lack of regular sexual events, unavailability of a mapping population and scarcity of sufficient genomic information in woody bamboos limit the application of breeding based segregation methods. In bamboo, due to long sexual cycle, it is almost impossible to test the genetic linkage between the identified marker with any superior fiber trait that unambiguously associated with the elite genotype/s. However, molecular evidence coupled with physical and chemical fiber traits possibly indicate that the superior fiber quality is not due to chance rather than genotypic difference.

In silico analyses of $Balco_{1128}$ sequence revealed presence of a putative 375bp ORF fragment (Bb.LK, GenBank Accession no. EU258678) and a 552bp promoter like upstream region. This finding further indicates a possible functional role of Bb.LK in yielding better fibers. Very high sequence homologies were obtained for the predicted ORF fragment with a putative *Oryza sativa* cv. *japonica* protein kinase (AAP13008, E-value=$2e^{-40}$) and a putative *Arabidopsis thaliana* protein kinase (NP171917, E-value=$3e^{-20}$). The conserved domain database search (http://www.ncbi.nlm.nih.gov/Structure/cdd/wrpsb.cgi) revealed leucine-rich repeat (LRR) protein domain (COG4886) within Bb.LK sequence (E-value: 0.00002). The presence of conserved LRR regions at the C-terminal end and predicted localization of a homologous sequence in chromosome 3 of *Oryza sativa* cv.

japonica through GRAMENE search result (http://www.gramene.org/multi/blastview) suggest a possible functional role of the Bb.LK sequence. Receptor like protein kinases (RLKs) with LRR plays important roles in diverse processes of plant development (Dievart and Clark, 2004; Torri, 2004). A RLK gene (*GhRLK1*) from cotton has been reported to perform a crucial role in cotton fiber development (Li *et al.*, 2005).

Conclusion

The application of molecular marker techniques in plants to select superior traits has the advantage over the traditional phenotypic markers since they are not environmentally regulated. Moreover, molecular markers linked to a trait are unaffected by the ecological conditions and are detectable in all stages of plant growth and development (Mohan *et al*, 1997). This strategy could also be extended for marker-aided screening of other plant species for selecting elite genetic resources and their subsequent characterization for judicious commercial utilization.

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Table 1. Principal geographical features of the collection sites

Location code	Collection number*	Place of collection†	Latitude	Longitude	Altitude (m)	Max. Temp. (°C)	Min. Temp. (°C)	Average annual rainfall (mm)	Soil Type
Bb1	SB/SIB/02/016	Sibpur	22° 34' N	88° 19' E	10.0	30.7	19.8	1633.6	New Deltic Alluvial
Bb2	SB/SAR/02/018	Saradapally	22° 56' N	88° 11' E	12.0	35.5	16.6	1555.0	Old Alluvial
Bb3	SB/BHA/03/023	Bhadreswar	22° 49' N	88° 21' E	11.6	36.0	17.5	1523.0	New Deltic Alluvial
Bb4	SB/DRA/03/025	Dighra 1	22° 54' N	88° 26' E	11.0	36.0	17.2	1542.0	New Deltic Alluvial
Bb5	SB/DGA/03/037	Dighra 2	22° 54' N	88° 06' E	11.0	36.5	17.5	1510.0	Old Alluvial
Bb6	SB/SRE/O3/046	Srerampur	22° 53' N	88° 24' E	14.2	35.0	18.0	1580.0	New Deltic Alluvial
Bb7	SB/SIN/03/056	Singur	22° 48' N	88° 13' E	13.0	36.0	16.8	1445.0	Old Alluvial
Bb8	SB/MEM/03/067	Memari	23° 11' N	88° 7' E	24.0	36.0	13.2	1621.0	Old Alluvial
Bb9	SB/MAN/04/082	Mankundu	22° 55' N	88° 24' E	18.0	36.5	17.0	1515.0	New Deltic Alluvial
Bb10	SB/RIS/04/087	Rishrah	22° 47' N	88° 22' E	13.8	35.8	17.8	1480.0	New Deltic Alluvial
Bb11	SB/DHI/04/094	Dhitara	22° 55' N	88° 18' E	12.0	36.0	17.2	1605.0	New Deltic Alluvial
Bb12	SB/CHU/04/104	Chuchura	22° 58' N	88° 25' E	18.0	35.0	16.0	1595.0	New Deltic Alluvial

* Collection number of representative accession

† Locations under different districts of West-Bengal, India

Table 2. A comparative account of physical and chemical characteristics of *Bambusa balcooa* fibers collected from 12 locations

Location code	Slenderness Ratio*	Runkle Ratio*	Flexibility Coefficient*	Cellulose content (%dry wt)*	Lignin content (%dry wt)*
Bb1	184.96 (32.66)^{c}	0.92 (0.33)^{bc}	54.16 (11.48)^{d}	58.98 (0.88)^{bc}	26.43 (0.86)^{b}
Bb2	187.95 (35.15)^{c}	1.02 (0.25)^{a}	50.83 (7.47)^{f}	51.72 (1.19)^{f}	25.13 (0.40)^{c}
Bb3	243.93 (32.08)^{a}	0.69 (0.08)^{f}	60.00 (6.09)^{a}	66.25 (1.15)^{a}	20.23 (0.75)^{e}
Bb4	212.99 (41.54)^{b}	0.80 (0.19)^{e}	57.24 (9.71)^{b}	64.53 (1.15)^{a}	17.97 (0.21)^{f}
Bb5	186.09 (34.60)^{c}	1.05 (0.30)^{a}	50.43 (8.24)^{f}	56.12 (1.19)^{d}	27.93 (0.40)^{a}
Bb6	187.31 (32.06)^{c}	0.85 (0.23)^{d}	55.64 (8.45)^{c}	59.75 (0.33)^{bc}	27.60 (0.89)^{a}
Bb7	187.32 (34.08)^{c}	0.96 (0.23)^{b}	52.35 (7.60)^{e}	56.12 (1.19)^{d}	27.83 (0.32)^{a}
Bb8	187.75 (36.97)^{c}	0.92 (0.32)^{bc}	54.22 (10.18)^{d}	58.03 (0.33)^{c}	25.90 (0.20)^{bc}
Bb9	184.43 (30.56)^{c}	0.89 (0.30)^{c}	54.70 (9.06)^{cd}	54.59 (0.33)^{de}	25.73 (0.25)^{bc}
Bb10	185.27 (30.18)^{c}	0.90 (0.31)^{c}	54.48 (9.24)^{d}	53.63 (0.99)^{e}	25.83 (0.40)^{bc}
Bb11	184.52 (51.55)^{c}	0.83 (0.30)^{de}	57.14 (11.87)^{b}	59.94 (1.15)^{b}	23.07 (0.15)^{d}
Bb12	185.15 (28.72)^{c}	0.89 (0.30)^{c}	55.02 (9.81)^{cd}	53.63 (1.52)^{e}	23.87 (0.35)^{d}

*Values within parenthesis represent ±SE; same superscript letters within a column do not differ significantly ($P < 0.05$) according to Duncan Multiple Range Test.

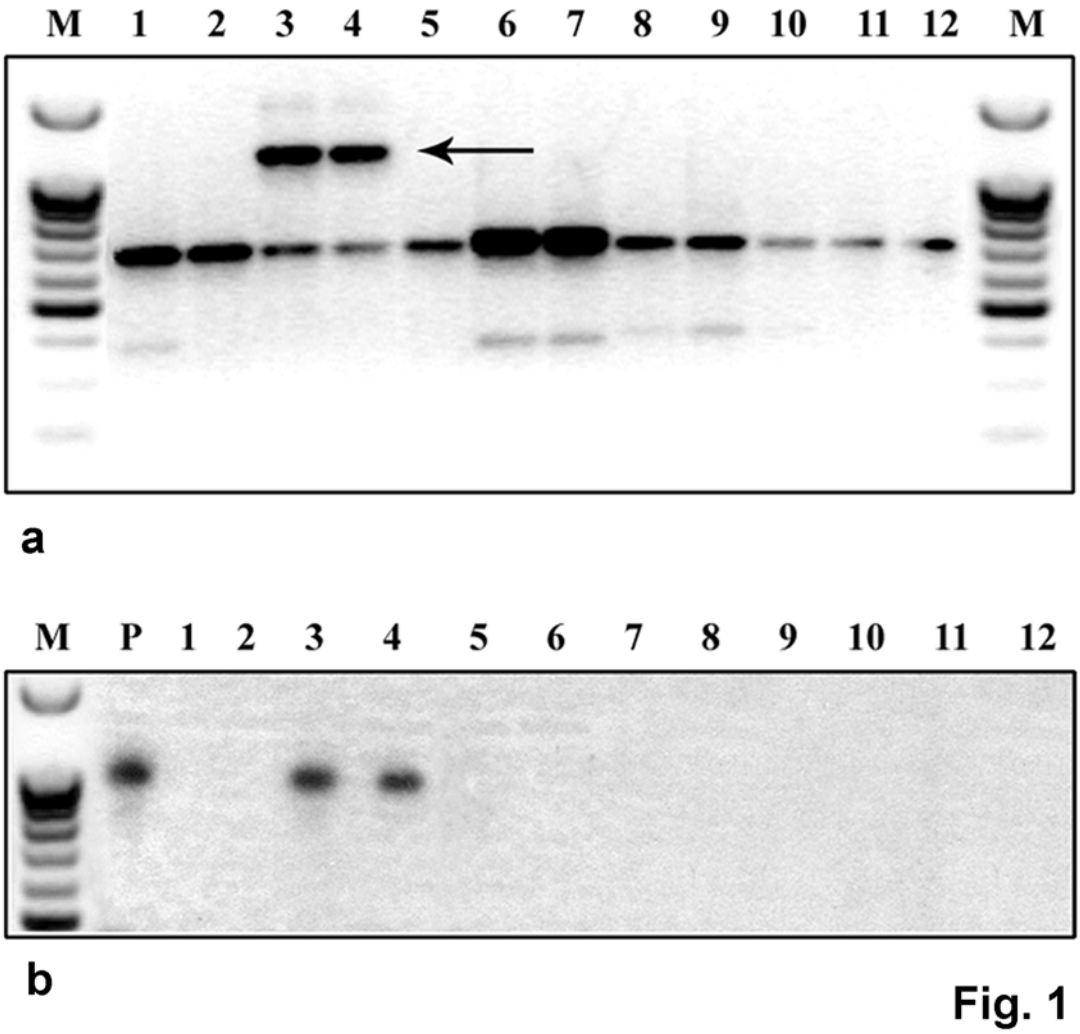

Fig. 1a. Electrophorogram showing PCR amplification products of representative members of *B. balcooa* collected from 12 locations. Lane number represents location in the same order as depicted in Table 1. M= molecular marker (1.5 Kb + 100 bp ladder). The arrow indicates presence of polymorphic DNA fragment (~1150 bp) only in Bb3 and Bb4.

Fig. 1b. Hybridization of ~1150 bp marker fragment with the blot of agarose gel containing PCR amplified products of DNA from representative *B. balcooa* samples collected from12 locations.The hybridization signals of target fragment are present only in Bb3, Bb4 and in the positive control (P).

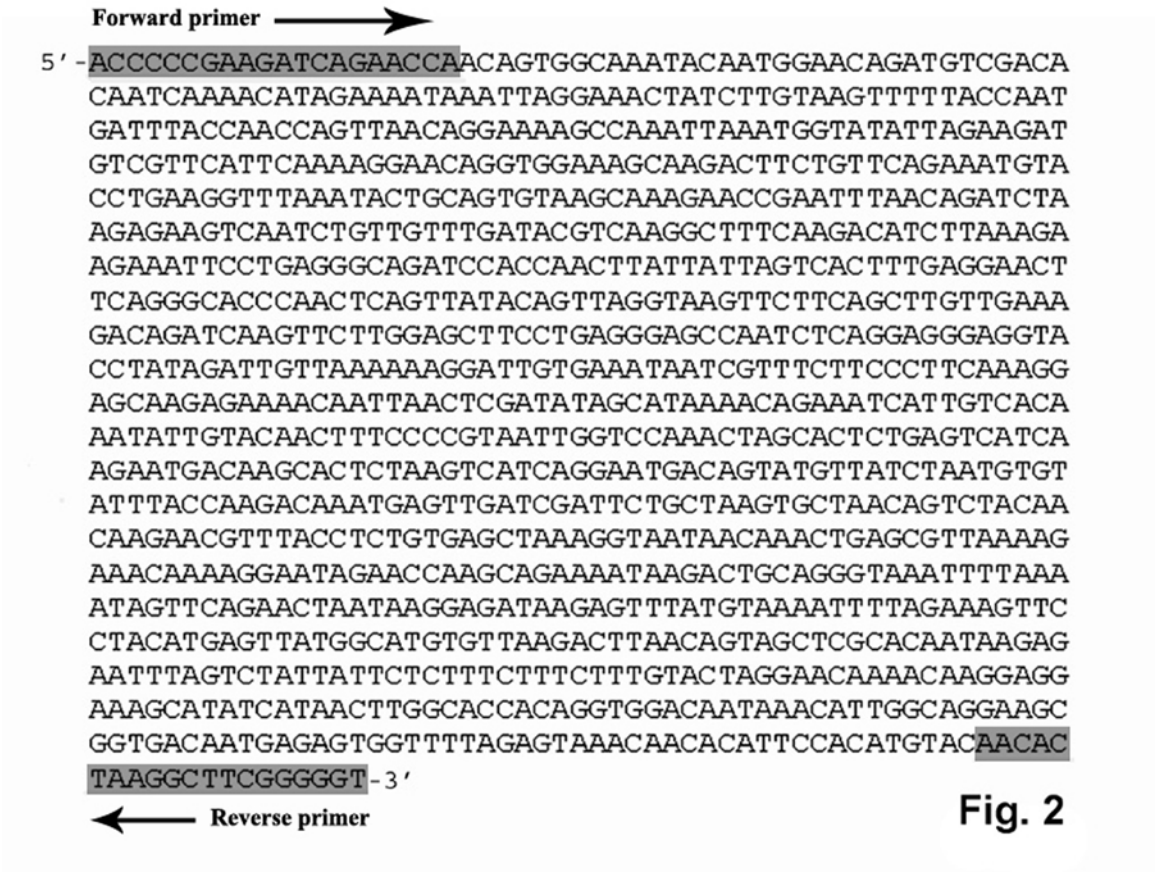

Fig. 2. Nucleotide sequence of the polymorphic DNA fragment showing the positions of SCAR primers, forward primer 5′ to 3′ and reverse primer complementary to 3′-5′ direction as indicated.

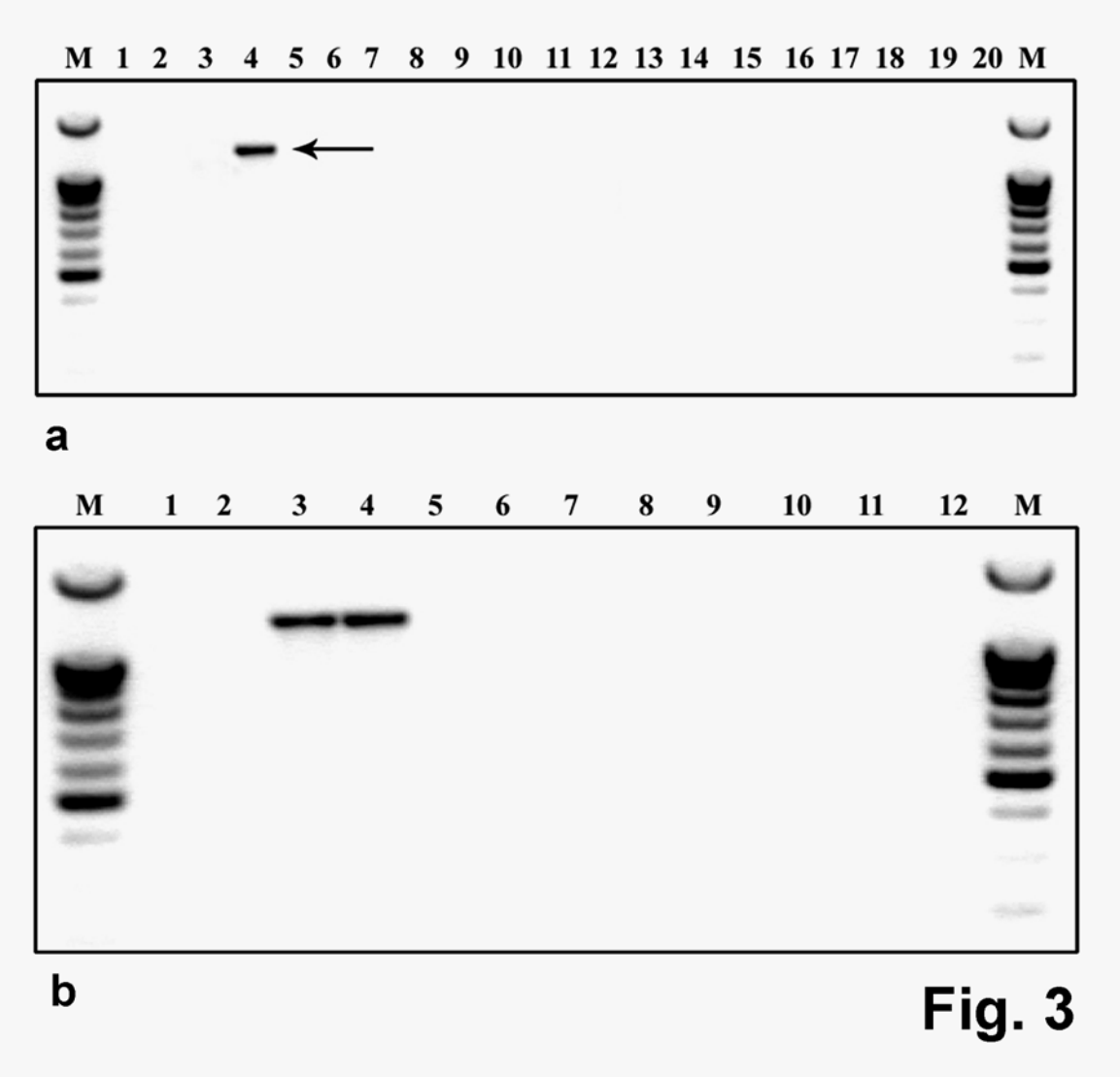

Fig. 3a. Electrophorogram of agarose gel (1.5%) that shows the amplification product only from the genomic DNA of *B. balcooa* using the SCAR primer pair, $Bb_{1128}F$ and $Bb_{1128}R$: Lane 1, *Bambusa bambos;* 2, *B. atra;* 3, *B.auriculata;* 4, *B. balcooa* (Bb4); 5, *B. burmanica;* 6, *B. multiplex* 'Riviereorum'; 7, *B.multiplex* 'Variegata'; 8, *B. nutans;* 9, *B. oliverina;* 10, *B. polymorpha;* 11, *B. striata;* 12, *B. tulda;* 13, *B. vulgaris;* 14, *B. wamin;* 15, *B. affinis;* 16, *Dendrocalamus giganteus;* 17, *D. strictus;* Lane 18, *Gigantochloa atroviolacea;* 19, *Oxytenanthera abyssinica;* 20, *Pseudobambusa kurzii;* the arrow indicates migration of 1128bp marker fragment. M, molecular marker (1.5 Kb + 100 bp ladder).

Fig. 3b. Representative electrophorogram of agarose gel (1.5%) showing amplification products only from single representative of Bb3 and Bb4 of *B. balcooa* using $Bb_{1128}F$ and $Bb_{1128}R$ SCAR-primer-pair, while no amplification products obtained from other 10 accessions. M= molecular marker (1.5 Kb + 100 bp ladder).

The Anatomical and Chemical Properties of *Bambusa Vulgaris* from Three Sites in Ghana

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Abstract

Most of the existing research on the anatomy of bamboo species in Ghana and most West African countries have centered almost entirely on the gross structure of bamboo species. Limited information exists on their microstructure structures and dimensions. This has rendered researchers and industrialists almost handicapped to fully understand and utilize the fascinating native bamboo species. The knowledge of the durability of bamboo culms in natural stand is low. In this present study, the ultramicrostructural characteristics of the predominant bamboo species in southern Ghana- *Bambusa vulgaris var. vulgaris and B. var. vittata* from three major bamboo sites were undertaken. Results revealed range in fibre bundle width from 311-506µm, the diameter of metaxylem vessels of 128-196 µm. The vascular were basically bundle types iii and iv with fibre strands of the heart-blocked and arc-like type. A strange inclusion of parenchyma close to fibre bundle was identified in sample from Assin Fosu. Further, preliminary phytochemical screening also shows the absence of alkaloids-an important decay resistant indicator but the presence of anthraquionone. These findings have added to knowledge the probable reason of the low natural durability of most bamboo species and nature of microstructure. The paper concludes with recommendations for further studies in the structure of other bamboo species including those in trial test in plantations for wider acceptance and enhanced utilization.

Keywords: *Bambusa vulgaris*, anatomy, ultramicrostructure, bamboo internodes,phytochemical properties.

Introduction

Bambusa vulgaris – a native sympodial bamboo species in Africa and Madagascar- has multiple uses (Bystriakova et al. 2004) and is rated as a moderately resistant bamboo species(De Guzman 1978).In Ghana, it is reported to be the predominant bamboo species (Ebanyenle and Oteng Amoako 2007;Tekpetey et al.2007).The detailed knowledge of its technological properties and variation is generally accepted to significantly influences the level of acceptance processing and utilization of bamboo resources. Information on the macro and ultra microstructural features of bamboo, for instance, is necessary for assessing its suitability and quality for specific product. The fibro vascular proportion, vascular bundle types and diameters of vessels influence bamboo behaviour (Liese 1987; 1998, 2000). Liese (1985) reports that anatomical properties of bamboo culm vary according to species, the condition of growth, age of the bamboo and part of the culm. The percentage

distribution orientation of cell such as parenchyma, fibres, and vascular bundles also vary considerably along and across the bamboo culm (Espiloy1985; Liese 1985; Soeprayitno et al. 1985).The bamboo culm comprises about 50% parenchyma, 40% fibres and 10% vessels and sieve tubes (Liese 1987).In an earlier work on *Bambusa vulgaris* Schrad. Ex. Wendl from Ghana the anatomical results revealed similar values proportions of different tissues (Assouan 2002).Little information, however, exist on the ultra microstructure of our native bamboo species and extent of variation in different ecological zones in Ghana to better understand their behaviour during processing and when in service. The relatively low durability of bamboo species have been attributed to low extractive content but qualitative differences in the content of extractive will explain the difference among species around the world. Without these studies, the observed difficulties and the behaviour of our bamboo in service can only be based on speculation rather than empirical evidences. Furthermore, investigating the bamboo chemical composition and phytochemical will offer significant basic data and information on the properties and durability of our bamboo species which have been cited as impeding wider acceptance in Ghana. The use of bamboo in papermaking and architecture in different areas in Ghana will be harnessed. The knowledge of these properties will enhance the mode of preservation treatment and industrial processing of *Bambusa vulgaris*. This is what the paper seeks to elucidate in three bamboo growing areas in southern Ghana.

Material and Methods

Anatomical Studies

Sound internodes of matured bamboo of above four years were harvested from Kumasi (Ashanti Region), Akim Oda (Eastern Region) and Assin Fosu in the Central Region of Ghana between August 20 and 30th, 2006. The samples were placed under shades at the Wood Science Workshop, KNUST and were transported to Open Key Laboratory at International **C**entre for Bamboo and Rattan (ICBR),Beijing, China for the anatomical studies . The 4th internodes from the ground level and the 12th internodes of *Bambusa vulgaris* were chosen for the anatomical studies. Three softened samples were sectioned from the middle part of selected internodes and the Leica Sliding Microtome – M2000R model was used to prepare transverse and longitudinal sections of the softened blocks. Sections were then observed using XL 30 ESEM ^{TM} FEG Environmental Scanning Electron Miscroscope in the ESEM laboratory. Vascular bundle types, the metaxylem vessels, parenchyma and its inclusions; and the arrangement of pitting among the two varieties were observed. The results were presented in Micrographs and Tables accordingly. The thickness of the fibre bundle at protoxylem side of the vascular bundle of Ghanaian Bamboo was also measured over the culm wall of base 4th internodes.

Phytochemical Screening

Some internodes were selected; air dried and was cut into small strips for analysis. The strips were small enough to be placed in a Wiley Mill at Forest Research Institute of Ghana. The material was sieved manually to pass through a No. 40 mesh sieve (425-µm) yet retained on a No. 60 mesh sieve (250µm). The resulting material was placed in glass jars labeled with appropriate code for chemical analysis and acetone and ethanol extraction were undertaken using the soxhlet apparatus. After the ethanol extraction, some portion of bamboo extracts take

Chemistry laboratory, Department of chemistry, Kwame Nkrumah university of Science and Technology for the phytochemical screening.

Results and Discussion

The observation of bamboo samples from the three sites revealed basically two main types of vascular bundles: the classical Types III and IV as reported by Liese and Grosser (2000). These are shown in Fig 1 and 2. This type of bundles is characteristic of sympodial bamboo like *Bambusa vulgaris.* The type iii, however occur occurring mostly on the 12th internodes whilst the type iv were found both in the 4th and 12th internodes in the three sites studied. This supports research work on the classification of vascular bundle type. The identified vascular bundle in the sample are cited to have a good condition for better pulp yield than in other monopodial bamboo species though depending on the age of the samples it might be more difficult to process than the mono types. The implication therefore during processing is that in machining of *Bambusa vulgaris* from natural stands in Ghana difficulty might be encountered in comparison to bamboo species of the monopodial type like *Phyllostachys pubescence* (Moso bamboo) since more polyllamenate fibre walls will be encountered. No expanded topology form of the vascular bundle types was recorded in all the samples observed. The fiber strands were mainly the heart- blocked shaped and arc-like shape described earlier researches (Liese and Grosser 2000.) Fig 1; Fig 2

Parenchyma Cells and Inclusion

A comparison of the shape of the parenchyma cells of moso bamboo seems more rectangular than those observed in the *Bambusa vulgaris* samples as evident in Fig 3 and 4.The implication from its processing cannot be cannot be predicted immediately rather than a significant genetic variation in monopodial and sympodial bamboo types. In figure 5and 6 most of the parenchyma cells were either partially filled or fully filled with starch granules. Many researchers who investigated culms of up to three years found no starch during the first year of growth but many starch granules in older culms. Liese (1997) reported the abundance of starch granules is characteristic of older bamboo culms two years and above. The absence or presence of starch granules in raw bamboo culms influences its susceptibility to termites and insect attack because the starch is a source of food for the insects. (*Fig 4;* Fig 5; Fig 6)

The season of harvesting has also been reported to have a great impact on the abundance of starch in bamboo culms at different height the need to plan for its harvesting is important to sustainable harvest and utilization. Most of the bamboo are in natural stands in Ghana and are mostly found in swampy areas, such bamboo resources may not readily accessible in the rainy season.

Metaxylem of Bambusa vulgaris

Measurement of the vessels diameter from the three sites gave values ranging from 128 to 196µm with minimum value recorded in the outer culm of the 12th internode of *Bambusa vulgaris* from Assin Fosu whilst the highest was from the base (4th internode)of culms from Assin Fosu. On an average, the conducting system, including the phloem, account for about 8% of the total culm and this appears rather small when compared with

the lumen area of softwood tracheids (60-70%), diffuse porous hardwood vessels (20-30%), ring porous hardwoods (15- 30%) and rattan metaxylem (15-20%) (Liese 1994). The variation in the vessel diameter could be responsible for differential conduction of fluid in culm wall.In related work from different zones of the world, varied results for these values were obtained. Espiloy (1987) obtained an average vessel diameter of 165 µm for *Bambusa. blumeana* and 220µm for *Gigantochloa levis* (values at the base were slightly higher). Wu and Hsieh (1991) reported a diameter decrease for *Dendrocalamus latiflorus* from the 6th internode towards the top, but a slight increase in the case of *Phyllostachys edulis*. Kumar and Dobriyal (1992) measured for *Dendrocalamus. strictus* a vessel size of 60 µm at the outer part, 85 µm at the middle and 100 µm at the inner part. Abd. Latif (1995) registered mean values of 147-187 µm for *Bambusa. vulgaris* and 114-137 µm for *G. scortechinii*, both with smaller diameters at the top. Such information is required for application in seasoning and preservative treatment.

The figures 8 is described as the structures of interest which might be a peculiar inclusion of parenchyma cells near the vascular bundles of Ghana bamboo especially *Bambusa vulgaris* . The position of the figure near to thick fibres and the presence of starch granules in other cells near make it difficult to identify. The structure was observed at the 4th internode from Assin Fosu from the Central Region.

Phytochemical Analysis

The phytochemical properties of woody plants including woody bamboo consist of the secondary metabolites-alkaloids, flavonoids, anthraquinones which impart different support to the plant. Results from the work revealed the absence of alkaloids in the sample is a probable reason for the rapid decay of bamboo species in service in Ghana especially when used in the raw state. Alkaloids are generally formed as metabolic by-products; however, their characteristic bitter taste and accompanying toxicity generally help to repel insects and herbivores. The absence of alkaloids coupled with large amount of starch granules in the parenchyma cells as observed in earlier work (Tekpetey 2006) may be the reason for rapid deterioration of bamboo culms when used in service in an untreated state**.** Low level of durability of bamboo culms has reported the abundance of starch and low extractive content as contributing factors (Liese1998). Additionally, the absence of alkaloids in the sample extracts explains better the low durability of Bambusa vulgaris which may be true for many other bamboo species. Relatively, low density species, high moisture content species with low extractive content are susceptible to insect attacks and hence rapid deterioration especially in raining seasons. The need for chemical preservation of bamboo culms may be preferable option to address the low durability rather than a method of reducing the starch content of bamboo culms before their use in service of matured culms. The purgative action of some bamboo species could also be attributed to the presence of anthraquinone in the extracts.

Conclusion and Recommendation

This work has established that there are slight structural variation in fibre bundles and vessel dimensions of *Bambusa vulgaris* from different zones in Ghana .It has also enhanced the knowledge on its treat ability, biological resistance, processing and utilization bamboo in Ghana . The phytochemical screening of the extracts of *Bambusa vulgaris* indicated the absence of anthroquinone glycosides, alkaloids but the presence of flavonoids. It is recommended that further quantitative analysis of phytochemicals of major bamboo species in

different part of the world should be collaboratively undertaken for both indigenous and exotic species. Further collaboration is needed to identify 'new structures' and also to understand the nature of bamboo species in most developing countries and it niche for diversified utilization.

Acknowledgement

The financial support from the International Tropical Timber Organization (ITTO) for the study is highly appreciated. The authors are grateful for the technical and financial support of Chinese State Forestry Administration through International Centre for Bamboo and Rattan, Beijing, China to undertake the anatomical and thermal studies under the Key Open Laboratory Research Scholarship. The authors appreciate the suggestions of a renowned anatomist during the draft stage of this article.

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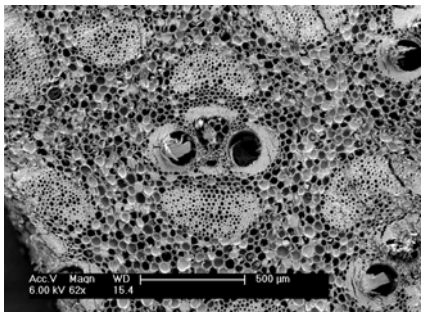


Fig 1

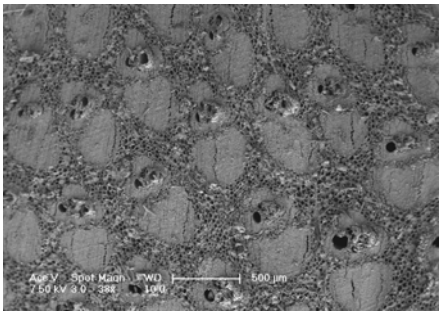


Fig 2

Fig 1- Vascular bundles with two isolated fibre bundles of *Bambusa* v*ulgaris* from Akim Oda, Ghana

Fig 2- Vascular bundle with one isolated fibre- bundle at the Protoxylem Assin Fosu, Ghana

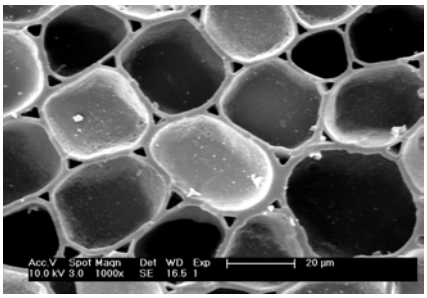


Fig 3- Shape of Parencyma cells of Moso bamboo SOURCE(ICBR,2006)

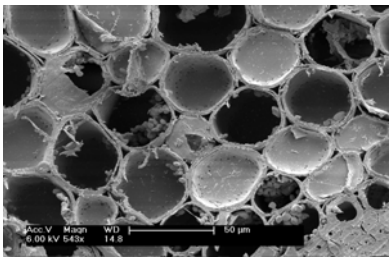


Fig 4-Parenchyma cell structure in Bambusa vulgaris from Ghana

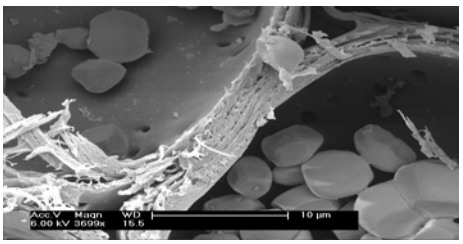
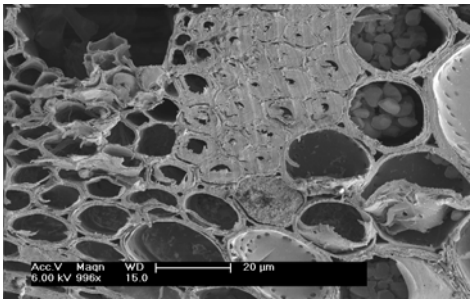


Fig 5- Starch granules in *Bambusa Vulgaris* from Akim Oda, Ghana.



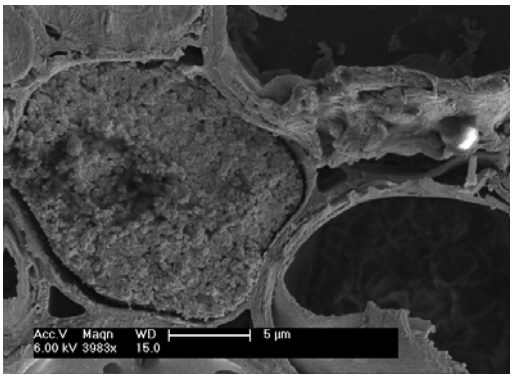


Fig 6 and 7- strange inclusion of parenchyma cells of Bambusa vulgaris from Assin Fosu, Ghana

Performance of *Dendrocalamus strictus* Treated with Combined Fire Retardant and Preservative Systems against Fire, Fungus and Termites

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Abstract

Bamboo is an economic substitute of wood. It is a major building material in several parts of India. Its wider acceptance however is often hindered because of its susceptibility to microbes and insects. Other factor which causes heavy losses of bamboo products is fire. The present work deals with the treatment of *Dendrocalamus strictus* with six fire retardant and preservative compositions. Different combinations of fire retardant and new eco-friendly preservative ZiBOC were tested in the above species for protection against fire, fungus and termites. Bamboo culms treated with six compositions at 15% concentration, were subjected to three tests, viz: flame penetration, flammability and rate of burning as per Indian Standard. Compositions (1) Ammonium sulphate +Ammonium phosphate + ZiBOC,(2) Ammonium sulphate+ ZiBOC , (3) Ammonium phosphate+ ZiBOC ,(4) Magnesium phosulphate+ Magnesium pyrophosphate+ ZiBOC , (5)Magnesium phosphate+ ZiBOC and (6) Magnesium pyrophosphate+ ZiBOC at 15 % were taken for the study. Results revealed that 7.4 kgm^{-3} was the lowest retention achieved by 6 no. composition while 19.90 kgm^{-3} was the highest retention achieved by no.1 composition. Treatment cost for Composition no..1 was comparatively higher as compared to other treatments because of high retention and solubility of chemicals in acid. Whereas, lower cost was observed by Composition no..2 as the chemicals were water soluble. All compositions performed as per standard except Composition no..3 in flame penetration test. Statistical analysis revealed that Composition no.. 4 performed best followed by no.2 and 1.Test against decaying fungus in laboratory and termites in mounds respectively exhibits significant protection by all compositions as compared to control.

Introduction

Bamboo is an important construction material, for simple and modern engineered structures. Bamboo houses of different kinds provide homes for a billion people, not only in rural areas, where it is considered to be moderate priced or even cheap, replaceable material, but also in urban environments. Its wider use as a substitute or alternative for wood is supported by the increasing scarcity and expense of timber in several bamboo-producing countries. Its wider acceptance however is often hindered due to its susceptibility to biological degradation and fire. There are million of bamboo thatched huts spread all over the country which becomes dry in summer, and in which most of the uneducated and poor population lives. In spite of this, although, no actual statistic is available. It has been estimated that less than 0.1 percent of these huts are destroyed by fire before they

disintegrate due to rot or other causes. If construction material like thatch, bamboo, wood etc. is given a preservative cum fire retardant treatment by soaking, it is probable that the loss of bamboo houses would be reduced to a very small fraction of the present number.

A tropical environment with high humidity and temperatures accelerates the natural bio-cycle. These hazards have their impact also in restricting building regulations. Few regions in India are most fire-prone and despite rigorous precaution a considerable loss of life and property occurs every year. Bamboo and wood are extensively used for construction purposes, both are cellulosic material which catches fire easily. A wide range of protective procedures, including chemical preservation methods are known, similar to those for timber under tropical conditions. But they are more seldom than regularly applied due to lack of knowledge about possibilities of bamboo protection, lack of adequate treatment facilities and chemical preservatives, uncertainty about the economics and lack of demand for treated bamboo components etc. Protection of this versatile material, especially in areas where longer service life is desired, can result in immense social and economical benefits. It would increase bamboo availability, facilitate rural employment potential, and save maintenance costs of constructions, which would occur due to replacement of degraded bamboo components.

During the last decade extensive work has been done to develop fire retardant composition of wood and panel products. Various chemicals like ammonium phosphate (mono and di-), ammonium sulphate, boron compounds aluminium sulphate and combinations of these have been recommended (Goldstein 1973; Dev and Kumar 1982). Performance of fire retardant cum preservative composition is also evaluated on plywood (Samani et al. 2007). Some conventional fire retardant, which are mainly water borne inorganic salts, provide a certain degree of decay resistance. These chemicals, if not permanently fixed, are not suitable for exterior purposes. A simple one step process that gives both resistance to fire and microbial decay is rarely known. There is, however, not much data on the performance of such treatments on bamboos is available.

Earlier a comparative study of fire retardant tests for timber and plywood treated with mono-ammonium phosphate at equivalent chemical loading was carried out and the behavior of plywood was found better than the solid wood (Dev et al. 1987). Different workers have worked on different compositions of fire retardants and antiseptic formulations. Most of the studies revealed either higher concentration i.e. 15 % (Purushotham et. al. 1963) of compositions or higher retention in wood i.e. 48 kg/m^3 is required (Dev et. al. 1992). Lower retentions of preservatives cum fire retardant combinations affect the treatment cost, which will be considerably lower at lower retentions.

This study evaluated various fire retardant mixture and preservative ZiBOC that could be used as a combined treatment for wood products. Related investigations on improving the decay resistance alone is already reported (Tripathi et al 2005). In the present study ZiBOC a new safe preservative developed at FRI Dehardun , India is tested along with other chemicals known to impart fire resistance. Because of the presence of borax, zinc and copper salt in ZiBOC in sufficient amounts and the different fire retardant compositions, it is expected that it will provide protection against various degrading agencies.

Material and methods

Green mature bamboo culms (3 nos.) of *Dendrocalamus strictus* of 3-5 years of age were collected from bambusetum of Forest Research Institute Dehradun , India . This study consisted of two parts. The first part consisted of selecting six compatible combinations and testing fire resistance capability in bamboo through various methods (IS: 5509: 2000). The second part of the study involved treatment of bamboo and its evaluation for decay resistance against fungus; brown rot (*Trametes versicolor*) and white rot (*Oligoporus placentus*) in laboratory and termites in mounds (*Odentotermes obesus* Rambur) in field.

Materials:Preparation of Preservative:

Zinc chloride ($ZnCl_2$), Borax ($Na_2B_4O_7$ .10 H_2O) and copper sulphate ($CuSO_4$ .5 H_2O) (AR grade) Merck limited, India taken in a particular proportions made water soluble with the help of co-solvent (Tripathi 2008).

Chemicals: Chemicals used for fire retardants were of commercial grade. The different chemical compositions (treatments) used are shown in table 1.Compositions ; (1) Ammonium sulphate +Ammonium phosphate + ZiBOC,(2) Ammonium sulphate+ ZiBOC , (3) Ammonium phosphate+ ZiBOC ,(4) Magnesium phosphate + Magnesium pyrophosphate+ ZiBOC , (5) Magnesium phosphate+ ZiBOC and(6) Magnesium pyrophosphate+ ZiBOC at 15 % were taken for the study .Composition 2 is water soluble whereas , all other compositions required addition of sulphuric acid for solubility, where sulphuric acid acted as co-solvent and resulted a homogenous transparent solution. The amount of acid mixed is mentioned against each composition (Table-1).

Procedures:

Treatment of bamboo: As bamboo has tapering ends, culm upto the length of uniform diameter was selected for sample preparation. Round Bamboo samples of one feet (30 cm) were cut and further four splits were made from each piece. Twenty four splits were taken for treatment with each composition. Six splits were taken as control. The samples were than treated with six different formulations of fire retardant chemicals and preservatives at 15 % concentrations by diffusion method (Kumar et. al .1994). Specimens of 1 feet length left in S.S. tank for 7 days and removed after that, excess treating solution was blotted from the specimens. After treatment the retentions of the chemicals were calculated.

Fire resistance test:

The samples after treatments were kept in humidity chamber to obtain moisture content 19-22 %. The samples were then tested for performance against fire by flame penetration test, inflammability test and rate of burning test as per IS 5509 (2000) and 1734 part-III (1972), where specifications mentioned are for fire retardant plywood. Treated bamboo splits were tested as per the standard except thickness and width, which was taken as such. Rest of the test procedure was followed as such. Data was subjected to statistical analysis using SPSS. ANOVA for different test was calculated and represented in table 2 and 5 .Critical difference (CD) was calculated through scheffe's test to find out which treatment differs significantly.

Flame penetration test :

125 mm long bamboo splits were taken, thickness and width of the split bamboos were taken as such without any alteration. The test specimens were taken and held horizontally 50 mm above the nozzle of a blowpipe flame. The test specimen was rotated in a horizontal plane at 75 rpm in such a way that the center of the flame forms a circle of 25 mm diameter on the specimen. The time taken for the flame to penetrate the thickness of the bamboo was recorded and calculated for per mm thickness of bamboo and shown in table 3. The time taken for the flame to penetrate the thickness of the bamboo was recorded. The time (T) taken in minutes is calculated as per the following formula:

$$T = \frac{15t}{6}$$ where t is the thickness of bamboo (mm).

Rate of Burning Test :

The test specimens of size 100 X 12.5 mm of full thickness of bamboo were prepared and suspended in a fire tube and adjusted at a height of 30 mm from the flame of the burner. A standard LPG gas flame was used to ignite the test specimens. Time taken to loose weight from 30 to 70 % was recorded.

Flammability test :

The test specimens of size 125 mm in length and of full width and thickness of bamboo were taken and held 15 mm apart. One specimen was held 40 mm higher than the other. An ordinary burner having 3 mm bore is fixed horizontally so that the flame touches the lower end of the inner face of the lower sample. The axis of burner is centrally disposed 22 mm above the lower edge of the lower specimen, the end of the burner being 12mm away from the face of the specimen. LPG gas was fed to the burner at the pressure of 100 mm of water, resulting in a blue flame which, when unobstructed is 100 mm long. The time taken for the higher specimen to be ignited after the ignition of the lower specimen was recorded.

Fungicidal efficacy:

The bamboo blocks 1.9 (L) × 1.9 (W) x and full thickness (T) cm^3 were prepared from *Dendrocalamus strictus* splits conditioned to a constant weight and treated with 15 % concentrations of the fire retardant compositions by dip diffusion process so as to attain maximum penetration and retention. For each composition six replicates were used. Soil block bioassay was conducted as per IS: 4873 (2008) against *Oligoporus placentus* (brown rot) and *Trametes versicolor* (white rot). After a time period of 14 weeks the blocks were removed, conditioned as done previously and the percent weight loss was calculated, as a measure of decay. Untreated samples served as control.

Termicidal efficacy:

Untreated control and treated specimens with dimensions 10 (L) x 2.5 (W) x full thickness (T) cm^3 were taken for the study. Termite resistance test was conducted in termite mound and methodology was followed as reported by Shukla (1977). The test was conducted to evaluate the natural termite resistance of bamboo as well

as efficacy of compositions in bamboo. This method was designed to get accelerated data while, by creating conditions near to nature. 12 replicates were taken for each composition and treatment was done by dip diffusion process for one week. Samples were removed and shade dried. The treated and untreated samples of bamboo were arranged randomly and then neatly woven with the help of wire in the form of a garland. The specimens were exposed to *Odentotermes obesus* Rambur in active termite mounds, in an un-weathered and unleached condition consecutively for two year. Samples were installed in the month of May of 1st year and removed in November of the same year, results were recorded and the specimens were installed again in May in the 2nd year and removed in November as done earlier, so as to have exposure for two successive termite seasons. Specimens were cleaned off mud and debris and evaluated visually for damage (IS: 4873 1993).

Results and Discussions

Table-1 shows 6 composition of fire retardant and preservative in different ratios. Cost of the preservative shows that Composition no.. 2 is the lowest in cost while Composition no.. 1 and 4 are comparatively higher. Minimum retention i.e. 7.4 kg/m^3 was achieved by Composition no.. 6 whereas high retention i.e. 17.90 and 15.90 was achieved Composition no..1 and 4 respectively.

Fire resistance test: Six combinations of fire retardant and preservative were evaluated for fire performance using different tests. The mean weight loss in rate of burning test for each combination, number of replicates evaluated in each group and ANOVA was calculated and shown Table- 2&3. Statistical analysis shows significant ($p<0.05$) difference between treatments and control which lie in different subsets. Table-3 shows that no statistical difference could be found among treatments. Therefore, no particular treatment stood out as better than the rest. Besides that time of glow and maximum temperature attained in treated and control was also noted. The maximum temperature rise in control sets during testing was upto 560 ^{0}C while temp. Observed in sets of treated samples was remarkably reduced.

Taking a similar approach in examining the fire performance of each combination, treated and untreated replicates, statistical analysis for flame penetration test and homogenous subsets are shown in Table- 5 & 6. All treatments were significantly effective ($P<0.05$) as compared to control. Subsets of compositions show that replicates of control failed badly while comp.no.3 performed slightly better than control. While rest of the compositions performed excellently. Table-6 shows that comparison 4 stood out best followed by 2 and 1. Inflammability test revealed that replicates treated by six combinations took more than minimum time prescribed i.e. 2.5 min. /mm thickness (I.S: 5509 ; 2000) for inflammability. Control replicates were ignited in considerably short time. Table 7 shows performance of treated bamboo samples with different fire retardants in inflammability test. Results show that temperature observed in the samples treated by all compositions was remarkably low.

Decay resistance:

Fungicidal efficacy: The blocks of treated and untreated bamboo samples were examined for fungicidal decay. There was no visual evidence of decay in any treated block. 23.7% and 38.9% weight loss was observed in control replicates against *Oligoporus placentus* and *Trametes versicolor* respectively. The results of the decay

test of treated blocks (Table-8) show that in general protection against both the fungus was imparted by all the compositions. The protection ranged between 34-76% against *Oligoporus placentus* whereas, higher protection i.e. 55-82 % was achieved against *Trametes versicolor*. On comparing effectiveness in terms of percent protection composition 3 and 1 were least effective whereas composition 4 had imparted maximum protection against both the fungus. Almost comparable results were observed by Composition no.. 2 and 4 and .5 and 6. In view of the importance of decay tests in assessing the merits of a wood preservative performance of composition tested no. 2 and 4 found most promising. Samples treated by all compositions revealed excellent protection against termite except no. 3 where a slight attack of termite (Visual rating sw) on samples was observed. While control samples were badly destroyed DW (visual rating 5.0) (Shukla 1977).

In this study the fire resistances showed that all the composition were fairly similar except no.3 which resulted marginally status as compared to recommended ones in flame penetration test. Decay test against termite and fungus exhibited best performance by Composition no..2 and 4. Comparing cost of treatment and chemical, Composition no.. 2 was found cheapest. and effective even at very low i.e. 11.50 kg/m^3 retention as compared to other known fire retardant chemicals (Dev and Kumar 1982) Therefore, it can be recommended for testing on pilot scale.

Table 1: Fire retardant compositions used for treatment of *Dendrocalamus strictus*

Composition no..	Compositions (treatments)	Ratio	Acid (H_2SO_4) added (ml) for Solubility in 80 liter of water	Cost/Kg (Rs.)	Avg. Retention (kg/m^3)	Treatment cost/m^3 (Rs.)
1	Ammonium sulphate+ Ammonium phosphate+Ziboc	5:5:5	1150	114	17.90	2028
2	Ammoniumsulphate+ Ziboc	10:5	Water soluble	60	11.50	690
3	Ammoniumphosphate +Ziboc	10:5	800	126	9.80	1242
4	Magnesiumphosphate+ Magnesiumpyrophosphate+Ziboc	5:5:5	500	114	15.90	1801
5	Magnesiumphosphate+ Ziboc	10:5	500	126	14.6	1849
6	Magnesium pyrophosphate+ Ziboc	10:5	500	94	7.4	688

Table 2: ANOVA for rate of burning test

Source	df	Mean Square	F	Sig.
Composition	6	82.776	59.105	.000
Error	35	1.400		

Table 3 : Mean weight loss in rate of burning test arranged in homogeneous subsets

COMPOSITION	Subset		Period of flaming(Sec.)	Maximum temp. at the top of tube (^{0}C)	After glow time (min)
	1	2	>0.2		
6.00	52.0428		>0.2	130	3
4.00	52.3179		>0.2	330	3
2.00	52.5782		>0.2	135	1
3.00	52.6584		>0.2	230	4
1.00	53.7541		>0.2	345	2
5.00	54.5167		>0.2	165	2
Control		62.5317	>0.2	560	4

Table 4: Performance of different compositions in rate of burning test

Composition	Average weight of sample(gm	Average wt. after 30%weight loss	Expected w. after 20 min.) / Average weight after70	Average actual wt. found after 20 minutes	Remarks
1	18.13	10.57	5.44	6.33	Pass
2	10.1	7.07	3.03	3.73	Pass
3	9.9	6.93	2.97	3.64	Pass
4	12.76	8.93	3.83	4.76	Pass
5	12.76	8.93	3.83	4.3	Pass
6	13.73	9.61	4.12	5.2	Pass
Control	15.73	11.01	4.72	3.35	fail

Table 5: ANOVA for flame penetration test

Source	df	Mean Square	F	Sig.
Compositions	6	7.638	44.453	.000
Error	35	.172		

Table 6 : Average time taken in flame penetration test arranged in homogeneous subsets

Compositions .no.	Avg. thickness of sample (cm)	Time required (min.) as per mm. thickness	Average time taken by replicates (min/mm thickness)				
			1	2	3	4	5
Control	1.0	2.5	0.83 (fail)				
6	0.7			2.15 (marginal)			
3.	0.86			2.59 (pass)			
5	0.65			2.50 (pass)	2.50 (pass)		
1	0.7				3.20 (pass)	3.20 (pass)	
2	1.05					3.70 (pass)	3.70 (pass)
4	0.8						4.21 (pass)

Table 7: Inflammability test of *Dendrocalamus strictus*

Composition no.	Average thickness (cm)	Average time taken (min.)	Remarks
1	0.96	30 ↑	Pass
2	0.93	30 ↑	Pass
3	0.8	30 ↑	Pass
4	0.8	30 ↑	Pass
5	0.9	30 ↑	Pass
6	0.9	30 ↑	Pass
Control	0.8	13.4 ↑	Fail

Table 8: Efficacy of different compositions against fungus in laboratory and termites in field.

Bioassay		Average weight loss (%) caused by white and brown rot fungus						
		Com.1	Com.2	Com.3	Com.4	Com.5	Com.6	Control
Fungus	*Oligoporus placentus*	14.8 (37%)*	5.6 (76%)*	5.1 (34%)*	15.6 (78%)*	7.3 (69%)*	7.3 (69%)*	23.7
	Trametes versicolor	16.3 (58.09)	7.1 (82.2)	17.3 (55.5)	6.9 (81.2)	13.0 (66.5)	14.1 (63.7)	38.9
	Deterioration rating caused by termites							
Termite Mound	*Odentotermes obesus*	N	N	sw	N	N	N	Dw

*Values in parenthesis are % protection as compared to control.

N = Normal (0 score) ; Dw : Destroyed by termites (5 score)

Sw : slight termite attack (2.5)

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Properties Evaluation of Dendrocalamus giganteus Treated by Heat

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Abstract

Despite a great number of applications for bamboo, two drawbacks are concerned to this raw-material. The first one is a short life span of most of the species, due to its high starch content at the parenchyma cells. The second one is an inadequate behavior when bamboo is exposed to climatic changes. In searching to minimize these drawbacks, bamboo strips from *Dendrocalamus giganteus* Munro culms were submitted to several temperatures: 140, 180, 220, 260 and 300 °C. Physical and mechanical properties of the specimens were evaluated, aiming to detect ideal conditions for apply thermal treatment, and at same time did not reducing the original bamboo characteristics. Results showed that bamboo strips properties were very sensible to temperature effect. Higher temperature provoked damages on bamboo structure, denoted by decreasing of the density and an important reduction on ultrasonic pulse velocity. Modulus of rupture was more sensible to detect temperature effects on thermal treated bamboo (TTB).

Keywords: bamboo, Dendrocalamus giganteus, thermal treatment, NDE

Introduction

Due to bamboo decay by insects and fungi, several treatment process were developed aiming to obtain a more adequate raw-material for several purposes, as building constructions, handicrafts, furniture, particleboards and laminates. In some of this industrial process, heat is applied (mainly for bamboos belonging to *Phyllostachys* genus).

If specific conditions are employed, heat can change lignocellulosic structure of bamboo, provoking then irreversible transformations as was reported by Brito (1992) for wood.

Bamboo natural dry is an example of a type of thermal treatment. However, in these conditions the effects produced on bamboo are much less aggressive when compared to the drastic condition that occurs in the case of a thermal treatment. In simple words, this is similar to a coffee toasted production. Chemical substances changes occur denoted by color, taste and flavor modifications of the coffee seeds, when compared to the original raw-material.

Thermal treatment is also a simple way to improve dimensional stability of the wood (Brito et al. 2006). If optimal conditions (temperature range and time of heating) are employed, thermal treated bamboo (TTB) can performs better than natural ones, eliminating chemical treatments which are normally hazardous to the environment.

Thermal treatment is like a pre-carbonization type in the range of 220 to 300 ºC. In these conditions, hemicellulose is modified, by removing water, acetic acid, phenols and others compounds of small calorific power (Luengo et al. 2008). One intermediate material between vegetal biomass and charcoal is produced at the end of this process.

The main objective of the thermal treatment is to concentrate biomass energy in a product after a short time, employing small heating rate and moderate temperatures. Physical and chemical properties of the vegetal biomass change according to temperature and wood specie (Felix et al. 2003; Brito et al. 2008).

One of the most important steps of the thermal treatment is the range of selected temperature. For *Eucalyptus grandis* wood, temperatures of 30 (control), 120, 140, 160, 180 and 200 °C were tested by Pessoa et al. (2006. After thermal treatments, specimens were submitted to decay. It was observed a favorable effect of the higher temperature on the death of the xylophage organisms.

Because its high content of sugars, carbohydrates, resins and starch, bamboo decayed by insects, bacteria and fungi. Among these organisms, bamboo borer (*Dinoderus minutus* Fabricius) provokes considerable weight loss, mainly for tropical bamboos. The intensity of the attack by borer and the magnitude of the weight loss depend on bamboo specie, age of the culms, season and treatment type applied to the bamboo culms (Hidalgo-Lopez 2003).

Like others natural materials, bamboo properties show great variability, mainly due to the specific condition of its growing. So, to evaluate bamboo properties it is necessary at apply tests to several specimens. Non destructive tests (NDT), mainly by means a ultrasound, is an alternative to the mechanical classic tests, because the ultrasonic pulse velocity (UPV) across the specimen probably can detect changes in its structures (by high temperature effect, for example), in a fast way (Calil Jr et al. 2004).

The effect of the thermal treatment on wood composite was evaluated by stress wave by Del Menezzi et al. (2007), denoting the accuracy of this method to estimate physical and mechanical properties of the OSB (oriented strand board).

Methodology

Strips preparation for thermal treatments

Seasoned culms (5 years old) from bamboo *Dendrocalamus giganteus* Munro were collected at School of Agricultural Engineering at the Campus of Campinas State University. By means a special device, strips of 30 cm x 2 cm x 1 cm were produced. Strips were dried at indoor conditions until moisture content value ranged 10 to 15%.

Except control, to eliminate moisture content effect on thermal treatment, all of the strips were initially dried at 100 °C and placed in plastic bags. Initially, 110 strips were randomically separated and submitted to thermal treatment at selected temperatures (22 samples by each temperature).

Thermal treatments were conducted at Forestry Science Department Laboratories from College of Agriculture Luiz de Queiroz (ESALQ/USP), in an oven with heat system by electric. Strips were submitted to 140, 180, 220, 260 and 300 °C. To avoid combustion, N_2 was employed for the last three temperatures. Initial temperature was 100 ºC, and a heat rate of 0.1388 ºC/min was adopted, according to Pessoa et al. (2006). Specimens remained during 1 hour in an oven, when target temperature was reached, and a time necessary to reach temperature equilibrium. Strips loss weight was evaluated by comparison of the mass before and after the thermal treatments.

Tests applied to Thermal treated bamboo (TTB)

TTB properties evaluation is necessary to select optimal range temperature aiming to obtain a more adequate product to a specific application, as furniture, for example. Specimens were evaluated according to the adaptation of the Brazilian Standard for wood (NBR 7190/97).

TTB color

Samples color parameters (L - lightness, a - absorbance and b - reflectance) was obtained in a Spectrophotometer CM-260d Minolta.

Density

Density (in gcm^{-3}) was obtained before and after thermal treatments directly from the samples.

Swelling and water absorption

Specimens were obtained after flexure test (5 cm x 2 cm x 1 cm) and soaked in water during 24 h. Central region (fractured ones) of the specimens was rejected. Weight gain and swelling (at three anatomical directions – axial, radial and tangential) after 24 h, were compared with control. A sophisticated research about changes of wood-water system by heat treatment was recently presented by Almeida et al. (2009),

Non destructive test (NDT) by ultrasound

Ultrasonic pulse velocity (UPV) across the specimens was evaluated after and before the thermal treatments applied to the strips. A Steinkamp BP-7 device, with transducers of exponential surface, with a 45 kHz resonance frequency, was employed. UPV was obtained by distance (in mm) divided by time of propagation (in µs).

With density and the VPU of the strips after and before thermal treatments, it was evaluated the dynamic modulus (E_d), by

$$E_d = \rho . V^2 . 10^{-9} \ (GPa)$$

ρ - density (kg/m³);

V – Ultrasonic pulse velocity (m/s).

2.2.5 Flexure

For the modulus of rupture (MOR) in bending, it was randomically selected 10 specimens by each thermal treatment. It was adopted a span of 150 mm in an EMIC device model DL/300 kN and a speed of displacement of 1 mm/min.

Results

TTB at 140 °C (second ones) shows almost the same color of the bamboo reference. Parameters obtained for both temperatures were: lightness 75.16 and 76.35; absorbance 6.24 and 5.27; reflectance 25.74 and 24.66, respectively. Similar behavior was observed for 220 when compared to 260 °C. So, in terms of color analysis, TTB can replace several tropical woods. On the other hand, TTB at 300 °C, the last ones in the figure, show an excessive deformation and a darkness color (as a charcoal) denoting an inadequate temperature for possible TTB applications (Figure 1).

Figure 1 – TTB according to the thermal treatment temperature (air dried – control; 140, 180, 220, 260 and 300 °C (upper).

Weight loss decreases more intensively at 300 °C, in order of 50%, corroborating the severity of this temperature on bamboo structure (Figure 2).

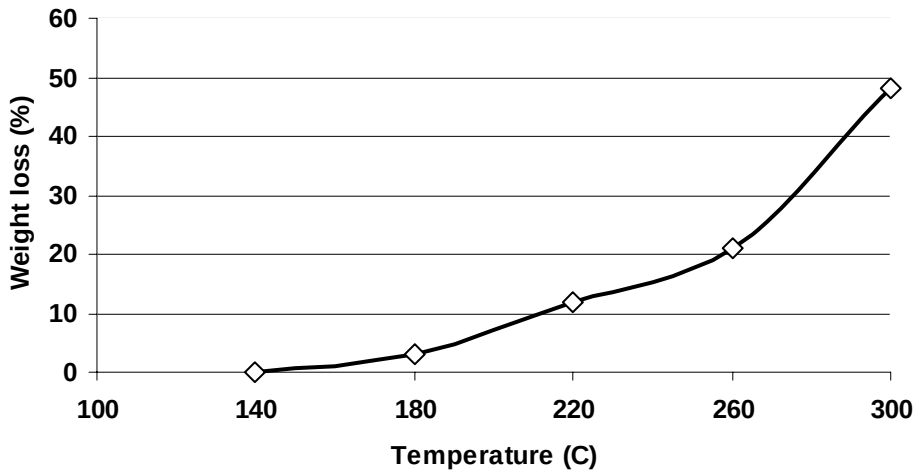

Figure 2 – TTB weight decreasing (%) as a function of the temperature.

For higher temperatures, TTB properties change drastically (Table 1). Density decreases because weight loss is more intensive than volume shrinkage (Figure 3). UPV (Figure 4) and dynamic modulus - E_d (Figure 5) grow-up because moisture content of TTB is reduced. However, for 300 ºC, these parameters are sensitive enough to detect important structural failure on TTB.

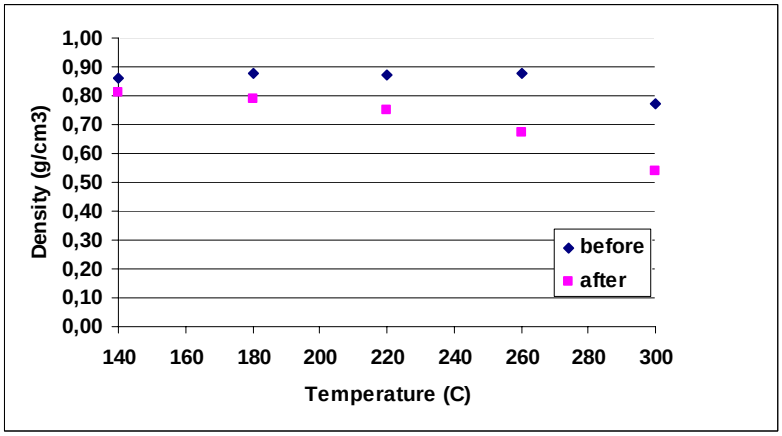

Figure 3 – Density of TTB.

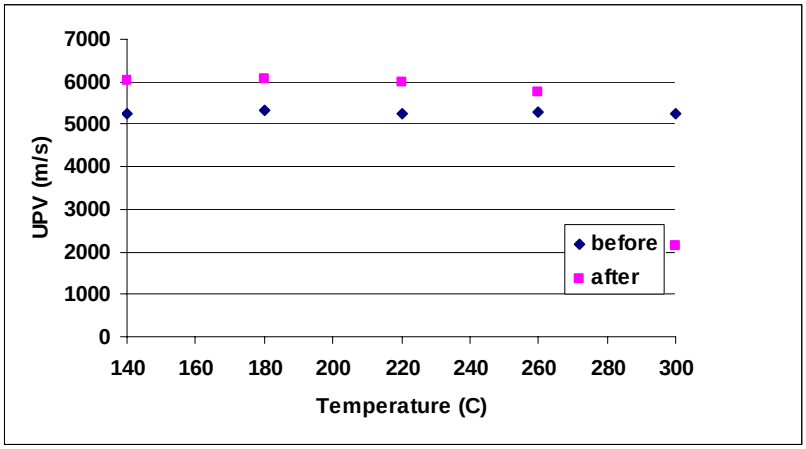

Figure 4 – Ultrasonic pulse velocity (UPV) on TTB.

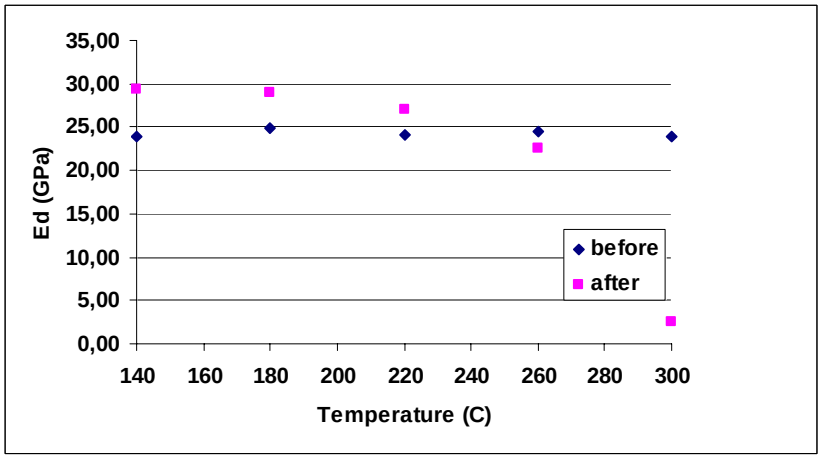

Figure 5 – Dynamic modulus of TTB.

For TTB at 140 and 180 ºC, the comparison of the modulus of rupture (MOR) seems to be more sensible than UPV or E_d to detect micro-cracks in the specimens (Table 1). MOR decreases quickly as temperature of treatment increases (Figure 6).

Table 1 – Properties of TTB.

Temperature	30 ºC	140 ºC	180 ºC	220 ºC	260 ºC	300 ºC
Density ($g.cm^{-3}$)	0.87^{a}	0.81^{ab}	0.79^{bc}	0.75^{c}	0.67^{d}	0.54^{e}
UPV ($m.s^{-1}$)	4354^{d}	6041^{a}	6055^{a}	5973^{b}	5774^{c}	2147^{e}
E_d (GPa)	16.56^{d}	29.42^{a}	28.92^{a}	26.95^{b}	22.47^{c}	2.47^{e}
MOR (MPa)	194.30^{b}	232.21^{a}	157.33^{c}	122.86^{d}	79.07^{e}	11.58^{f}

Different letters at the same line signifies a significant difference at 95% probability level by Tukey's Test.

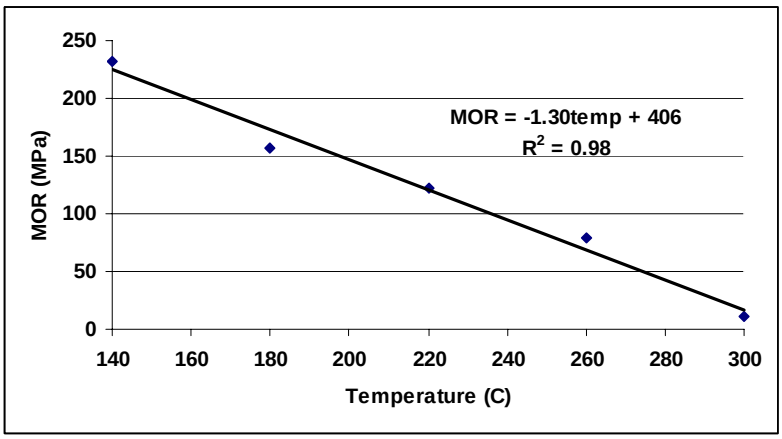

Figure 6 – Modulus of rupture (MOR) of the TTB as a function of temperature.

Swelling after 24 hours was negligible (0.12 to 0.18%) for axial direction, except for treatment at 300 ºC (1.60%), indicating in this case the degradation of the specimens. Swelling at radial direction was higher than tangential direction (this is an opposite behavior when compared to normal wood). For temperature higher than 220 ºC, it can be observed a tendency of the stabilization (2%) of both anatomical direction changes (Figure 7). However, specimens at higher temperature became brittle and it was observed tendency to cracking and torsion (Figure 8). Also, at 180 ºC, it was possible to detect that parenchyma wall and starch were damaged (Figures 9 and 10).

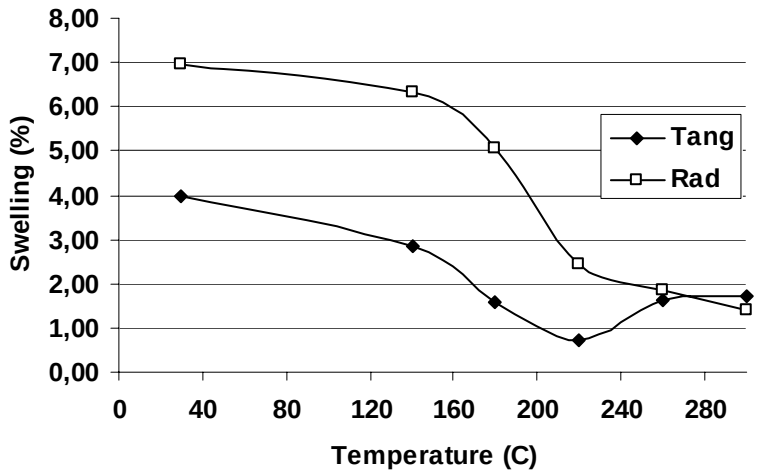

Figure 7 – Swelling according to anatomical direction (radial and tangential).

Figure 8 – Specimens after swelling.

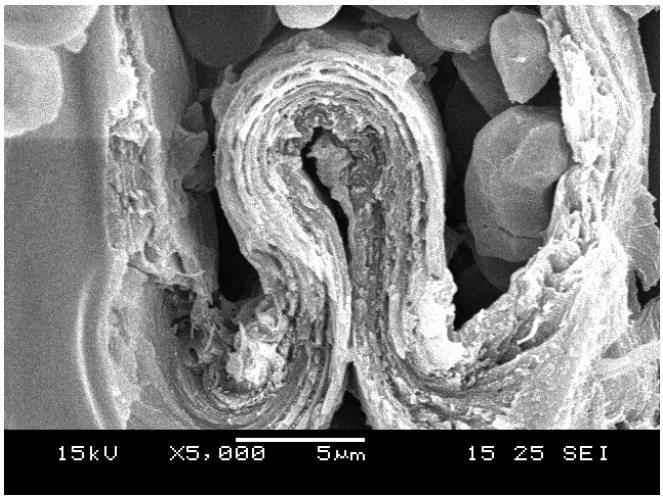

Figure 9 – Parenchyma wall shrinkage.

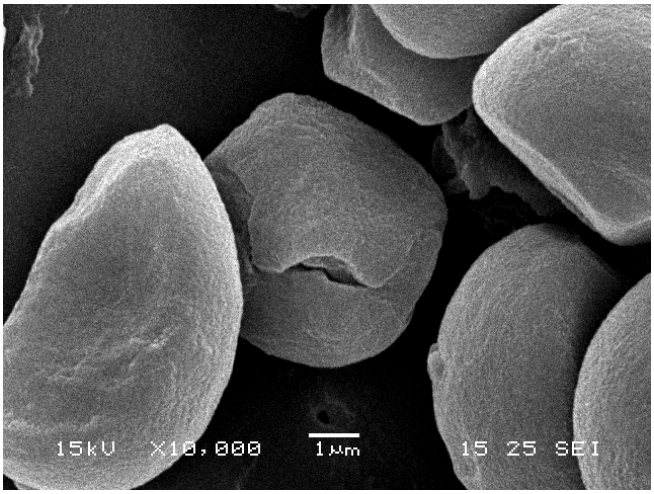

Figure 10 – Cracks on starch surface.

Conclusions

Thermal treated bamboo (TTB) has potential to be applied for several applications depending on temperature range. At 180 ºC, there is an important change on bamboo structure. Temperature greater than 260 ºC provoked considerable damage on bamboo structure and can prevent its special application as furniture. Structural changes at TTB can be performed by non destructive evaluation (NDE), but modulus of rupture was more sensitive to detect internal micro-cracks. Thermal treatments improve the dimensional stability of bamboo when soaked in water.

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Chemical Protection of Bamboos, *Bambusa bambos* and *Dendrocalamus strictus* for their Commercial Utilization

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Abstract

Though highly perishable, utilization of bamboo in various commercial applications is increasing in India. Enhancement of durability of two commercial bamboo species *Bambusa bambos* and *Dendrocalamus strictus* by chemical treatment was studied. To test the efficacy of different new commercial insecticidal chemicals viz Cypermethrin, Bifenthrin , Imidaclorpid, Chlorpyriphos, Fenvalerate, Cypermethrin Carbamate and two neem based biopesticides, dip, spray and pressure treatment were used. The treated bamboo stakes were implanted in the termite testyard as per IS 4833-\1968 and evaluated over a period of 36 months for their efficacy. The studies indicated that Bamboo pressure treated with Bifenthrin was more effective followed by Imidaclorpid, Chlorpyriphos, Fenvalerate and Cypermethrin against termite attack. Carbamates and Neem based Biopesticides were found less effective.

Keywords: Bamboo, durability, chemicals, botanicals, termite, *Bambusa bambos, Dendrocalamus strictus*

Introduction

Bamboo is a very important forest resource that benefits the life of people in a myriad ways including meeting the need for structural uses like posts, pole fencing, scaffoldings, house building etc. Bamboo compares favorably with such timber as 'sal' and 'teak' in strength properties. Bamboo, considered as one of the strongest structural material available, often succumbs to termite attack and biodeterioration during storage. In tropical humid areas, enormous quantities of bamboo culms stored in forest depots, mill yards, etc. deteriorate. The natural durability of bamboo is low and varies from 1 to 36 months, depending on the species and climatic conditions During storage for upto 12 months, about 25 -40% damage of culms has been reported in India (Thapa *et al* 1992) The severity of termite attack and deterioration depends on the duration of storage, bamboo species and environmental and storage conditions. Subterranean termites account for at least 80% damage and drywood termites account for more than 20% (Su and Scheffrahn 1990). Most bamboo used for structural purposes in rural and tribal housing deteriorates within a couple of years and the demand for frequent replacements puts a heavy pressure on the resource.

Chemical treatment using various insecticides and preservatives has been the most widely used method to control post –harvest pests of bamboos. Various pesticides have been recommended and used in different

countries. 5% water soluble copper-chrome-arsenic composition (CCA); 5-6% water solution of copper-potassium dichromate-borax (CCB); 5-6% water solution of boric acid borax –sodium pentachlorophenate in 0.8:1:1 or 1:1:5 ratio (BBP); 2-3% water solution of borax:boric acid in 5:1 ratio and 10% or 20-25% water solution of copper sulphate. These are mostly applied by soaking under normal pressure, cold or heated conditions or under high pressure (Singh and Tewari 1979,1981 a,b;Kumar *et al.* 1985; Thapa *et al.* 1992) Chlorpyriphos and other synthetic pyrethroids have recently become available for use in organic solvent type formulations (Satish kumar 1995) Bamboo stakes pressure treated with Chlorpyriphos, Cypermethrin and Alphacypermethrin were free from damage for more than 28 months. The efficacy of chlorpyriphos against subterranean termites has confirmed the findings in the earlier reports (Remadevi and Raja.Muthukrishnan 1997, 2004). *B.bambos* pressure treated with acephate and permethrin showed no damage upto 12 months of implantation. Thereafter, acephate treated bamboo stakes showed total damage within 48 months after implantation and permethrin treated bamboo stakes showed 60% damage at 54 months after implantation (Remadevi *et al*. 2005) Timber treated with Chlorpyriphos@ 1% and 2% a.i and Fenvalerate @1% and 2% a.i showed 100% protection till 24 months of implementation. (Sundararaj *et al*. 2007)

Enhancement of durability with some economically viable preservatives may help in reducing the frequent replacement of the natural resources. Developing information on enhancement of durability of bamboo helps the end users. Presently, many new bio- pesticides and insecticides are available in the market and an attempt has been made to test the efficiency of some synthetic pesticides and two neem based formulations in protecting two bamboo species *Bambusa bambos* and *Dendrocalamus strictus* against termites.

Materials and Methods

Field evaluation of 8 chemicals and 2 botanicals on two bamboo species viz *Bambusa bambos* and *Dendrocalamus strictus* were done at the termite test yard of the Institute at Nallal Field station as per IS 4833-1968. The field status in the Longitude of 77.38^0E and latitude 12.58^0 N and the soil condition is red, loamy and acidic. The rainfall in this area was 650-750mm and the water retaining capacity was 37.77 at 15 cm depth. The test site was abundant with 4 species of termites. All the experiments were conducted with five replicates. Bamboo culms free of borer and fungus attack were purchased from the market. Bamboo stakes of 30 cm length having a node were taken from the different levels of culms and they were labeled using galvanized sheet labels.

The chemicals evaluated includes two neem based formulations viz 1) Nimbecidine (neem) 0.03%EC and 2) Gromin (neem)EC 1% w/w min. and synthetic insecticides viz 1) Chlorpyriphos (Lethal) 20% TC 2) Chlorpyriphos (Dursban) 20% TC 3) Cypermethrin (Cypercid)10% EC 4) Indoxicarb (Avaunt)14.5% SC 5) Fenvalerate 20%EC (Fencid) 6) Imidachlorpid 17.80%SC (Confidor) 7) Imidaclorpid (Termex) 350EC 8) Bifenthrin 2.5 TC (Biflex).

The treatments were done by spraying, dipping and pressure impregnation. Stakes treated with water served as control and the experiment was done with 5 replicates using the two bamboo species *B. bambos* and *D.strictus* as follows:

Treatment 1(T1): Spray treatment, by spraying and drenching the entire stake with the chemical.

Treatment 2(T2): Dip treatment by submerging the stake in the chemical for 48 hours

Treatment 3(T3): Vacuum for 15 minutes followed for by 50 pounds / sq. inch pressure for 60 minutes.

All the treated and untreated (controls) bamboo test stakes were air dried and thoroughly mixed up and firmly implanted in a randomly block design with half their length buried in the soil 60 cms apart from each other along with a set of untreated bamboo stakes of both the bamboo species and tested as per (IS 4833-1968) at the termite test yard in the Nallal Research field station (Hoskote) of the Institute of Wood Science and Technology Bangalore. Observations of the stakes were made at interval of 6 months. During each observation each stake was pulled out of the soil and visually assessed on the extent of damage and re-implanted for further observations.

Results and Discussion

The termite fauna identified in the test yard were *Odontotermes horni (*Wasmann*), O. obesus* (Rambur), *O. redemanni* (Wasmann) and *Microtermes obesi* (Holmgren). Among these *O. obesus* (Rambur) is considered to be a major wood-destroying termite. The data presented in Table 1&5 shows that the untreated controls are totally damaged over a period of 12 months after implantation.

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Table-1 Percentage of destruction to Bambusa bambos stakes impregnated with different insecticides by subterranean termites and different months after implantation

Chemical	Dosage	Treatment	Mean per cent damage in stakes at different MAI*					
			6M	12M	18M	24M	30M	36M
Nimbecidine (neem) 0.03%EC	1%	T-1	0	10	20	35	40	60
		T-2	0	0	10	10	20	35
		T-3	0	0	0	0	15	25
Gromin EC 1%w/w min.	1%	T-1	0	10	15	25	35	65
		T-2	0	10	25	35	40	50
		T-3	0	0	10	20	30	40
Lethal 20% TC (Chlorpyriphos)	1%	T-1	0	0	0	0	0	10
		T-2	0	0	0	0	0	0
		T-3	0	0	0	0	0	0
Dursban 20%TC(Chlorpyriphos)	1%	T-1	0	0	0	0	10	10
		T-2	0	0	0	0	0	0
		T-3	0	0	0	0	0	0
Cypercid 10% EC (Cypermethrin)	1%	T-1	0	0	0	0	0	10
		T-2	0	0	0	0	0	5
		T-3	0	0	0	0	0	0
Avaunt 14.5% SC (Indoxicarb)	1%	T-1	10	30	40	60	75	80
		T-2	0	0	0	10	10	25
		T-3	0	0	0	0	5	10
Fencid 20%EC (Fenvalerate)	1%	T-1	0	0	0	5	10	15
		T-2	0	0	0	0	5	10
		T-3	0	0	0	0	0	0
Confidor 17.80%SC (Imidachlorpid)	1%	T-1	0	0	0	0	0	0
		T-2	0	0	0	0	0	0
		T-3	0	0	0	0	0	0
Termex 350EC (Imidachlorpid)	1%	T-1	0	0	0	0	0	5
		T-2	0	0	0	0	0	0
		T-3	0	0	0	0	0	0
Biflex 2.5TC (Bifenthrin)	1%	T-1	0	0	0	0	0	0
		T-2	0	0	0	0	0	0
		T-3	0	0	0	0	0	0
Control			40	100	-	-	-	-

MAI – Months after implantation

One way ANOVA showing significant difference between the chemicals used for protection of *Bambusa bambos*.

Table.2: Spray treatment, by spraying and drenching the entire stake with the chemical.

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	48909.09	10	4890.909	21.90702**	9.38E-16	2.007792
Within Groups	12279.17	55	223.2576			
Total	61188.26	65				

Table.3: Dip treatment by submerging the stake in the chemical for 48 hours

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	43144.7	10	4314.47	37.34492**	6.03E-21	2.007792
Within Groups	6354.167	55	115.5303			
Total	49498.86	65				

Table.4: Vacuum for 15 minutes followed for by 50 pounds / sq. inch pressure for 60 minutes

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	43252.27	10	4325.227	47.53789**	1.9E-23	2.007792
Within Groups	5004.167	55	90.98485			
Total	48256.44	65				

** shows significant difference at 0.05 Level of significance.

Table-5 Percentage of destruction to *Dendrocalamus strictus* stakes impregnated with different insecticides by subterranean termites and different months after implantation

Chemical	Dosage	Treatment	Mean per cent damage in stakes at different MAI*					
			6M	12M	18M	24M	30M	36M
Nimbecidine 0.03%EC (Neem)	1%	T-1	0	15	20	35	40	55
		T-2	0	10	10	25	35	45
		T-3	0	0	10	15	25	35
Gromin 1% w/w min. EC	1%	T-1	10	20	30	40	45	50
(Neem)		T-2	0	0	10	25	35	55
		T-3	0	0	0	10	35	45
Lethal 20% TC (Chlorpyriphos)	1%	T-1	0	0	0	0	0	15
		T-2	0	0	0	0	0	0
		T-3	0	0	0	0	0	0
Dursban 20% TC (Chlorpyriphos)	1%	T-1	0	0	0	0	10	15
		T-2	0	0	0	0	0	0
		T-3	0	0	0	0	0	0
Cypercid 10% EC (Cypermethrin)	1%	T-1	0	0	0	0	0	0
		T-2	0	0	0	0	0	0
		T-3	0	0	0	0	0	0
Avaunt 14.5% SC (Indoxicarb)	1%	T-1	0	35	40	45	50	75
		T-2	0	0	0	15	25	35
		T-3	0	0	0	10	10	10
Fencid 20% EC(Fenvalerate)	1%	T-1	0	0	0	25	35	45
		T-2	0	0	10	10	15	25
		T-3	0	0	0	0	0	0
Confidor 17.80%SC (Imidachlorpid)	1%	T-1	0	0	0	0	0	0
		T-2	0	0	0	0	0	0
		T-3	0	0	0	0	0	0
Termex 350EC (Imidachlorpid)	1%	T-1	0	0	0	0	10	15
		T-2	0	0	0	0	0	0
		T-3	0	0	0	0	0	0
Biflex 2.5TC (Bifenthrin)	1%	T-1	0	0	0	0	0	0
		T-2	0	0	0	0	0	0
		T-3	0	0	0	0	0	0
Control			30	100	-	-	-	-

MAI – Months after implantation

One way ANOVA showing significant difference between the chemicals used for protection of *Dendrocalamus strictus*.

Table.6: Spray treatment, by spraying and drenching the entire stake with the chemical.

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	43975.76	10	4397.576	18.82841**	2.2E-14	2.007792
Within Groups	12845.83	55	233.5606			
Total	56821.59	65				

Table.7: Dip treatment by submerging the stake in the chemical for 48 hours

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	40877.27	10	4087.727	23.63469**	1.85E-16	2.007792
Within Groups	9512.5	55	172.9545			
Total	50389.77	65				

Table.8: Vacuum for 15 minutes followed for by 50 pounds / sq. inch pressure for 60 minutes

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	41335.61	10	4133.561	31.55755**	2.98E-19	2.007792
Within Groups	7204.167	55	130.9848			
Total	48539.77	65				

** shows significant difference at 0.05 Level of significance.

Anova was conducted to know the effect of different treatments viz., spray, dip and pressure treatments separately for the two bamboo species *Bambusa bambos* and *Dendrocalamus strictus* (Table 1 & 5)

Anova indicates that the effectiveness of the chemicals was significantly different in all the treatments viz., spray, dip and pressure treatments. (Table 2-4 & 6-8)

The data presented in table 1 and table 5 shows that the untreated controls are totally damaged over a period of 12 months after implantation. The two bamboo species *Bambusa bambos* and *Dendrocalamus strictus* pressure

treated (T-3) with the chemicals Bifenthrin, Imidachlorpid, Chlorpyriphos , Fenvalerate and Cypertmethrin showed good results. The bamboo stakes treated with Bifentrhin 2.5 TC showed 100% protection against termites with all the three treatments T-1, T-2 and T-3 during the entire study period of 36 months. Bifentrhin TC is presently the most advanced development in today's growing world of termiticides. Based on a unique pyrethroid called bifentrhin, Biflex TC brings all levels of termiticidal activity. The active ingredient present in this termiticide, prevents the termites from crossing the barrier and kills them in contact. Even when the barrier weakens over a period of time, it still provides protection since it reduces the pressure of attack through repellency and do not attack or penetrate the barrier.

Imidaclorpid also known as a new generation termiticide, is a non-repellent systemic cum contact insecticide, being a latest and fastest growing molecule also gave good protection to bamboo with its lethal action against termites. This chemical is known to act on acetyl chlorine, binding the nerve receptor cells of termites leading to lasting impairment. Consequently, the feeding termites stop feeding and die. However, although the treatments (T-2) and (T-3) proved effective against termites, it was observed that treatment (T-1) i.e bamboo stakes spray treated with Imidaclorpid, slowly lost its efficacy over a period 36 months. Pressure treated bamboo stakes with Chlorpyriphos, Fenvalerate and Cypertmethrin showed more or less the same resistance against termite attack i.e Bamboo pressure treated (T-3)with Chlorpyriphos, Fenvalerate and Cypertmethrin were totally free from termite attack during the study period of 36 months. Earlier studies indicated that bamboo stakes pressure treated with Chlorpyriphos, Cypermethrin and Alphacypermethrin were free from damage for more than 28 months. The efficacy of chlorpyriphos against subterranean termites has confirmed the findings in the earlier reports (Remadevi and Raja.Muthukrishnan 1997, 2004).Bamboo stakes treated with Carbamate were found less resistant to termite attack. Feeding on these treated stakes (T1) for this chemical commenced during 12 months of exposure.

Bamboo stakes treated with two neem based formulations fared badly to termite attack. Even bamboo stakes pressure treated with these neem base formulations were prone to termite damage after 12 months. The above observations were similar for both the species of Bamboo i.e *Bambusa bambos* and *Dendrocalamus strictus* tested in the termite test yard.

Conclusion

Under Indian conditions, the study revealed that the two commercially available bamboo species *Bambusa bambos* and *Dendrocalamus strictus* treated with Bifentrhin 2.5 TC has proved a better termiticide compared to Chlorpyriphos , Imidachlorpid Fenvalerate and Cypermetnrin, which also gave good protection during the study period. Carbamates showed less resistance to termite attack. Two Neem products also proved less effective against termite attack.

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Protection of Bamboo by Environment-friendly Chemicals against Short-term Molding

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Abstract

The protection of the bamboo species *Bambusa stenostachya* and *Thyrostachys siamensis* against molds was tested with environment-friendly chemicals in the laboratory. Bamboo samples were treated with various organic acids and their salts. Mold growth on the specimens was evaluated 1, 2, 4 and 8 weeks after inoculation with a conidia mixture of seven moulds isolated from bamboos in Vietnam. A second experimental set used specimens which were not inoculated but contained the mold flora from the original bamboo samples. Treatments with 10% acetic acid, 7 % propionic acid as well as with a mixture of 3% boric acid and 7% propionic acid inhibited mould growth totally.

Keywords: Bamboo, Molding, Antifungal treatment

Introduction

The bamboos Bambusa stenostachya (Tre gai) and Thyrostachys siamensis (Tam vong) are two of the important species of Vietnam. They are used for production of furniture and for housing mainly to export (Phan 2004). Generally, several fungi from the groups of deuteromycetes (molds), ascomycetes and basidiomycetes colonize the culms and leaves of bamboos (Mohanan 1997). Molds can also occur on the surface and at the cross-ends of culms in a humid atmosphere as they require high relative humidity above 70%. Especially, exposed bamboo material during storage, processing, transport in container and its final use is affected by molds (Liese and Kumar 2003).

Figure 1 shows molded bamboo culms at arrival in Hamburg harbour after container transport from Vietnam.

For protection of wood and bamboo against molds and other fungi, pentachlorophenol had been widely used. However, pentachlorophenol is banned due to its high toxicity in many parts of the world as well as in Vietnam (Tang 2009). Therefore, bamboo manufacturers have pressing problems to protect bamboo for home use and export. Since Vietnam exports large quantities of bamboo culms and utilities in containers to Europe the damage due to mold growth at arrival has become quite serious. Manufacturers greatly need cost-effective but also environment-friendly treatment methods.

Welling and Lambertz (2008) used chemicals of alkaline pH value in order to reduce molding of pine sap wood specimens and obtained protection with potassium and sodium carbonate. Liese and Walter (1978) showed the efficacy of an acid formulation (boric acid) on the protection of sugar cane bagasse against molding. Our emphasis was on the use of free acids. The protective efficacy of organic acids like acetic, boric, citric, formic, propionic and sorbic acid has been applied long time for food and as antiseptica (Wallhäußer and Schmidt 1967). Therefore, we combined the preventing effect of acids with the additional protective effect of their low pH-value against microorganisms (Schmidt 2006) for short-term protection against molding.

Material and Methods

Bamboo Specimens

Each ten mature bamboo culms of 3 - 4 years age of *Bambusa stenostachya* Hackel and *Thyrostachys siamensis* Gamble were collected from a bamboo-plantation in Tay Ninh province, South Vietnam. From the fresh culms, samples of 70 mm length were taken halfway between the internodes and longwise split. Their moisture content was 100 to 120 %.

Chemicals

Acetic, boric , citric , formic , propionic, sorbic acid, and the salts potassium citrate, sodium acetate, sodium borate and sodium propionate from laboratory providers were applied in the formulations listed in Table 1.

Table 1. Acids and salts used for anti-mold test

Formulation	Acid / salt	Concentration (%)	pH –value
1	acetic acid (AA)	7	3.0
2	AA	10	2.8
3	citric acid (CA)	7	2.7
4	CA	10	2.6
5	formic acid (FA)	7	3.8
6	FA	10	3.7
7	propionic acid (PA)	7	2.9
8	PA	10	2.8
9	sorbic acid (SA)	0,6	3.7
10	Na-acetate (NA)	7	8.4
11	NA	10	8.5
12	Na-propionate (NP)	7	8.0
13	NP	10	8.1
14	boric acid (BA)+Na-borate (BS)	2% BA + 3% BS	8.7
15	BA + NP	3% BA + 7% NP	7.0
16	BA + NC	3% BA + 7% NC	7.9

17	BA + K-citrate(KC)	3% BA + 7% KC	8.3
18	BA + AA	3% BA + 7% AA	3.0
19	BA + SA	3% BA + 0.3% SA	3.9
20	BA + CA	3% BA + 7% CA	2.5
21	BA + PA	3% BA + 7% PA	3.0
Control	H_2O	-	-

Fungi

The seven molds used were isolated from bamboo at the Nong Lam University of Ho chi Minh City, Vietnam. Identification by DNA-ITS sequencing as described by Schmidt (2000) revealed *Aspergillus niger, A. flavus, A. oryzae, Aspergillus* sp., *Mucor* sp., *Paecilomyces variotii* and *Penicillium* sp.

Treatment, Inoculation and Incubation

Two specimens of the two bamboo species were dipped 5 min. in the respective treatment solution and placed in a small plastic basin 10 x 10 x 6 cm (Fig. 2). Specimens were not sterilized before incubation. For one test series, artificial infection with a water-based mixture of conidia of the 7 molds was performed with a small brush. The other series contained the molds from the natural flora of the bamboo plants and from the sample processing. The basins were incubated at 30°C and 75 % RH. Evaluation was done after 1, 2, 4 and 8 weeks.

Assessment of Mould Growth

The development of mold growth on the surface of the bamboo specimens was assessed according the ranking shown in Table 2.

Table 2. Rating for determining mold growth on bamboo specimens

Rating	Description	Definition
0	no coverage	no growth
1	1-10 % coverage	slightly overgrown
2	11-25 % coverage	moderately overgrown
3	26-50 % coverage	severely overgrown
4	>50 % coverage	very severely overgrown

Results and Discussion

Figure 3 shows effective and ineffective treatments of the series `artificial infection´.

The treatments with 10% acetic acid (formulation 2), propionic acid (formulations 7 and 8) as well as with the mixture of 3% boric acid and 7% propionic acid (formulation 21) prevented mold growth totally over the whole incubation period of 8 weeks.

The results of both test series are summarized in Table 3.

Table 3. Efficacy of anti-mold treatments (cf. Table 2)

Incubation time (weeks)	1				2				4				8			
Bamboo species	Ts		Bs		Ts		Bs		Ts		Bs		Ts		Bs	
Test series	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
Formulation 1	0	0	0	0	1	0	0	0	4	0	3	0	4	3	4	3
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	2	1	4	3	4	4	4	4	4	4	4	4	4	4	4	4
4	2	0	4	4	4	3	4	4	4	4	4	4	4	4	4	4
5	4	1	4	2	4	4	4	4	4	4	4	4	4	4	4	4
6	4	2	3	4	4	4	4	4	4	4	4	4	4	4	4	4
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	2	0	4	3	4	3	4	4	4	4	4	4	4	4
10	4	3	4	4	4	4	4	4	4	4	4	4	4	4	4	4
11	4	3	4	4	4	4	4	4	4	4	4	4	4	4	4	4
12	0	0	2	0	3	1	4	3	4	4	4	4	4	4	4	4
13	0	0	1	0	4	1	4	4	4	4	4	4	4	4	4	4
14	0	0	3	3	4	2	4	4	4	4	4	4	4	4	4	4
15	0	0	0	0	3	1	4	1	4	4	4	4	4	4	4	4
16	1	1	3	1	4	3	4	4	4	4	4	4	4	4	4	4
17	1	0	3	2	4	3	4	4	4	4	4	4	4	4	4	4
18	0	0	0	0	0	0	0	0	1	0	0	0	3	2	0	0
19	2	0	2	0	4	2	4	3	4	4	4	4	4	4	4	4
20	2	0	2	2	4	4	4	4	4	4	4	4	4	4	4	4
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Control	3	0	3	0	4	3	4	3	4	4	4	4	4	4	4	4

Ts =Thyrostachys siamensis, Bs = Bambusa stenostachya, A = artificial infection, B = natural mould flora

After 8 weeks, there were no significant differences in final molding between the test series `artificial infection´ and `natural mould flora´´. Some differences occurred within the first two weeks, the inoculated specimens being faster overgrown due to high amount of spores in the inoculum.

Ten percent acetic acid, 7% propionic acid and the boric/propionic acid mixture prevented mold growth in both series completely. All other formulations allowed severe (rating 3) or very severe (rating 4) mold growth. Both bamboo species behaved rather similar regarding mold susceptibility and prevention. The exception was formulation 18, showing moulded *T. siamensis* and clean *B. stenostachya* specimens.

To avoid drying of the bamboo specimens during eight weeks of culture, completely closed plastic basins were used as culture vessels for fungi. As objection to the experimental design, a shortage of oxygen should be considered. However, the air volume in the culture basins of over 500 cm^3 should have been sufficient for the relatively few mold hyphae living on the small bamboo specimens.

For the laboratory experiments, only one infection of bamboo specimens was performed. Under field conditions with larger samples, bamboo is exposed to permanent infection pressure from the surrounding air. Possibly, the applied concentrations do not meet those practical conditions.

The tested chemicals do not fix to the bamboo tissue. Washing out by rain and evaporation of active substances, particularly under direct sunshine, reduce protective efficacy (Willeitner and Liese 1992). For practical use, samples must be protected from rain and sunshine all the time, both being during container transport.

Conclusion and Recommendations

The laboratory experiments have shown that molding of bamboo can be prevented by simple treatment with environment-friendly chemicals. Results revealed that treatment of bamboo samples with acetic acid, propionic acid and a mixture with boric acid prevented mould growth for 8 weeks. The other chemicals were less effective or ineffective.

Experiments with the effective formulations will now be continued under field conditions in Vietnam with larger bamboo dimensions as culms, round and split as well as handicrafts and commodities. Since molding of bamboo is a serious devaluation in trade, corresponding experiments are recommended for other bamboo countries with their respective species.

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Figure 1. Molded bamboo culms at arrival in Ha
Vietnam

Figure 2. Specimens in plastic basins for mould protection test

Figure 3. Artificially infected and differently treated bamboo specimens after 8 weeks of incubation

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Architecture and Engineering

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The Den, Soneva Kiri Resort, Koh Kood Island, Thailand

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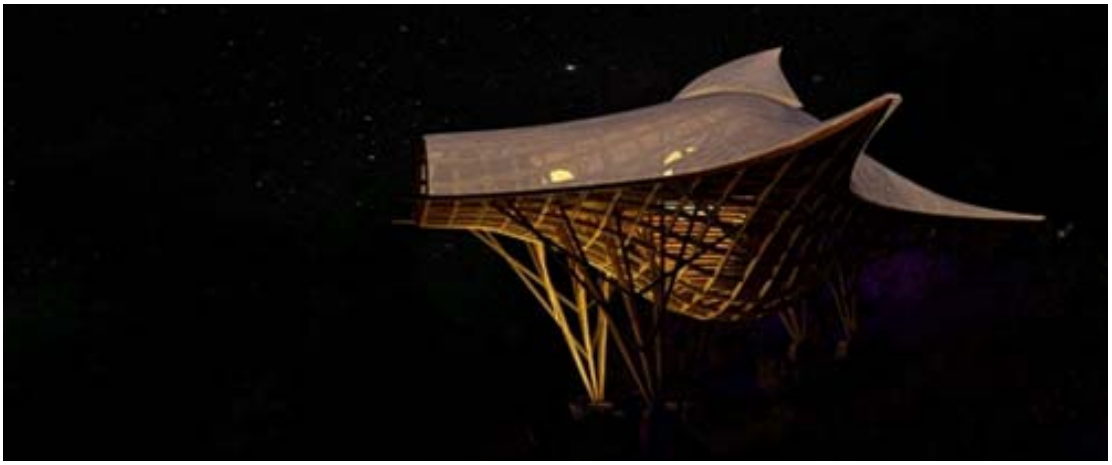
Project Architect
24h-architecture, the Netherlands
Boris Zeisser & Maartje Lammers



Artist's impression

Introduction

On the lush green tropical Island of Koh Kood in the Gulf of Thailand the ecological 6-star Soneva Kiri Resort is being built. All activities for the resort's children are accommodated in the Den. This bamboo structure encloses a small theatre, art room, fashion room, music room and library.

Birds-eye view towards the bay

Concept

Situated on a rocky hillside, the building is overlooking the resort's bay. The organic shape of the building is inspired by the manta ray fish below in the water and acts as an inspiring and exciting environment for the children's activities. With its muscular fin-shaped bamboo columns the sculpture seems to be ready to jump from the rock back into the crystal clear water.

View from below

Design & climate

The design adopts all bioclimatic aspects to suits its humid tropical environment. The roof cantilevers up to 8m acting like a big umbrella providing shade and protection from the heavy rains. The elevated rooftop and setback floors allow a natural airflow inside.

Steam oven

Adjustable formwork for making the curved beams

Construction

All beams have been generated from a 3D computer model. After the individual bamboos have been heated in a specially developed steam oven, they were assembled in an adjustable formwork with a coordinate system, forming each of the more than 70 individually curved beams.

Roof structure under construction

Bamboo

The main structure has been made using *Pai Tong* bamboo (*Dendracolamus asper*) in lengths up to 9m and a diametre of 10-13cm. The secondary roof- and 'belly' structure is made from *Pai Liang* bamboo (*Bambusa multiplex*) in 4m lengths and a diametre around 5cm.

Both types of bamboo come from plantations in the neighboring Thai province of Prachinburi.

Bamboo shingle roof being installed

Conference

The presentation at the conference will mainly focus on the process from an abstract design concept towards the actual construction details.

Detail of back column

Front column

Interior under construction

Going Multi-Storied With Bamboo

Ar.Jaigopal G.Rao

Inspiration, an architecture and construction firm based in South India has been shaping bamboo buildings for the past 6 years, Inspiration's own office being the first major attempt in this field. (Figure 3, Figure 4)

Bamboo has been used in combination with optimized RCC members, ferro-cement and limited reinforced plaster, so as to arrive at an aesthetic, functional and cost-effective technology option. (Figure 2)

All the bamboo utilized has undergone adequate preservative treatment with water-borne preservatives like CCB and liquid organic solvents. Split bamboos used for floors, roofs and walls span between ferro-cement, wood or steel members spaced at 1.30m centre-to-centre. The dead load of the composite has been taken as 1500N/m^2 and it was found to take liveloads of over 4000N/m^2. (Figure 1) It has further been observed that the fibrous nature of the material makes design for lateral loads such as earthquakes and cyclones easier. This effort went on to win several National and International Awards including 'Urban Building' Category Award in the International Bamboo Designs Competition 2007 based in Hawaii, USA.

Ensuing this, 10-12 buildings have been erected by Inspiration. Fine-tuning the above basket of technologies, (Figure 5) the use of bamboo steel composite was observed to be advantageous with regard to 1. The carbon footprint of the building, 2.Self weight of the building which is reduced by 40%, 3.The duration of construction which is reduced to 1/3rd, 4.Temperature reduction averaging 3-4degrees Celsius owing to lower conductivity of material; the costs remain comparable to conventional buildings.

The advantage of considerably reducing the self weight favoured Inspiration to explore the possibility of introducing these technologies in multi-storied buildings. Care is being taken in making bamboo fire retardant too. Currently, the design of a Ground+12 structure housing a 76-room hotel is underway; construction is scheduled to begin by Sept.2009. (Figure 6)

The design makes extensive use of bamboo-reinforced mortar composite for floors and walls resulting in the reduction of self weight of the building. The highlight of the same is the consequent lessening of the volume of cement, steel and other chemicals used in pile foundations, building frames and floor slabs.(Figure 7) It is determined that a reduction of over 6150 bags of cement and around 100 tonnes of steel is possible. This leads to an eventual considerable decrease in carbon footprint and a 10% reduction in construction cost of the structure of the building in Indian conditions.

Comparison of Use of Steel and Cement							
Conventional building with DMC piles, RCC slabs, beams and Brick Masonry walls			Building with friction piles and strip raft foundation, RCC frames, Bamboo-reinforced mortar floor slabs and walls				
	Unit	Quantity		Unit	Quantity	Difference in Quantity	Unit
Total Qty. of RCC	m^3	1966		m^3	1259	707	m^3
Total Qty. of Cement	bags	16990		bags	10870	6120	bags
Total Qty. of Steel	Tonnes	220		Tonnes	130	90	Tonnes

Figure 1 – Inspiration Office: Ground Floor Plan and First Floor Plan

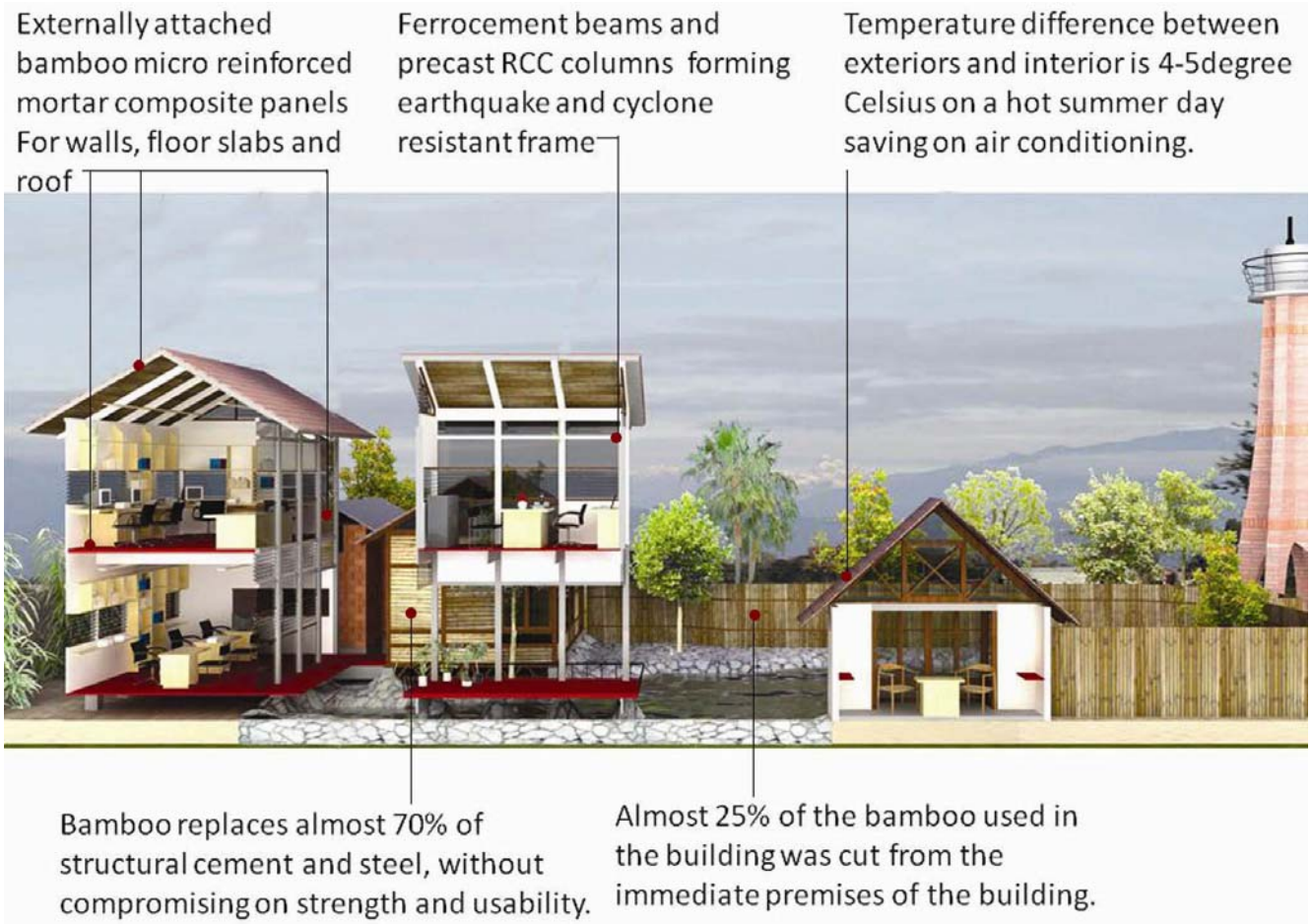


Figure 2 – Inspiration Office: Section

Figure 3 – Inspiration Office: Exterior Front View ;
Bamboo-reinforced Mortar Floor Slab finished with Polished Red Oxide

Figure 4 – External View with Central Pond in Foreground; Interior of Design Studio

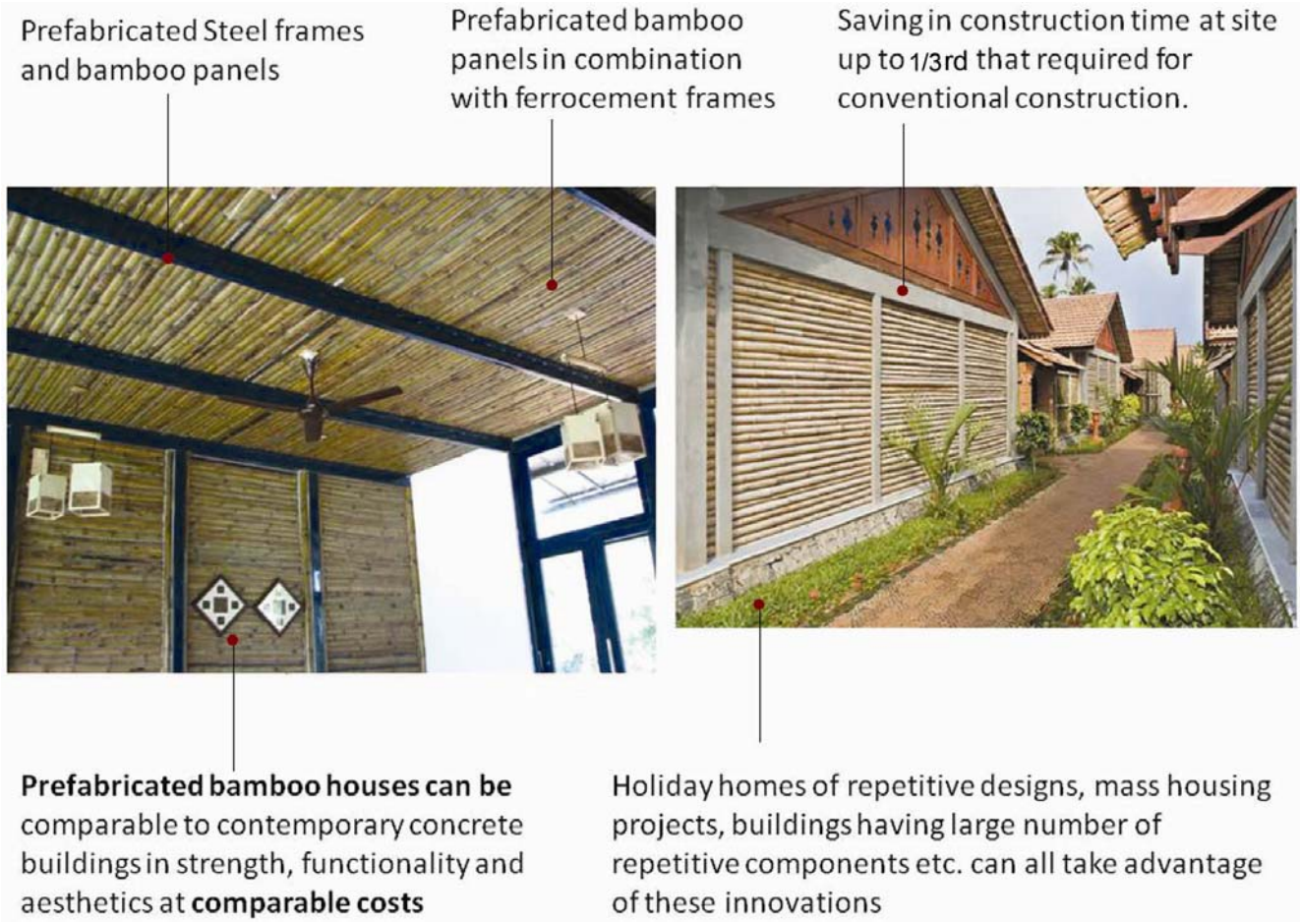


Figure 5 – The Technology Basket

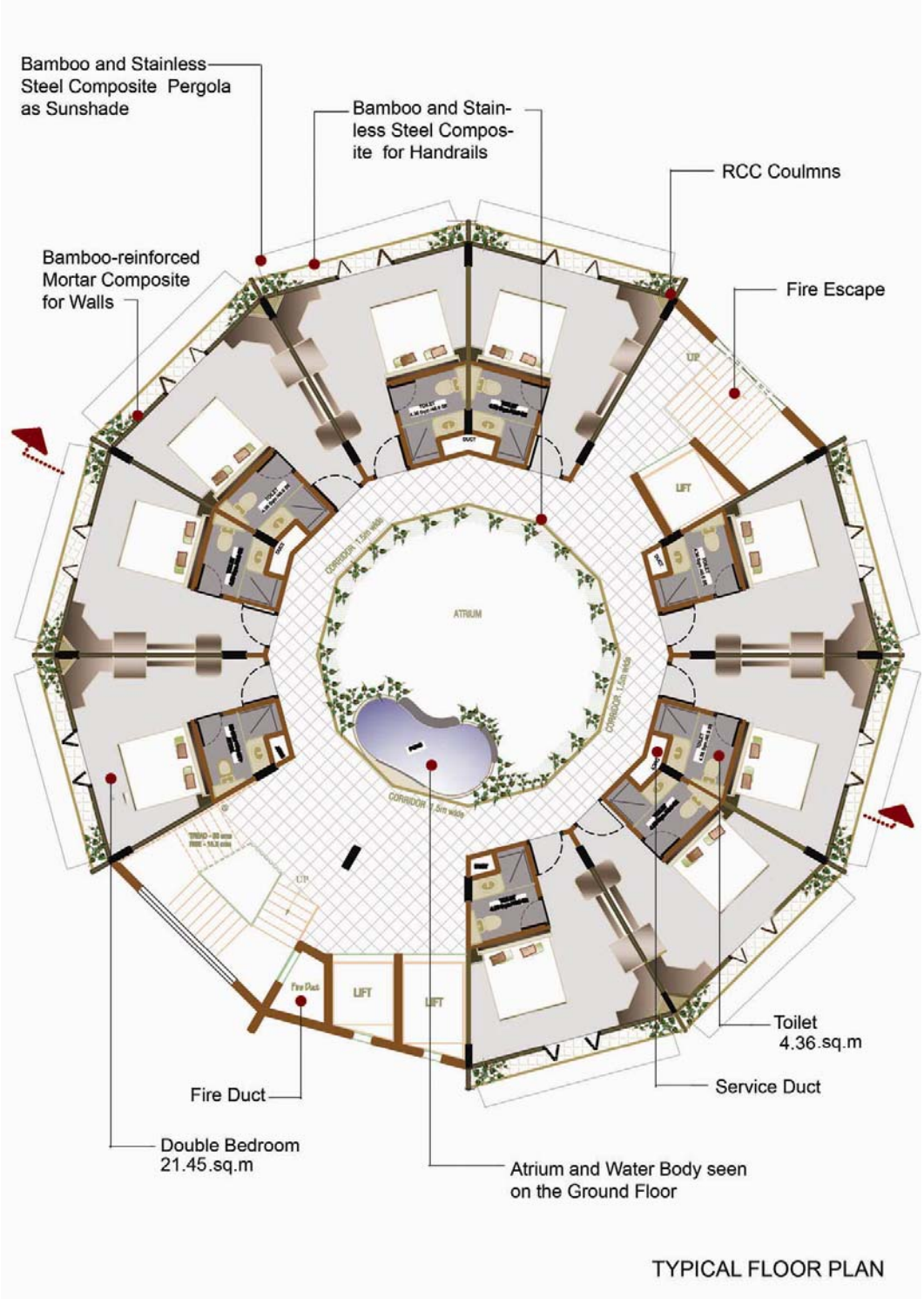


Figure 6 – Sarovaram Hotel – Floor Plan

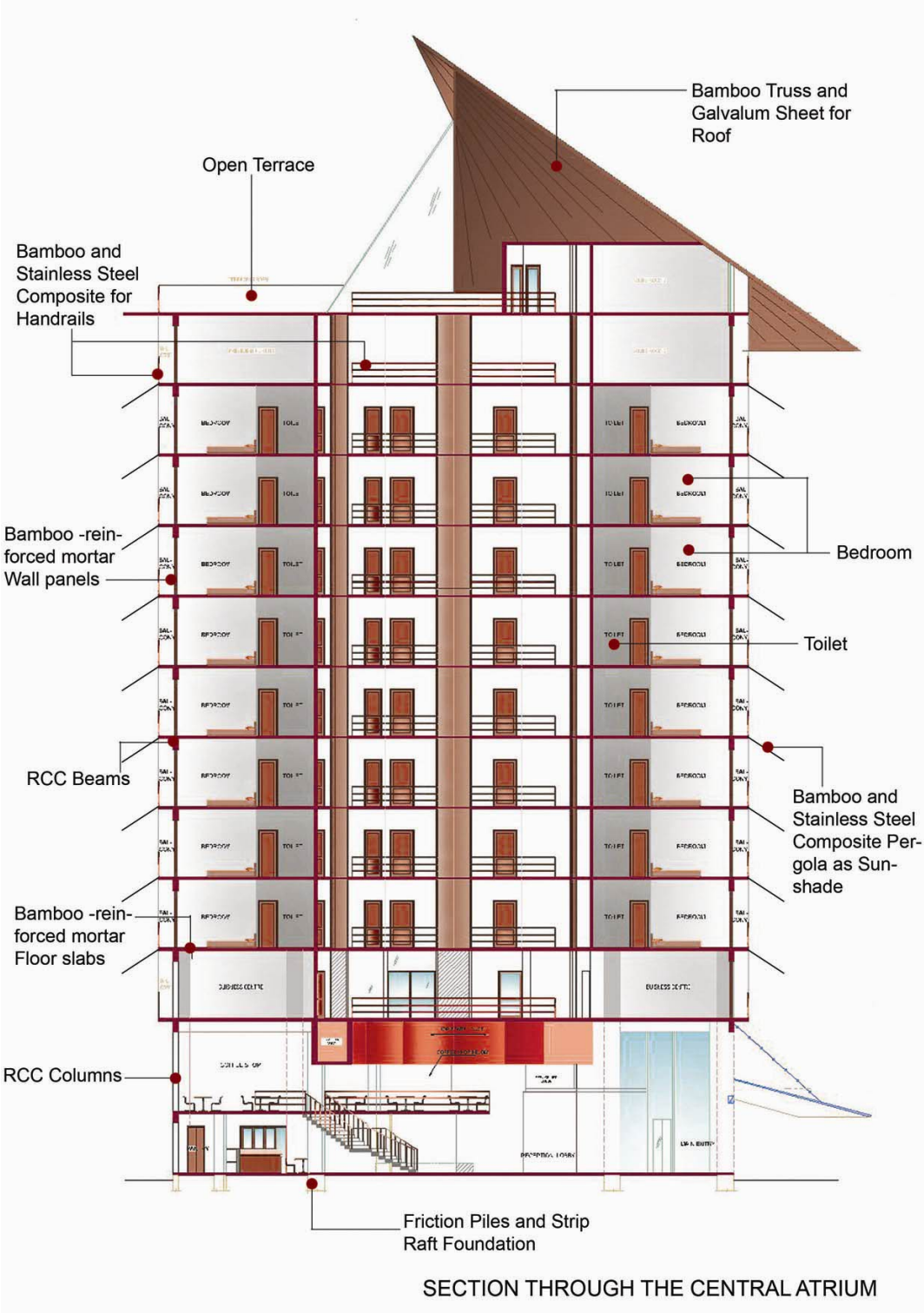


Figure 7 – Sarovaram Hotel – Section

Conventional vs. Substitutive Bamboo Construction: The Classification of Bamboo Construction

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Abstract

Based on numerous past studies and field experiences dealing with bamboo construction and the ongoing development of bamboo utilization, it is widely recognized that bamboo construction can be found in a very wide variation. Bamboo can be used in all parts of the building, either as structural or architectural elements. It can stand alone or in combination with other materials. Bamboo also can be simple-transformed or high-tech-transformed to become a new material that has specific characters and properties and thus can be constructed in a different way.

In these wide ranges of variations, the question 'how was bamboo originally constructed?' become interesting to be answered. In the form of original or simple-transformed, bamboo has specific characteristics and these will distinguish between other constructions. But in spite of using 'original', the term 'conventional' is purposed to represent a wider variation of bamboo construction that takes directly from the specific nature of bamboo, a 'convention' of bamboo construction.

Nowadays bamboo is often used to replace other materials, lead by the issue of sustainability. In this case, bamboo is treatted and constructed with a different kind of material logic. One example is the replacement of timber construction with laminated bamboo. Therefore part of bamboo construction can be classified as a substitution of other construction, such as timber construction. This will be categorized as "substitutive bamboo construction".

This paper presents a classification of bamboo-based construction world-wide. This categorization is based on the way bamboo is constructed. It is different with other literature which distinguishes it based on the building elements or building types, such as footings or roof construction, housing or bridge construction, etc. It does not depend on where the bamboo construction will be placed or what it is for, but how it will be constructed.

Introduction

Bamboo plays an important role everywhere it grows naturally. The culture of bamboo grows in line with the civilization and makes many human activities inseparable from the existence of this amazing grass.

One of the important uses of bamboo is for building construction. It is believed that bamboo became the first option as a building material when people began to occupy area where bamboo grows naturally. The common

reasons are its availability and ease of use. And later due to its lack of durability, most of people replaced the use of bamboo with other, more resistant material, such as wood and brick. According to Hidalgo (2003), “due to the low durability of most of giant bamboo species of Southeast Asia, at present most countries in this area do not use bamboo for the construction of the main structure of their houses”.

In recent years, with the issue of sustainability the use of bamboo has regained a new value. Bamboo offers many advantages that fulfill most of the criteria of a sustainable material, especially as timber replacement to reduce deforestation. This awareness is followed by a massive amount of bamboo research and utilization. Bamboo is used with minimum preparation or even with high-tech transformation. Great bamboo buildings out of preserved bamboo-poles and as well as for luxurious interiors out of bamboo lamination or plybamboo can be found at the present time. Traditional or vernacular bamboo construction is also still prevalent in rural areas.

In the hands of artists, architects and engineers, bamboo becomes a challenging material to be constructed to fulfill as many building types as possible, as small gazebos, long-span building, bridge, etc. And the bamboo itself is applied as a building material in many possible ways, like as flexible splits or a rigid laminated-beam, in order to fit with a specific type of construction.

It can be understood, these circumstances drove many authors to classify bamboo construction in different ways, based on building type, building element, time frame, material combination, transformation, etc. This paper will present another bamboo construction classification, which is based on the method on how the bamboo is constructed. It does not depend on the building type or building element, but it of course has a close correlation with the form of bamboo-based material, structural system and connection.

The Form of Bamboo as Building Material

As a building material, bamboo takes many forms (Figure 1). There are at least 4 basic forms of bamboo of building materials: bamboo poles; splits, including flattened bamboo (*pelupuh*, *esterilla*); woven and rope. These basic forms have a long history of use. Most are still used except a limitation in bamboo rope application.

Bamboo also can be mixed with other materials for several purposes. The main reason for this mixture of materials is to replace other materials or one part of a composite material. Laminated bamboo can replace almost all kinds of timber product or construction. The high tensile strength of bamboo led to further applications such as the replacement of rebar in steel reinforced concrete construction.

Classification of Bamboo Construction

The question ‘how was bamboo originally constructed?’ is always interesting to be answered, since utilization of bamboo as building material become wider and already replaced other established material. Solid proofs of hundred years old bamboo constructions in many variations are also hard to find in existing bamboo buildings nowadays, because of lack of bamboo-durability without proper preservation.

But in this widespread variation of bamboo construction, there are some types of construction and joinery that are specific to the characteristics of bamboo and there are other types of construction that are using bamboo to replace a different kind of material logic. Therefore bamboo constructions are classified into two main categories (Figure 2):

1. Conventional Bamboo Construction
2. Substitutive Bamboo Construction

In spite of using ‘original’, ‘conventional’ bamboo construction is used to describe a construction of bamboo which is based on the specific character of bamboo and have been in practice since previous generation. A convention is a set of unwritten rules, a set of agreed, stipulated or generally accepted standards, norms, social norms or criteria. Conventional bamboo construction stands for the construction which based on a convention of bamboo construction that lived in the community. This convention is not only used in traditional building, but also applied in the modern bamboo building with or without development.

The term ‘original bamboo construction’ is not used because it is so hard to say that there is no influence of other construction, especially timber construction. But within this conventional bamboo construction, there are ‘original bamboo connections (not constructions)’ which is made of bamboo poles. This connection can only be made by using bamboo poles, not other materials.

Newer utilization of bamboo is to replace other possible materials, thus bamboo will be constructed with the logic of other materials. For example, bamboo construction in the form of laminated bamboo is used to be constructed in the same way as wood construction. There are many other uses of bamboo such as replacing steel as concrete reinforcement or replacing steel member in a space frame or space truss structure. These bamboo constructions thus will be classified as “substitutive bamboo construction”.

Conventional Bamboo Construction

Conventional bamboo construction is based on a set of unwritten rules or conventions of bamboo constructions. The construction technique has been passed down through generations of working closely with specific characteristics of bamboo. This rules or standards grow from one generation to next generation with enrichment. That is why it cannot be separated with the time line. For that reason, conventional bamboo construction can be divided in two main categories:

1. Traditional (Vernacular) Bamboo Construction
2. Engineered Conventional Bamboo Construction

Traditional (Vernacular) Bamboo Construction

The term "vernacular architecture" refers to structures made by empirical builders, without the intervention of professional architects. It is the most traditional and widespread way to build (Arboleda 2006). Sometimes it is also called as traditional architecture, although some references distinguish these two terms.

The term ‘vernacular’ is not to be confused with so-called "traditional" architecture, though there are links between the two. Traditional architecture can also include buildings which bear elements of polite design; temples and palaces, for example, which normally would not be included under the rubric of "vernacular" (Brunskill 2000).

In traditional way of building with bamboo, a bamboo is used in its original form (bamboo poles) or in its simple transformation as split, woven or rope. It is also used in combination with plastering process.

Bamboo Poles/Tubes

Traditional bamboo pole constructions came from a long empirical experience and it became a basic of conventional bamboo construction. In this construction the specific character of bamboo is highly benefited. Therefore some specific connections (such as fish-mouth and rope connection) are considered as ‘original bamboo connection’ which could not be duplicated with other material.

The joinery most often used in this category are fish-mouth (Figure 3, 4), rope (with coco-fiber, bast, rattan, bamboo rope), plug-in, and positive-fitting connection (Figure 5). Rope connection is regarded as one of the oldest type of bamboo connection because the circular cross section of bamboo makes the friction of bamboo and the rope more effective. To make a strong rope connection in most cases, bamboo has to be pinned, holed or fish-mouth shaped and it is easy because of the hollowness of bamboo, even with simple or traditional tools.

In most traditional bamboo buildings the supporting structure is formed from straight full-section canes. They are almost always under compressive or bending stresses. Canes under tensile stress are rarely found (Dunkelberg 1985). Although bamboo has a very high tensile strength it is difficult to connect the bamboo poles to afford that strength, especially when the connector is made of traditional material that commonly out of natural resource.

Most of traditional bamboo buildings consist of planar frames (Figure 6). Commonly this two dimensional frame is composed of one layer (Figure 7). In Asian culture, where bamboo in different culm diameter is easy to find, this planar and one layer frame is constructed with a positive-fitting connection, a smaller diameter of bamboo as beam is connected through a bigger diameter bamboo as column (see also Figure 5).

The other specific character of conventional bamboo construction is the existence of eccentricity of load transfer in the connection. It is very important to make a connection close to a node and it is not easy to connect many bamboos at once in one point (Figure 8, see also Figure 7). Splitting bamboo pole is one of the most essential problems to be overcome in bamboo connection. Trujillo (2007) mentioned a function of node to stop cracking, “Shear strength is relatively low, and becomes quite critical due to the relatively thin walls of the culm and the action of the all too frequent cracking of culms, which greatly reduces the shear strength of a section. The only favourable factor is the nodes that act as ‘stirrups’ stopping the progression of any cracking or splitting”.

Bamboo Split and Woven Bamboo

Splitting bamboo to become a flexible strip is one of the most ancient uses of bamboo. Bamboo’s ease of splitting since it only has fibers in the longitudinal direction. Mostly these strips or bamboo splits were weaved

to become a wider sheet and then attached to bamboo-poles or timber frame. Hidalgo (2003) reported an interesting traditional use of bamboo split/woven as housing in Ethiopia, Africa (Figure 9).

Bamboo Rope

One of specific utilizations of bamboo compared with timber is bamboo rope (Figure 10). This application is benefited from the longitudinal bamboo fiber. In China, bamboo plaited or twisted ropes have had applications in many fields of engineering, e.g., in the construction of suspension bridges, for tracking junks on the upper Yangtze River, in the construction of gabions and fascine bundles used in the construction of dikes, and the hogging trusses that were used in the construction of boats (Hidalgo 2003).

Bamboo Plaster

Basically a bamboo plaster construction is a construction of a sheet of bamboo woven (South-East Asian) or flattened bamboo (Latin America) that attached to a bamboo pole or timber frame and in the end was covered with plaster mixture. Traditionally, mud, clay, cow or horse dung, or lime is used as plaster material (Figure 11). Rough surface of woven/flattened bamboo and gaps between its split members make them possible to be plastered although there is a lack of adherence between plaster and bamboo. Traditional '*Quincha'* wall from Peru showed the use of woven bamboo in combination with bamboo poles and plaster.

Engineered Conventional Bamboo Construction

Based on traditional or convention techniques of bamboo construction, many architects, artists and engineers developed a further utilization of bamboo that is scientific acceptable. Scientific approached such as basic research and calculation, had been conducted to determine constructability of bamboo building. Therefore this utilization is categorized as engineered conventional bamboo construction.

In this category, there are three type of bamboo-based material which can be found in today practice: bamboo poles, bamboo splits and plastered bamboo, but only bamboo poles and plastered bamboo that are used excessively.

Bamboo Poles/Tubes

Engineered conventional bamboo poles construction is also part of conventional bamboo construction which is based on a basic principle of bamboo construction. The greatest development of traditional to engineered conventional bamboo construction is the use of nut-bolt connection with mortar injection, benefitted a modern tools electrical drill machine. This connection provides an easy workability, high durability and capability to connect many bamboo poles at once because of availability of long bolt. The great impact is easier to make a building frame with more than two layers (Figure 12, 13). A column of four poles of bamboo in three layers is widely used in engineered conventional bamboo construction. Different with traditional bamboo construction, three dimensional frames is also introduced in this category (Figure 13).

Like in most traditional bamboo construction, in this category bamboos are almost always under compressive or bending stresses. Canes under tensile stress are also rarely found. There are also eccentricities of load transfer in

this type of construction because of benefiting the existence of nodes and difficulty of making connection in one point (Figure 14).

Bamboo Split

Nowadays bamboo splits were used to make many building with new forms that was not recognized in traditional bamboo building. But the principle is the same as the use of bamboo in traditional craftsmanship. Bamboo split can be use easily to make a curve form and can be weaved to have a rigid form. Most of these applications are in the field of experimental building or for temporary shelter (Figure 15).

Bamboo Plaster

The basic principal of the plastered bamboo construction in traditional way is same as in engineered way. Bamboo woven is treated as a sheet of wall cover or partition and then plastered. In Colombia, the new '*bahareque'* system use cement-based mortar as replacement of mud or cow-dung as plastering material. In order to improve the adherence between mortar plaster and the flattened bamboo wall, chicken wire is added.

Another improvement in engineered conventional bamboo plaster construction is the use of halved bamboo pole to replace bamboo pole or timber frame in traditional construction (Figure 16). The basic idea of this construction is to have a better adherence between bamboo and mortar as building frame. Therefore the frames as well as the walls are made of bamboo plaster (Widyowijatnoko 1999).

Substitutive Bamboo Constructions

Beyond the conventionality, bamboo is utilized to replace other established material in building construction. Many types of construction with many kinds of building material exist today. Parts of these materials were produced in a high cost or endangered the sustainable development or not available in some places. Therefore the new idea came to replace those materials with bamboo. Once again, its sustainability and flexibility are the main reasons of using bamboo as replacement. For that reason, this type of bamboo construction is so called 'substitutive bamboo construction'.

In this category, bamboos are transformed, combined or connected with other material to fit with existing type of construction. The forms of bamboo-based building material are at least as follow:

1. bamboo poles
2. bamboo split
3. laminated bamboo
4. bamboo composite

Bamboo Poles/Tubes

In this category bamboo pole is used to replace other material in its type of construction although the construction is foreign to the nature of what bamboo wants to be. Therefore bamboo is sorted or treated to fit

with the requirement (Figure 17). Different with previous bamboo pole construction, in this category bamboo are also utilized under tension.

An example of this category is the use of bamboo in a typical steel space frame. In this construction there must be no eccentricity of load transfer (Figure 18). Therefore the connections of bamboo are created to fulfill this requirement. In a specific connection which nodes have an important role, the process of sorting become very crucial to find a number of poles in a certain length with certain distance to an end-nodes.

Bamboo Split

Mostly bamboo splits are used in conventional way, but there is at most an example of utilization as truss member (Figure 19). It is already well known that most of truss systems are made of steel or timber construction.

Laminated Bamboo

Both laminated bamboo, glued and non-glued, are created especially to replace timber in building constructions, both architecturally and structurally. Therefore the constructions of this bamboo composite are almost the same with timber construction (Figure 20). An experiment also had been conducted to use laminated bamboo as I-beam which is commonly made of steel.

Bamboo Composite

Another unconventionality of using bamboo as building material is in combination with other building material to become a composite material. There are many experiments that have been conducted to create bamboo composite. At least the forms of bamboo composites are as follow:

1. bamboo reinforced concrete
2. bamboo-fiber reinforced concrete
3. plybamboo (in combination with timber)
4. bamboo reinforced wood
5. bamboo reinforced polypropylene

The constructions of all these bamboo composite are the same with original composite material which have been replaced with bamboo except more variation in the use of bamboo as concrete reinforcement. Bamboo-fiber reinforced concrete will be constructed in the same way as glass-fiber reinforced concrete. Plybamboo construction is similar with plywood construction.

Up to the present time, bamboo has been the natural fiber most used experimentally as reinforcement in concrete due to its high tensile strength (Hidalgo 2003).The advantages of using bamboo as a reinforcing material in concrete are: (a) the high tensile strength and (b) the low price. The common tensile stress in steel reinforcement is 160 N/mm2 and in bamboo 20 N/mm2, a ratio of 8 to 1. The mass per volume of steel is 7 850 kg/m3 and of bamboo is about 500-600 kg/m3, a ratio of 16 to 1. Evidently, bamboo will be cheaper because the price of bamboo per weight will be less than half that of steel (Jannsen 2000). As concrete reinforcement, bamboo

mostly is in the form of split (Figure 21) and the rest is in the full bamboo pole (Figure 22) and halved pole with some treatment.

Conclusion

Bamboo can be used in its original form or in a simple transformation with a conventional way of construction that is based on a set of unwritten rules, agreed, stipulated or generally accepted standards, norms or criteria of bamboo construction. This construction is classified as conventional bamboo construction.

The newer utilization of bamboo is to replace other possible material with bamboo, thus bamboo will be constructed in other material logic. For example, bamboo construction in form of laminated bamboo is used to be constructed in the same way as wood construction. There are many other utilizations of bamboo such as replacing steel as concrete reinforcement or replacing steel member in a space frame or space truss structure. These bamboo constructions thus will be classified as 'substitutive bamboo construction'.

This classification of bamboo construction describes more detail about the variety use of bamboo in building construction. This is very important to people or organization dealing with bamboo to have a wider perspective of bamboo construction and in the end to focus in some particular bamboo construction that fit with their need or the properties of available bamboo.

With a better understanding, hopefully in the future a wider cooperation will be conducted in research and development of bamboo construction, not only in conventional bamboo construction, but also in the field of bamboo as substitutive material. And the participation in this cooperation also become wider, not only in country where bamboo grow, but also everywhere in the world (such as Europe), because bamboo is one of sustainable biomass source that can fullfil some parts of the need of building material in the world.

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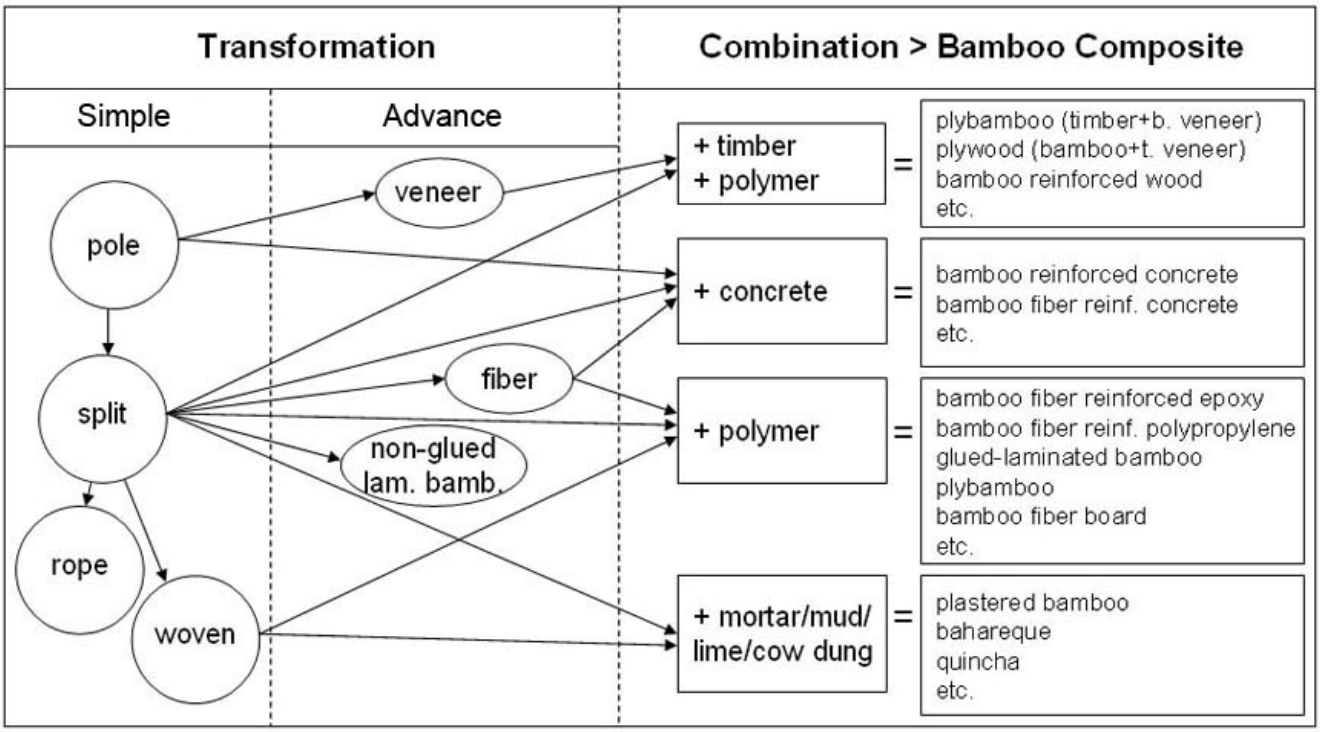

Figure 1 Maps of bamboo-based building material

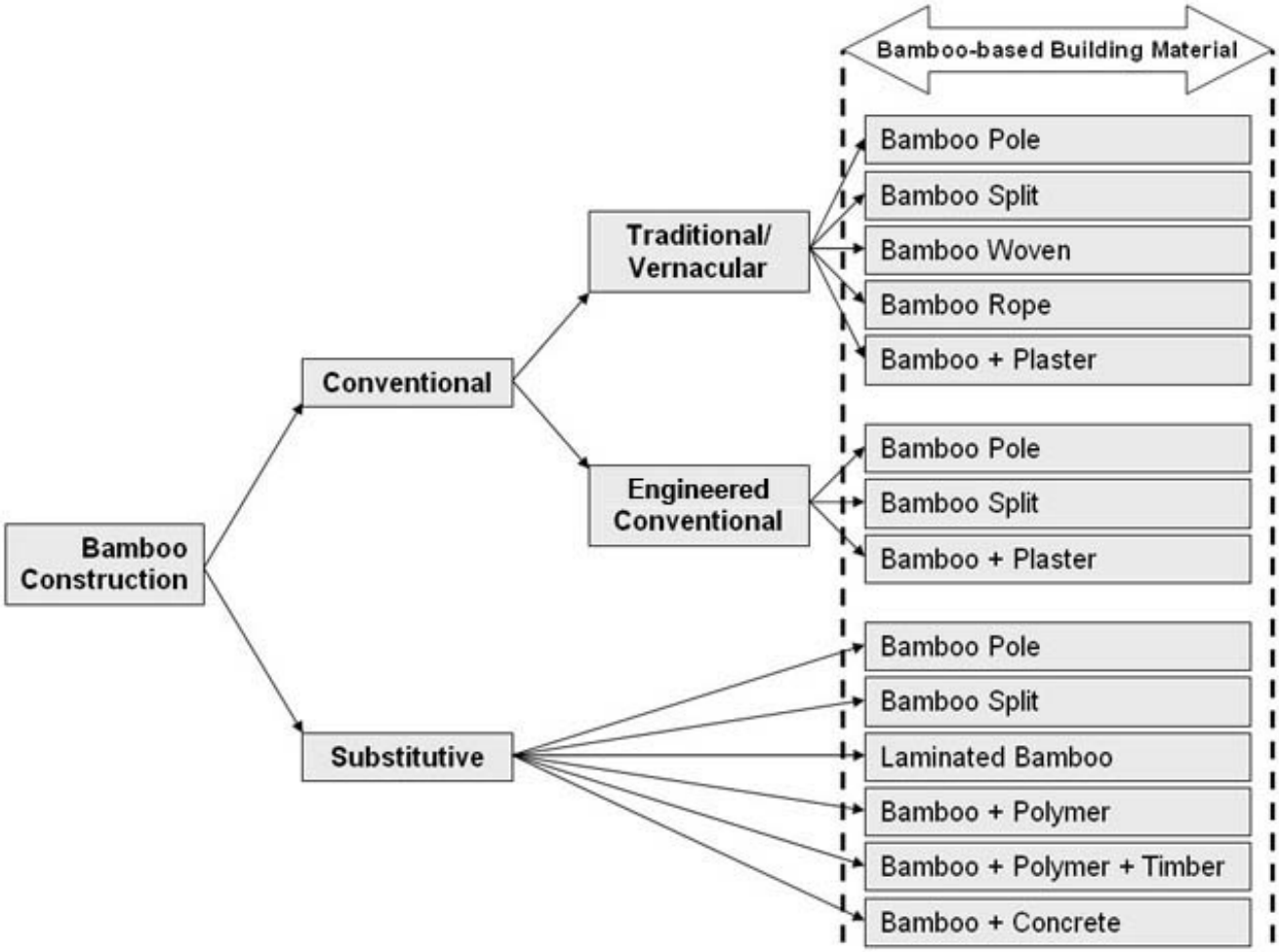

Figure 2 Tree of bamboo construction classification

Figure 3 Fish-mouth joint with two pinned flanges (Courtesy of Benjamin Brown)

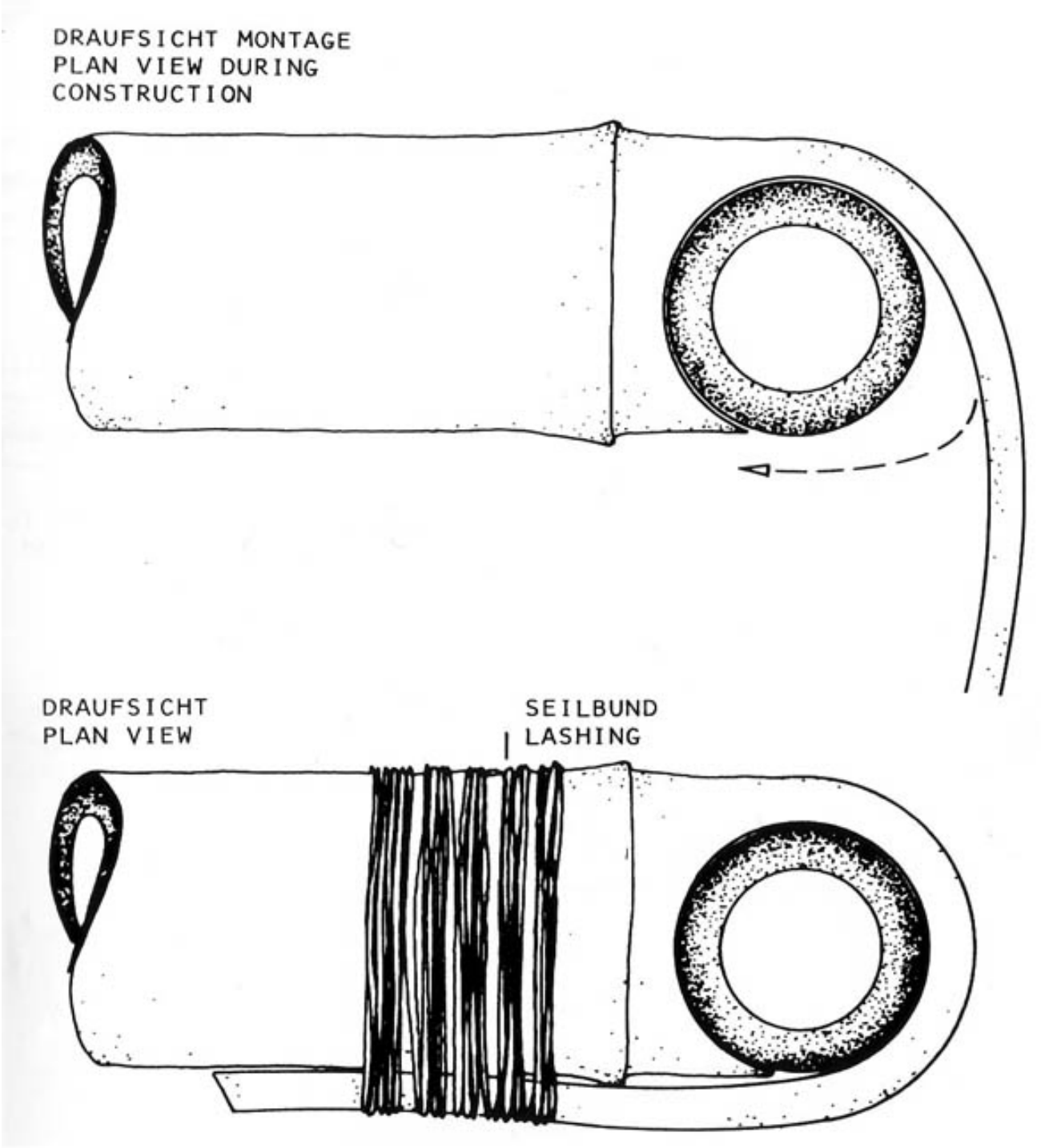

Figure 4 Fish-mouth joint with bended thin flange and lashing (Dunkelberg 1985)

Figure 5 Traditional bamboo gazebo in Indonesia with positive fitting and rope connection

Figure 6 Planar frame in common traditional bamboo constructions (Courtesy of AMURT)

Figure 7 Traditional bamboo housing in Colombia (Courtesy of Lionel Jayanetti)

Figure 8 Eccentricity in traditional bamboo connection and the effort to place the connection near to the node

Figure 9 Traditional bamboo construction that made of split or woven bamboo (Velez 2000)

Figure 10 Himalayan Suspension bridge using bamboo cable (Hidalgo 2003)

Figure 11 Traditional plastered bamboo from Nepal (Courtesy of Lionel Jayanetti)

Figure 12 Two dimensional frame with many layers (Courtesy of Jörg Stamm)

Figure 13 Three dimensional frame (Courtesy of Simon Velez)

Figure 14 Eccentricity of load transfer in a connection (Courtesy of Jörg Stamm)

Figure 15 An innovative form made of bamboo split (Kalberer 2007)

Figure 16 The development of plastered bamboo construction in Indonesia

Figure 17 Bamboo as compression element in combination with steel tension wire

Figure 18 The development of bamboo connection to avoid eccentricity of load transfer with a space frame connector (Courtesy of Evelin Rottke)

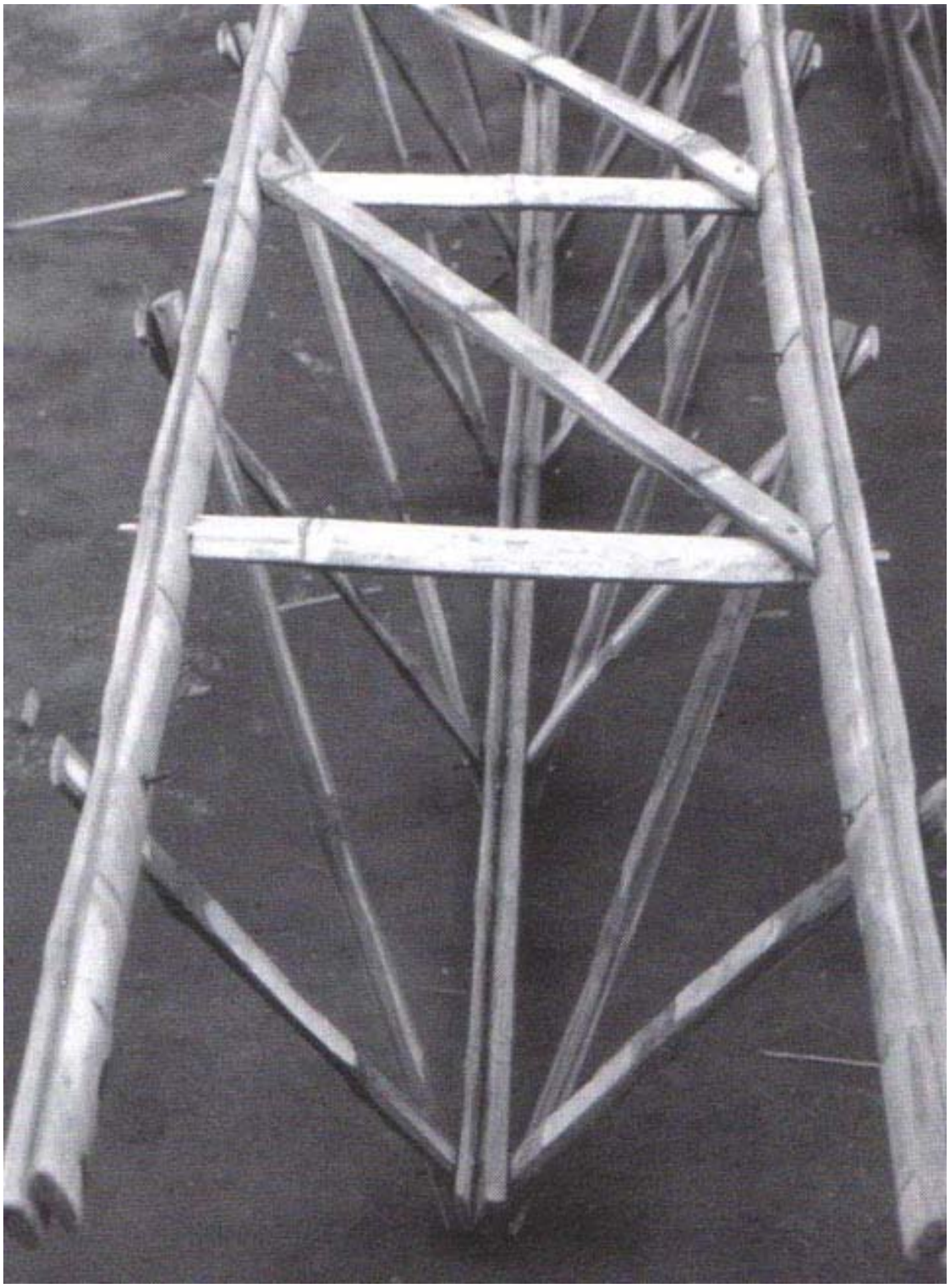

Figure 19 Space truss beam out of bamboo split (Hidalgo 2003)

Figure 20 Glued laminated bamboo as roof frame (Courtesy of Chen Xiaoan)

Figure 21 Bamboo split as concrete reinforcement in Bali, Indonesia

Figure 22 Utilization of bamboo pole as reinforcement for prefabricated concrete beam

Our Explorations in Bamboo Constructions

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Abstract

Bamboo, as an ecologically sustainable, aesthetically pleasing and structurally high performing material has fascinated us since the time we came to know it. We see a great potential in bamboo as an alternative material for the modern society's housing industry. Though our main intention is in promoting the use of bamboo in small-scale building industry, we have explored a wide array of possibilities with bamboo by making small products, furniture, temporary stalls and permanent sheds.

The paper talks about our explorations with bamboo as a material for a sustainable future. By the term 'explorations' we mean the new designs we've created and the experimentation we have done with various connection details and sculptural forms. Although we have explored bamboo design at various scales, the paper will mainly focus on the bamboo structures that we have designed. All these projects were made possible by the involvement of various people like tribal craftsmen who were highly skilled in bamboo skills, local community who had wood-working skills but no knowledge of bamboo or University undergraduate students who did not know anything about bamboo nor had the skills of working with various basic tools. The projects were mainly conducted as construction workshops for the participants to learn the skills in working with bamboo through hands-on experience.

Each project has enriched our knowledge of this material and provided a better understanding on working with bamboo. Through this paper, we intend to be able to share our learning from our past projects with the interested community from around the world as well as to be able to learn something new from other's experiences. We end the paper with future directions that we intend to take, after reflecting upon the lessons learnt from these construction projects.

Introduction

We were introduced to this amazing natural material by Professor M P Ranjan from the National Institute of Design (NID) India. With a background in architecture, we were immediately fascinated by the works of the great bamboo architects like Simon Velez, Darrell DeBoer, Marcelo Villegas and others from around the world. At the time we were working in India which has vast bamboo forests especially in the north-east, but found an overall lack of contemporary bamboo architectural designs which used this beautiful material in an appropriate manner. We immediately realized this gap and started exploring the potential of using bamboo for the construction of contemporary structures along with products and furniture items.

The beginnings

In mid 2003 an opportunity came our way to work with Professor M P Ranjan as part of NID team stationed at Bamboo and Cane Development Institute (BCDI) in Agartala, NE India. At the time only one of us was able to go to Agartala due to other commitments and hence it was decided that Mittul would work at NID-BCDI with the local craftsmen. The task at NID-BCDI was to teach the craftsmen basics of design and develop new designs. Being part of NID-BCDI was a big learning curve for Mittul and was a satisfying experience to work in close collaboration with the local craftsmen.

In year 2004, The Mayor of Dang commissioned us to conduct a Skill and Product Development Workshop, which involved training the local craftsmen in the contemporary use of bamboo. This was our first project in bamboo and we were very excited to work on this project which involved designing and constructing bamboo products and a small structure. Immediately after finishing the structure we moved to Sydney Australia for higher studies. Having successfully completed a structure out of bamboo before leaving India provided us a good background to continue our work with bamboo in Sydney.

During our studies at the University of New South Wales (UNSW) Sydney, we got to know Peter Graham- a lecturer at the Faculty of the Built Environment (FBE). Peter was highly impressed with our passion for bamboo and with the work that we had done in India. With rising concerns about sustainability and the need for fostering thinking about alternative materials amongst students, Peter asked us whether it was possible to build a structure designed for steel patented as *The Loveshack*, out of bamboo. We readily accepted the challenge and responded positively. Hence in July 2005, a modified version of *The Loveshack,* named the *Bamboo Loveshack* was designed and constructed under our guidance by undergraduate students of UNSW. *Bamboo Loveshack* was a great success for the university and it also became a showcase project of our skills with bamboo.

We began to spread our experience in bamboo construction by engaging in various hand-on construction workshops and giving talks about bamboo architecture at various eco-living and sustainability festivals. We got opportunities to teach short courses at the University of Canberra and University of Adelaide. Some of our bamboo projects include Greenfield Stage Entrance, Peats Ridge Festival Walkway, Chicken Shed at Eco-living Centre and Bamboo Spiral at the Earthdance Festival.

Our approach

Our interest in bamboo is grounded in the intention to foster the widespread use of this structurally high-performing, low cost and ecologically sustainable material in small-scale building industry. There is a vast amount of information available for building with bamboo but it is very important to have hands-on experience to be able to successfully understand the qualities of this amazing material. This statement would hold true for working with any natural material. Since bamboo is not a product of an industrialized process, its form is not perfectly cylindrical, its skin is not of the same thickness and it tapers along its length. Hence active, hands-on, experiential engagement is required with bamboo to be able to understand the material and successfully work with it.

After moving to Australia we wanted to continue our work with bamboo, but without local craftsmen and the required skills it seemed difficult to get anything built out of bamboo. So we decided to conduct workshops teaching people about bamboo construction and develop the required knowledge and skill base for 'do it yourself' construction. This slowly developed our 'active learning' approach to all the bamboo projects and workshops. During workshops we spend very little time over theory or lectures and encourage our participants to have experiential learning by working with bamboo. Each hands-on project is followed by reflection on our learning by writing papers, photo documentations and passing it onto the participants of future workshops during open discussions. With each structure we have tried and experimented with bamboo's building form and connection details. Each new project brought new challenges and opportunities which enabled us to 'break the grounds' expanding our understanding of this fabulous material.

All these projects have enabled us to work with varied strata of people ranging from craftsmen, local community and University students. It has always been a two way learning process during these hands-on workshops. We are here to share our experiences during various bamboo explorations in this discussion and learn from others' experiences.

Design and construction

Exhibition Stall, Dang, May 2004

Our first bamboo structure was a small 'Exhibition Stall' built by the craftsmen of the tribal village of Ahwa in western India. Ahwa is a small town in Dang district in the state of Gujarat and has vast bamboo and teak forests which are managed by the Department of Forest. The two main species of bamboo growing in Dang are *Dendrocalamus Strictus* and *Bambusa Bambos*, locally known as '*Katas*' and '*Manvel*' respectively. The tribal people of Dang have used bamboo for their day to day purpose since centuries and are highly skilled in working with bamboo. Some local craftsmen also produce small handicraft items from bamboo to earn their living. Although the local people are skilled in working with bamboo they have little knowledge of contemporary design and lack the skills required to make furniture and structures.

We were invited by the local government of Dang to conduct a Skill and Product Development Workshop and train the local craftsmen in more contemporary use of bamboo. The Exhibition Stall structure was designed and constructed as a part of this workshop and was used to display various other bamboo products at a state wide festival called '*Gujarat Diwas*' held in the city of Surat.

The Exhibition Stall was a rectangular structure consisting of eight portal frames arranged parallel to each other. Before finalising the design of the portal frames we had experimented with various connection details and tested their strength and rigidity. A connection detail which utilised the corbelling of bamboo members was finalised to achieve a rigid joint. The portal frames of the structure were fabricated in the workshop and transported to the site for assembly. Since the structure was temporary in nature the portal frames were directly fixed in the ground by digging a trench and backfilling with earth. Rigidity for the structure was achieved by tying the frames laterally on the top and from the sides by beams (Figure 1).

The main purpose of the structure was to exhibit bamboo products and hence we had designed a display system that utilised the hollow characteristic of bamboo. Support for the display shelves were made by cutting and bending a strip of bamboo from the culm and the shelves were made from flattened bamboo boards plugged with whole bamboo on either side. The display shelves spanned across the portal frames and connecting them enhanced the rigidity of the structure. The structure and the new product range were highly appreciated at the festival and the craftsmen were satisfied with the final outcome with some visitors placing orders for the exhibited products. During the course of this project we learnt a lot more about bamboo and became more confident is using this material for structures which are more permanent in nature.

Bamboo Loveshack, UNSW, Sydney, Jul 2005

The Bamboo Loveshack was our first major structure which had all the components of a small building. It is Australia's first student designed and built bamboo structure built for the Eco-Living Centre at the University of New South Wales (UNSW) Sydney. The structure is based on the original Loveshac*k* designed by Darwin based architect Simon Scully which was built by students out of steel for the past two years as a part of the winter elective at UNSW. The elective was run over 3 weeks full-time with students from varied departments of the Faculty of the Built Environment. Most of the students were working with bamboo for the first time and knew very little about this amazing grass. Our intention was to provide the students with a holistic understanding of bamboo starting from its various species, harvesting, treatment, connections and assisting them with the construction process.

The Bamboo Loveshack used the same form as the original design with some modifications to suit the site and the new material. The driving motivation was to test if the same form that was designed for steel could be used for bamboo. The material was sourced locally from northern NSW and the species of bamboo used were *Phyllostachys Bambusoides* (for the main structure), *Phyllostachys Aurea* (for decking and smaller members) & *Dendrocalamus Asper* (for foundation). All the bamboo was treated prior to beginning of the elective by dipping it in an aqueous solution of boric acid and borax.

The elective started with an introduction for students into the various species of bamboo, their potentials and limitations, our past explorations and understanding of the qualities of bamboo. Simultaneously the students were divided into teams based on the various components of the structure: foundation; floor; walls; roof and deck. Each team was responsible to design and build their part of the structure while coordinating and collaborating with the other teams. The first week was focused on design development and laboratory testing of prototype connection details with the help of an engineer John Carrick, the second week was for the fabrication of various components in the workshop and the third week for on-site construction of the structure (Figure 2).

Bolting was used as the main connection detail throughout the structure with some joints poured with quick hardening cement to increase its rigidity. The wall panels within the structure were made as various types of bamboo screens sandwiched between two layers of persplex to provide weather protection. Bi-fold timber doors at the corner of the structure provided access while opening the building towards the garden. The deck around the structure was cantilevered from the main support to create a floating effect (Figure 3).

The Bamboo Loveshack was an intense workshop run over the period of three weeks, which provided an intense learning experience for everyone involved and raised a lot of issues for us to reflect on. Through subsequent evaluations of their written journal, students demonstrated strong learning in their understanding of working with this eco-friendly material. Towards the end of the elective students presented a sense of ownership of the structure and were very proud of this shack, which was the greatest achievement of this elective. It also became a significant step forward in our own explorations with bamboo as a construction material.

Greenfield Stage Entrance Structure, Sydney, Apr 2006

The entrance to the Greenfield Ecoliving Stage was a very small project that was delivered in a short time frame and had to be simple enough to be built by volunteers. As an entrance structure the design needed to be an inviting and attractive entrance canopy to a marquee that would house the Greenfield Stage. The purpose of the stage was to spread awareness about sustainability by a series of workshops and talks and hence bamboo was the right material to create the entrance structure.

The design of the structure was based on two intersecting hyperbolic paraboloids supported on a frame structure with posts at varying heights. The resulting form resembles the flight of a bird and creates a curved and flowing effect using straight and rigid bamboo poles. The form revolved around two major constraints for the project i.e. the maximum length of available bamboo was only 4m and was on loan from the supplier for the duration of the festival. Lashing with sisal rope was used for connecting the bamboo poles because it would be easy to construct by the volunteers as well as not damage the bamboo. Treated 'Moso' imported from China by House of Bamboo in Sydney was used for the structure. Preparing drawings was difficult due to the complex form of the structure so we had made a scaled model to get the right form and effect. The model was then used to explain the structure to the volunteers and as a reference during construction process (Figure 4).

We briefed the volunteers on the design of the structure and it was built in a short time frame of just two days. The final product created a dynamic effect of a movement frozen in time. It also created interesting light and shade through the rhythmic use of bamboo.

One of the volunteers was from construction background and was really impressed with the outcome of the structure and the ease with which it could be constructed. He had learned a new skill of working with bamboo and wanted to try building one structure at his home. We were glad to have engaged at least one such person in the exploration of bamboo construction.

Peats Ridge Festival Walk-way structure, Sydney, Australia, Dec 2006

Peats Ridge Festival is a sustainability, arts and music festival held every year in the Glenworth valley at Peats Ridge, one hour drive north of Sydney. The festival is held during the New Year with approximately 8,000 people attending. The site for the festival is set in a beautiful valley surrounded by national parks, with a creek snaking through the middle creating several paddocks. The bamboo structure was to be designed so that it became the main entrance gateway and walkway to the festival area from the camping area. One of the main challenges was to make the structure of a significant scale with respect to the huge tents and marquees that were to be erected in the festival paddock.

The concept for the structure was derived from the adjacent creek and beautiful natural surrounding with a primary aim of making a structure that was simple yet dynamic, easy to construct and belonging to the place. The idea was to make the structure as an experience for the people to walk through while admiring the beauty of bamboo and the surrounding nature, rather than making a gate separating the camping area and the festival site. The entrance was to be built by volunteers and hence needed to be simple in terms of its construction method but still have a visual presence. It also had to be dismantled once the festival was finished. The design consists of curved overlapping walls made out of vertical bamboo posts of varying heights, placed at approximately 30cm apart. Three different interlocking portals of varying heights make up the entire structure with a total length of 25m and a width of 4 to 7m. The closely spaced vertical bamboo poles create a sense of enclosure screening the festival site and the overlapping adjacent walls allows for an opening, providing a glimpse into the natural surrounding and the festival site. The roof of the structure was also made of straight bamboo poles creating various interlocking hyperbolic paraboloids. Lashing was used as a method of connection as it would allow for the necessary flexibility in the organic form and would be easy to construct without any special tools. Bamboo strips were lashed on the top of the vertical bamboo posts to keep them vertical and it also acted as a beam to support the roof members.

The bamboo species used was *Phyllostachys Bambusoides* which was sourced locally from a wild patch in Glenorie. Since this was a temporary structure it was not necessary to make any concrete foundations and the bamboo posts were directly fixed in the ground. There were some last minute changes to the original design due to the available length of bamboo and some on-site challenges but the organic nature of the design accommodated these changes and in fact enhanced the beauty of the structure. One such modification was the gap in the roof which was left because of the unavailability of the required length of bamboo. While we were contemplating on the ways to resolve this issue, someone suggested that it would be full moon in a couple of days and since the structure was facing east the moon would shine right through the gap in the roof, which would act as a pause point for people walking through the structure in the evening. So the gap was left as part of the design and in the evening we did see the full moon unobstructed through this void in the roof. Brendon, a sculptor and one of the volunteers came up with an idea of incorporating bamboo wind chimes with the structure. This added another dimension of movement and sound to the frozen dynamic form of the structure which created rhythm of light and shade (Figure 5).

The structure looked completely surreal at night with all the colourful lighting and was highly appreciated by everyone who had walked through it. The owners of the site liked the structure so much that they wanted it to be retained. Hence till this date, the structure stands on the site, its condition unknown, since the entry to that part of the paddock is restricted but we are sure it will slowly deteriorate and become one with the land.

Chicken Shed Workshop, UNSW Eco-Living Centre, Sydney, Jun 2006

We had conducted a community workshop in Sydney which involved building a small shed structure to house 5-7 chickens at the Eco-Living Centre of University of New South Wales (UNSW). The purpose of this workshop was to introduce the participants to the various possibilities with bamboo as a construction material and to enable them to build with bamboo in their backyard. The participants were also involved in the concept design of the shed that used passive design and permaculture design principles. Apart from building the structure out of

whole bamboo, they were also taught the skills of making bamboo strips and weaving bamboo mat which was later used as one of the walls.

The structure was approximately 1.2m wide and 2.0m long with a single sloping roof opening towards the north to capture the sunlight. The north wall had large opening to allow for the sun and the south wall was made of bamboo mat rendered with mud for insulation. The floor of the shed was made of recycled concrete with a layer of straw on the top. The structure was approximately 1.5m high to allow easy human access for cleaning purposes. For this structure we had experimented with a specific connection detail that is commonly used in the construction of temporary metal fencing. The fencing connection was essentially a metal clamp which clamped the ends of bamboo. Each member of the structure had to be selected carefully such that its ends had same diameter because the clamps were of standard size. Rubber padding was used between the clamp and bamboo where necessary to achieve a tight hold. By using such a connection we were able to reduce the number of bamboo poles significantly as compared to bolting connection and that too without compromising the strength of the structure. This was particularly possible due to the small size of the structure (Figure 6).

Although the construction of the shed was not finished due to various reasons, the participants got a hands-on experience in working with bamboo and were highly inspired to continue doing more. This particular clamping detail had some limitations because of its standard diameter and rigidity, but the good thing was that no holes were required to be drilled through the bamboo, which would help avoid its cracking. We think that a similar but more flexible clamping detail if designed specifically for bamboo construction could be a really useful connection. This could make the building of small structures out of bamboo a very quick and easy process.

Our reflections:

With every bamboo project we have learned something and advanced our knowledge. At this point we would like to reflect upon some of the learning.

- The form of the Bamboo Loveshack used the traditional post-beam construction system and was originally designed for steel. Although the connections were redesigned for bamboo, the bolting connection created pin joints which had to be stabilized by diagonal members and truss system. After the structure was finished we realized that a more integrated structural system, where all the structural elements like floor, wall and roof are not thought of separately but as part of one whole structure is required if full potential of bamboo is to be utilized.

- Since bamboo is a natural material the construction process is very different compared to other industrialized materials which are available in standard size. During the construction of Bamboo Loveshack, the foundations were laid only for the floor team to realize that it didn’t line up with their pre-fabricated floor frame in spite of all coordination on drawing board. Similar issues were faced between the floor frame and the wall frame alignment. Hence in bamboo construction a real on-site involvement is required to get a successful outcome, this is clearly visible in the works of architects like Simon Velez.

- One of the most important lessons from Bamboo Loveshack was that although bolting is a preferred joinery for large structures that are built in Colombia using Guadua, it is not suitable for other structural species which have thin walls like *Phyllostachys Bambusoides*.

- Clamping was used as a connection detail for the Chicken Shed structure to overcome the issue of cracking in bamboo due to bolting. The clamps we used were made for metal fencing joints and had standard size. We used rubber strips at the connection to accommodate the minor change in the size of bamboo but it was still difficult to find the bamboo of right size and get a strong connection. A similar kind of custom built clamp with adjustable diameter and angle would be very useful for making bamboo structures that are quick to build.

- Lashing was explored for temporary structures at the Greenfields Stage and at Peats Ridge Festival. Lashing allows for slight movement of bamboo poles in relation to each other and also retains the structural strength of bamboo as there is no need to drill a hole. But it also has its drawbacks in terms of requiring regular tightening and maintenance and is time consuming to build.

- Custom made joints like flexible clamping or other kinds may be one of the connection details that might work well with a natural, cylindrical and tapering material like bamboo. We think that a lot more experimentation is needed from our side to find a right connection detail that is strong, durable, easy to build, uses minimum level of skill and works for various species of bamboo.

- Most of our work to date has been limited to temporary structures and pavilions due to the lack of building regulations in the western world. This makes it extremely difficult to get building approvals for any habitable structure to be built out of bamboo. More work needs to be done to get some standards for bamboo construction, which has been acknowledged in many research papers.

Future projects:

Our explorations with bamboo have ranged from products and furniture items to temporary exhibition structures and small permanent sheds. Though we haven't yet constructed our perfect dream structure, but to ignore the vast array of our previous 'less than perfect' structures is to miss out on a lot of creativity. It is only with these past experiences that we have a platform to celebrate what we have done so far and develop further structures.

Bamboo has the possibility to replace timber as a sustainable alternative material in many structures especially in small scale buildings and small structures. Our main interest is in using bamboo as a low-cost, ecologically and socially sustainable construction material.

Some of the projects that we are currently working on include:

- Design of a structure based on the principles of Pyllotaxis. Currently this project is at a conceptual stage but we see lot of potential with this form which will result in a structure that would be lightweight and strong.

The resulting form could be used as a temporary shelter that can be built easily in areas that have an abundant supply of bamboo or used as a permanent dwelling (Figure 7).

- Design an eco-home by combining bamboo with other environment friendly materials like mud bricks, straw bale, etc. These eco-homes could also be used as cabins for eco-tourism purposes.
- Design a clamping connection detail that is adjustable. This would make constructing temporary bamboo structures very quick and easy to assemble as well as dissemble. The connections would be made from strong material like iron so that they can easily be reused for a long time.

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Figure 1 – Exhibition Stall

Figure 2 – External view of the Bamboo Loveshack

Figure 3 – Internal view of the Bamboo Loveshack

Figure 4 – Greenfields Stage Entrance

Figure 5 – Night view of Peats Ridge Walkway

Figure 6 – Connection detail for Chicken Shed

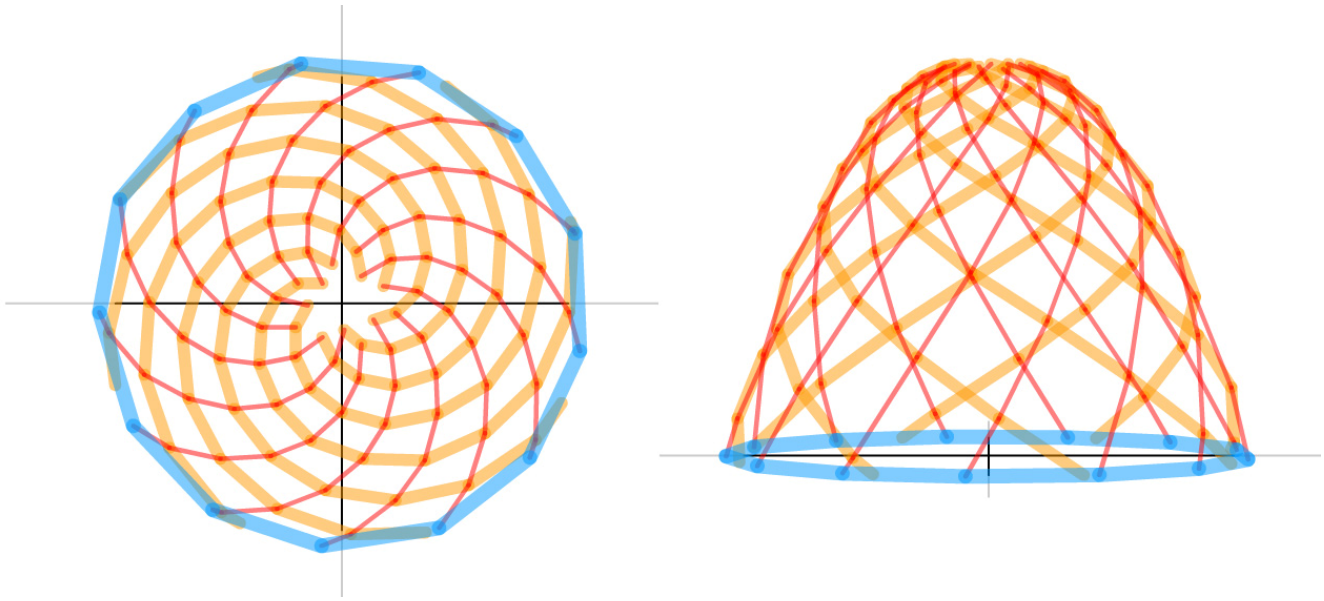

Figure 7 – Phyllotaxis Dome concept

Construction and Construction Methods: Bamboo Building Essentials

Darrel DeBoer
Architect

Megan Groth
University of Washington

Note to Committee

We have imagined this presentation as either a lecture with a significant discussion component, or as a hands-on, design session. As a lecture, we would quickly present our twelve points of building essentials – complete with case studies and specific, regional and global examples – in order to begin a dialogue with participants about what they have found to work well in their local species, ecosystem, and cultural tradition. What is the most important information about building with bamboo? And what is the most effective way to distribute this information to the greatest number of people? During this conference, we are looking to not only share the information that we have gathered from various experts around the world, but also to use this event as a starting point toward increasing awareness about bamboo building principals and skills that can help millions of people around the world.

Abstract

Bamboo buildings have been attempted everywhere that bamboo grows, but only rarely are these buildings designed for the long-term. In remote places, people partially reinvent what has already been refined after much trial and error. We will present the basic steps we have found necessary for successful structures in order to start a dialogue among experts about the elements of good bamboo building design. We would also like to discuss the best ways to properly distribute this information in the various regions represented by the participants. This is not an academic paper in the sense that it presents original research. It is instead the collected experience of hundreds of papers put into some usable form that can be easily spread around the world. In summary, these principles include:

1) Plant the hardiest species for the climate

2) Plant where there is plenty of water and sun

3) Harvest mature poles

4) Harvest when the sugar content is lowest

5) Use less-toxic treatment methods

6) Work with the bamboo once shrinkage has taken place

7) Plan on splitting

8) Don't let the bamboo touch soil or concrete

9) Give the building a good hat and boots

10) Achieve shear strength with triangles in your truss design or with shear walls

11) Build with triangles

12) Use bolted and filled joinery systems

Paper

1) Plant the hardiest species for the climate

When growing bamboo species for building, choose varieties with thicker walls, as well as a cold tolerance that relates to your area - the key is to plant a species that is capable of withstanding the coldest seasonal temperatures. Refrain from using fertilizer on the bamboo, in particular nitrogen, which leads to rapid growth and weaker poles.

The current international building code tested strength of a species from a single place and time as applicable for the entire species, regardless of growing conditions. Several builders have put forth the "unproven" idea that the density of the wood is a better measure of how soil, rainfall, care and age have all had their effect - regardless of species. Unfortunately, there are currently no grading or quality standards for bamboo poles. This means that the purchase of poles involves a great deal of faith and relationship-building between buyer and grower.

Different species are chosen for import into the U.S. because of a unique visual characteristic like striped leaves or colored culms. For builders, the most intriguing species are seen by others as "just another green bamboo." But imagine what we consider the holy grail of bamboos: in the tropical latitudes of the Himalayas, over thousands of years, plants have been forced to adapt to the rise of the mountains to very high elevations. So, the unique combination of a clumping, cold-tolerant, large diameter with strong fiber and tremendous pole production when grown in a more favorable climate might exist.

2) Plant where there is plenty of water and sun

Bamboo requires plenty of water year round, as well as an abundance of sunshine. For this reason, bamboo is seen growing wild in ravines and along the banks of rivers and in places with a Monsoon hot-season climate: tropical Southeast Asia, the temperate foothills of the Himalayas, and the tropical northern half of South America primarily.

In places where there is less rain (i.e. southern California), wastewater is a good water source. The dense feeder roots make great filters and bamboo is capable of handling and using much hotter sources of nitrogen than most plants. Moso bamboo, for example, seems not to thrive unless watered every day.

When growing bamboo in places without monsoon rains, liberal use of mulch and cardboard will both hold in the moisture and allow the plant to use less energy otherwise needed to force its roots through the heavy clay soil. Additionally, oxygen enters through the rhizomes of the bamboo, therefore it is important that the plant is able to drain well. Mulch will allow for this process to happen efficiently.

The amount of sun required varies by species and past experience is catalogued by the American Bamboo Society. It is important to know that some bamboo species are native understory plants and need to be established in partial to full shade. In general, though, growth rates are significantly faster in full sun.

3) Harvest mature poles

Bamboo reaches maturity three to six years after the shoot first emerges. At this point the fibers are strongest and there is less moisture in the culm. The beauty of planting your own bamboo is that you will know the age of your culms, and therefore when it is time to harvest. Unfortunately this is often not the case, but there are a few tell-tale signs to look for in order to determine whether or not a culm is ready to be harvested. In tropical climates, the oldest culms are the ones with the most lichen and mosses. Clean, smooth poles should be avoided as they are probably new shoots and are lacking the strong structural qualities needed for building. Some species (i.e. Genus *Phyllostachys*) have a characteristic white wax ring below the nodes that will gradually darken over time. Once it is no longer "white," the pole is in its third year. Other species acquire color slowly over time, for example *Phyllostachys nigra* and *Phyllostachys nigra* "bory" acquire their dark spots over several years. Also in the *Phyllostachys* genus, plants grow another sub-branch on the same lateral branch each year - therefore the age of the culm can be found by counting the branchlets.

4) Harvest when the sugar content is lowest

It is best to harvest bamboo when the starch content of the plant is lower and therefore less susceptible to attacks by insects (though some argue that this is due to seasonal changes in insect populations and not the starch content of the plant). There is rich regional folk lore and traditions that describe the optimal bamboo harvesting day and time. In Colombia, for example, it is widely believed that bamboo needs to be felled during the waning moon, just before sunrise. In parts of India, bamboo that is cut during the bright, new moon is believed to be less susceptible to insect attacks. The important point is to harvest when sugar is at a minimum: after the spring and fall growth spurts, and following the rainy season can make a difference.

When felling the culms, cut at the base, “over the first node located above the ground", using as narrow a cutting tool as possible to reach between culms. A battery-powered Sawzall, chain saw, machete, pointed handsaw or a hatchet are all effective. Make sure that a bowl isn’t formed by the node that will collect rain water and rot the rhizome. While bamboo is relatively resistant to pests, the reason for the concern about sugars is related to attacks by powder post beetles, *dinoderus minutus*. Termites are generally uninterested, and other insects see the bamboo more as a home than food, the beetles will drill their 1/8" diameter holes and eat until very little

structure remains. The damage might not be obvious since the beetles tunnel back and forth within the fibers and only visibly emerge when they're done - at which point the thin-walled poles can be crushed with your bare hand. The advantage of choosing the thicker walled poles is that the edible portion is the pithy interior fiber, not the structural exterior material. In this case, the pole will retain its structural qualities after an insect attack.

5) Use less-toxic treatment methods

There are two main ways that treating bamboo extends the life of the pole: it makes it distasteful to insects and it changes the pH and keep the moisture levels low to keep out fungus.

When thinking about treatment methods, consider how framing lumber is treated in your area, and do the same. Since Douglas Fir is never used exposed to weather, then keep bamboo inside in order to achieve maximum longevity. In general, untreated bamboo poles have a life of 1-2 years when exposed to the elements, 3-5 years when sheltered from rain, and up to hundreds of years when used indoors. The current less toxic treatment salts remain water soluble, but the task of treatment is to get it into the interior fibers, so it can, in theory, be exposed to the rain for awhile... it's just not great practice. In particular, do not expose the interior of bamboo to the outdoors. If bamboo is split open to reveal the interior, the sugar will cause little black dots of mildew to appear as soon as the rain starts. Surprisingly, one of the most effective treatments combines the ingredients found in eyewash and laundry soap. Boric acid -- found in Visine and Dr. Pepper, and most inexpensively sold as a fertilizer or mouse poison -- has little ill effect on mammals. Combine in equal parts with borax (sold as Twenty Mule Team laundry detergent) is not good for plants, but at about the 5% concentration that won't dissolve further, it is effective against both fungi and powder-post beetles. In Bali, the vertical soak diffusion method is used where the borax mixture is poured into the pole which has had the nodes punched out, leaving only the last one. The mixture is left in the pole for nearly a week where it diffuses through the pithier interior cell walls.

Another treatment method is the Boucherie system: a form of pressure injection that must be done within 24 hours of harvest or the capillaries close. This one can be a challenge. Various experiments have been done using smoke, but with mixed reviews. Japanese companies have perfected the method but the specific details have not reached other countries. At the moment, there are good things to say about hydrogen peroxide (but it's relatively expensive) and various plant-based traditional treatments practiced locally and worthy of intense study.

6) Work with the bamboo once shrinkage has taken place

It is possible to work with fresh, green bamboo if adjustable joinery (a system that can be tightened over time as the poles shrink) is used, but it is recommended to work with dry bamboo. After harvesting the bamboo, leave the culm in the grove - upright, propped up off the ground and with the branches and leaves still attached - for a few weeks. It will continue to photosynthesize and use up the remaining sugar in the culm until the plant runs out of water. The powder-post beetles are unlikely to enter the culm during this time because they enter through the cuts (i.e. where the branch is cut off).

Moisture content varies greatly between culms (as well as between sections of the same culm) and as the bamboo dries it will shrink about 6-10% in diameter, but almost not at all along the length. A general indicator

is that once the green color is gone - which might be between 6 weeks and 6 months - it may be checked to see if it is in the desired 10-15% moisture content. Air-dry the bamboo by storing it in a covered area, out of the sun, preferably vertical for good air circulation and to keep it from becoming more curved months or so after harvest.

7) Plan on splitting

When it comes to bamboo splitting, do not ask "whether," ask "when." The bamboo you are working with will split, the key is to be prepared for this and know what to do when it happens. Outside of a few species of guadua, the fiber structure of bamboo runs in one direction, the length of the pole. The only exception is at the node where the fiber turns and runs perpendicular to the exterior to fill in the middle of the pole. Unfortunately, when the pole dries, the shrinkage of about 6-10% is entirely across the grain and the node shrinks differentially from the rest of the pole, causing the pole to split. This is especially true when a heat source, like the sun, hits the pole on just one side. Fence builders in Japan have learned that completely punching out the nodes can often prevent splitting. The stress can also be relieved by making a pre-emptive cut on the bandsaw the length of the pole, then gluing it back together (just as with a curly piece of wood). Joinery that wraps all of the way around the pole can also contribute to holding the pole together. Using banding or fiber binding at crucial joints will keep the fibers together, even if it never splits. With hollow bamboos, using something as simple as a radiator hose clamp can hold the fibers together. Joints can also be wrapped with twine for a different aesthetic.

Choosing the right bamboo specie for the job is extremely important. Some of the solid bamboos are much less prone to splitting: *Phyllostachys heteroclada* 'solid stem,' *Dendrocalamus strictus*, *Otatea acuminata* 'aztecorum', and several of the *Chusquea* genus. Of the hollow bamboos, those of the *Guadua* genus are generally thicker walled and have more of a helical fiber pattern. The lower portion of the culms especially will accept a nail or screw without a pilot hole, a characteristic not found in any other bamboo.

8) Don't let the bamboo touch soil or concrete

Regardless of climate, a main objective of bamboo design is to prevent the wicking of moisture on the ground up into the bamboo. Building codes generally require eight inches between wood and soil, and at least several inches between wood and exterior concrete.

The other simultaneous need in a post is to prevent it from pulling out of the ground. A good joint puts a separator like metal between the bamboo and the foundation, while at the same time holds onto that metal vigorously. The simplest way to achieve this is to make a bridge between the cellulose (bamboo) and the damaging water (in the ground or concrete). For example, use a piece of steel rebar or angle iron cast into the footing and mortar it several nodes into the bamboo to prevent withdrawal.

9) Give the building a "good hat and boots"

This is undoubtedly the most important lesson and one that is often overlooked. The first choice is to use all bamboo *inside the structures*. This will keep the sun and rain from affecting your building. Even small rafter tails peeking out beyond the overhang are guaranteed to split and provide insect habitat in a couple of years.

In the United States, millions of board feet of our favorite framing lumber - Douglas fir - are used, but almost none on the exterior where it would quickly rot. The first thing that happens is the sun and rain dissolve the protective wax, the surface bleaches to silver, the heat from the sun on only one side of the pole causes it to expand unevenly then split, and the fibers become brittle and break.

10) Achieve shear strength with triangles in your truss design or with shear walls

Use bamboo in tension and compression, not bending (imagine the flexing of a pole). It is important to recognize that bamboo wants to bend, but it is put to best use in pure tension or compression. Structural design principles for bamboo structures are the same as any other building system: for longer spans, design trusses. This will keep the poles from acting in bending.

When designing, do not ask for the same curve in multiple poles. Tight curves especially will be more of a fight than you want. Recognize the ever-present curvature. Most bamboos naturally curve in two dimensions not three, in a direction that is related to the branches. Poles can be turned until the flat is found in order to put multiple poles in the same plane.

11) Build With Triangles.

Designing a building with a series of triangles will provide stability by making the entire structure rigid. No shear walls will be required to carry the horizontal forces down to the ground. On the other hand, to rely on the strength of the joinery to this degree means that joinery should be optimized as much as possible. Additionally, longer spans have two or three bamboos stacked in the structural equivalent of a glu-laminated wood beam.

12) Use bolted and filled joinery systems

Here is where planning ahead helps the most. If you plan a structure that is quick to assemble and relies on simple joinery that is hundreds of times stronger than traditional lashed or pinned joints, then a relatively small investment in hardware makes perfect sense.

In western cultures, we think of our favorite building materials, especially wood, as subtractive. We start with a large piece and keep making it smaller until it is right. The surface is usually made flat and of standardized shape. With bamboo, the thinking is more akin to masonry, with the shape predetermined and not easily changed. The key is to celebrate the difference and use bamboo where the shape is an asset and very visible in the finished surfaces. Design the structure in order to avoid time-consuming joinery, especially where materials must be coped and curved in order to meet the bamboo. This will allow more effort to be put into smart design rather than into laborious repetition.

Conceived by Simon Velez and Marcelo Villegas, the mortar-filled joint is a recent development in the history of bamboo buildings, and one that has made the largest impact.

Seven Concepts To Build A Bamboo Bridge

Jörg Stamm
Thailand, 29 de Abril de 2009

This article compares the basic concepts of traditional construction systems with modern and contemporary ones. It wants to analyze them in terms of raw material consumption, simplicity of techniques and structural problems. The article succeeds a conference on "Evolution of construction systems in Bamboo", presented in Spanish language in Puebla, Mexico in March 2008. But here the theme is focusing on how to apply those concepts to bridges, which are the maximum expression of load bearing structures. Obviously these examples can be used also for roof structures and are part of the basic formation of architects and master builders. Based on the important scientific publications on bamboo trusses and joinery by engineers like Prof Jules Jannssen from Eindhoven University in the Netherlands and Kaori Takeuchi at National University in Colombia, this article offers a more conceptual approach, without repeating or going into the numerical engineering. That detailed analysis has still to be carried out by a specialist.

Abstract

After two decades of modern bamboo construction, good and bad examples, we are evaluating and forging the bases for norms to include bamboo in future construction industry. To ensure uniform raw material supply we have advanced considerably in themes like sustainable harvesting, preservation, drying and joinery. To define homogeneous characteristics for the desired poles an "ICONTEC" Norm compendium is already regulating the above mentioned themes for Colombia. Although the daily reality is still far from this goal, this regulation gives an important orientation for the forestry sector, to redirect its production towards a secure market with added value, instead of the traditional uses like "throw away" formwork. But the norms also include the danger of limiting creativity by favoring simple and commonly known systems. Independently of the broad variety of joints there is also quite a variety of structural concepts, in order to gather the elements of a truss. Similar to the need for norms in quality of poles and norms for bamboo joinery, we also need a clear order for the different systems of load bearing structures.

Construction in Colombia is based on traditional post and beam concepts. At a technical and professional level there is a lack of knowledge of other methods. This article offers some concepts that are very suitable for construction with giant bamboo poles. Developing one upon another, seven different concepts are presented. Some of these structures can even compete technically and economically with constructions of industrial materials. This article presents:

- *Construction systems for bamboo in their structural essence of long and slender poles.*
- *Bamboo poles are composed to recreate their natural length and cover even bigger spans.*

- *Suitable Joints for Bamboo construction with short and straight pole segments.*
- *Traditional Truss structures that cover big spans and respond to the required loads.*
- *New structural aspects for natural fibers in contemporary architecture.*

Introduction

Several universities have been investigating how to apply modern truss systems with bamboo, basically transferring the typical models of steel frames. Other approaches have been from experienced wood builders, which transfer their knowledge of traditional wooden trusses with more or less success into the hollow and crooked bamboo culms. Both ancestors give quite good guidance for frameworks needed in houses and schools, but still fall short to provide solutions for major roof structures and bridges, as the internal forces of a truss increase exponentially to the length of the free span. A 40 meter Bridge has double the load and the cost of a bridge with only 30 meter span, although it covers only 30 % more distance. The bamboo truss does not live up to a conventional truss made from steel or wood, which has been perfected over time and is nowadays a mature result of structural evolution. So it's understandable that these engineered structures, copied into bamboo, very seldom reach the acknowledgement of a structural engineer and consequently lack the financial input of the user.

Nevertheless we are closing the gap and have investigated the load bearing behavior of bamboo poles and improved the joinery techniques like mortar grouting. This trick allows transferring the loads from one bamboo to another, by using not only by steel bolts, but also through the cement cylinder inside the hollow bamboo culm, that distributes the pressure on the thin wall towards the strong diaphragm at the nodes. On the other hand we have to develop structural concepts that enable us covering bigger spans as the normal 3 to 5 meter in traditional dwellings. Some of the concepts presented here are contemporary three-dimensional trusses, other construction systems take in mind the advantage to work with the natural culm length and use the full potential of the high tensile strength of bamboo.

Based on the conference on the "Evolucion de Estructuras en Bambu" published in Puebla, March 2008, we can list the structural concepts in a system according to its complexity.

A. Traditional Structures B. Modern Structures C. Contemporary Structures

A) – Reduces the traditional structures into woven systems or simple post and beam concepts, using fish mouth joinery or natural fibers like vines and raw hyde. Basic tool is the heap knife.

B) – the modern structures are based on traditional concepts but have a more sophisticated level in joinery techniques. Basic concepts of two dimensional trusses are copied by civil engineers. The elements are straight and relatively short sections of the culm are used. The joints are bolted and grouted with cement. Although the tools like electric drills and chizels are quite simple, a very high skilled labor is required. The raw material needs to be straight and uniform.

C) – the contemporary structures have to pay respect to principles like protection by design, but it´s geometry is three dimensional and “free of form”. It plays with curves, “shell” shapes, “hypars”, joinery is either very simple or highly engineered. The size of these buildings can be very big, due to the use of the natural fibre lengths of entire bamboo culms. The raw material can be curved, conical and crooked, short or large, depending on the object.

Methods

The construction system depends on the availability of the resource and the technical grade of the tools. These conditions and the geological situation of the riversides, together with the ingenuity of the Pontifex (Latin for bridge builder) determine which concept is to be chosen. The article name “seven concepts” explains the simple to the complex, and later discusses the advantages and disadvantages concerning their application using bamboo poles.

This article will not go further into engineering specifications or joinery details as this merits a separate discussion. Moreover this paper is a conceptual tool for the architect and master builder, to go through a variety of possibilities and analyze how to combine the structural considerations with the external factors at the chosen site. A clear distinction of structural concepts enables us to see and to determine the direction of the forces and their reactions. The quantification and exact determination of these vectors must be reviewed obviously by a structural engineer.

1. The Beam
2. The Arch
3. The Suspension Bridge
4. Cable stade Bridge and Cantilever
5. A Bridge with form active surfaces
6. The Truss
7. Space frames

The article can be seen as a guide for the planning of bamboo bridges, although its approach is merely focusing on structural concepts, not taking in mind the important and complex architectural contexts like functionality, social and aesthetic aspects. The structural concepts here proposed are not only limited to bridges, which also can be either small or big, simple walkways or for vehicles. But there are much more challenges to a bridge than to a roof truss, due to the mobile load assumptions it has to deal with. A cattle herd on a rural bridge outweighs easily a line of cars. Passengers on elevated walkways sometimes have the bad habit of leaning towards one side, for example to gain a better view to the sports event on the road below, creating unprecedented lateral forces on the handrail that can flip the bridge over its lengthwise axis. The high load assumptions of 500 kg in

the norm for passenger bridges have their origin in the prevention of these disasters. These norms generate tremendous costs which the public sector has to assume, as he created them.

But a private client who just needs a personal access road over a creek to get to his property can have a look for more economic solutions. The cost of the roof is also always a discussion point, but taking in mind that the static height of a truss is almost giving the necessary roof support for free. There is no doubt that the roof will increase the life expectancy to minimum 30 to 50 years, similar to the standard of north European Wood Bridges.

And there is one warning to the urban developers: bridges shouldn't have stairs! Although there is a growing need for access ways and overpasses in cities, there is apparently no way to prevent children and adults to cross below the elevated walkway. Ramps are more comfortable to use than stairs, however they are more expensive, as their inclination should not pass 8 %.

Description

The Beam

a. The bamboo: - a tube with ring reinforcement

The bamboo tube is an excellent structural element. It is strong outside, where the buckling forces act and it is light and hollow inside, in its neutral zone. Rings act like reinforcement to prevent the tubes circular walls from the dangerous oval and interconnect the fiber bundles with each other to decrease splitting tendencies. A typical guadua supports about 2 tons of tension force and 700 kg of compression per square centimeter wall thickness. It also is flexible and quite resilient against buckling, although the engineering literature says the opposite. This paradigm is rooted in the definition of old-fashioned testing procedures where the culm was tested for flexion by pressing him laterally and deforming his tube just at a place without nodes. In its natural habitat we see a slender and very tall culm bending surprisingly strong in the winds, but rarely does it break. By evolution this culm developed a refined tissue composition and wall thickness, which in every section does respond perfectly to the challenges by wind force and the leverage created on the long pole. This property has a lot of incidence on design of structures, because we can choose if we go for the strong and heavy parts or for the light and flexible one.

In the base section we find a thick wall and thick fiber bundles surrounded by big parenchyma cells, which serve as shock absorber for the strong leverage. Further up the culm, the ratio changes from one third of fibers versus two thirds of parenchyma towards the opposite. This denser composition allows higher elasticity, but is less tolerant when it approaches the breaking point. Splits from the upper culm sections have shown in tests less fatigue than tempered steel. But the upper part is also less tolerant to cracks when shrinking of drying bamboo poles creates tensions. This is even more significant in old and mature poles whose cell walls are full of silica. The base of the culm is relatively heavy because of thick diameters and thick walls and the water retained in this tissue. But due to its tubular shape it is always lighter than a piece of solid wood of similar diameter. Wood of

similar specific density (guadua= 750kg/m3 = oak) and similar cross section would have better performance in lateral forces perpendicular to the fibre, but lengthwise the bamboo tube has less buckling. Laminated bamboo lumber would compete perfectly with oak or other precious hardwoods, but with laminated softwoods our bamboo lumber is economically out of competition, due to the high percentage (3 to 10%) of glue needed to rejoin the splits. Bamboo timber - or round bamboo poles – is vulnerable to lateral pressure, especially when the tube is not grouted and permanent punctual loads are applied. This happens often when used as a beam. The rafters transfer the heavy load of the roof tiles to the horizontal bamboo beam, which squeezes over the years. This phenomenon is also typical for ageing wood, but it is far more dangerous in bamboo, due to the hollowness of the tube. It seems that the daily change in humidity causes expansion and contraction and the cell walls over the years adjust their position to each other. Therefore it is recommended to load bamboo mainly with axial forces. Load bearing joints should be grouted to enhance their resistance. Horizontal beams should be avoided, unless their lateral load is insignificant, - like in space frames. Horizontal elements like tension beams in King trusses can be doubled and precisely designed to withstand the required lateral forces by walking passengers.

Spaced columns or composed arches are apparently very strong, but should better be calculated as several individual beams. Doubling or "Sistering" of beams will not have any significant "EULER Effect", because the contact area of bolts and dowels is very limited in round poles.

Photo 1: Four guaduas of 8 meters are joined as a "spaced column".

Photo 2, 3, 4: This sculpture designed by Marko Brajovic in Mallorca was inspired by the DaVinci Bridges, who may have seen Marco Polo's description of the "rainbow bridge" in China. Several short bamboo beams are "woven" into a 16 meter arch. These systems are quick to install and are still used for timber extraction in Germany and Austria. The arch is quite weak due to his low static height, but this improves considerably, if the tips are extended and join as a handrail, creating triangles, enabling a relatively stable 12 meter bridge.

b. The curved Beam

The thumb rule formula for the internal moment of a beam is:

Internal Momentum = (Live Load + Dead Load) x Span² : by 8

If a beam gains static height its load bearing capacity enhances. The height of a beam decreases proportionally to the force of internal moments. The bottom part of a beam is under tension, whereas the superior is under compression. Imagine these forces being theoretically split in one arch under compression and one catenary line under tension. But the cohesion of the fibers in a beam does neutralize these two forces in the center where no moments are acting. This is why in the interception with another elements by tenon could be made by cutting a groove at the center of a beam without compromising its strength. The same principle is valid for a spaced column. Tension and compression are taking place in the outer perimeter and the connecting dowels. But in the center is a neutral zone, where all kinds of beams and diagonals can be interconnected without any harm.

Without this cohesion the resulting force, in either the arch or the catenary, is transferred to the side, where it creates a reaction. The arch under compression pushes into the footings of the bridgehead. The catenary pulls on the counterweights. If the catenary is hanging high the reaction is minor than in a very little slip. That is why long bridges need high towers. The same is valid for the arch: if the arch is high its resulting moment and the reaction in the footings is less.

Arches are very powerful systems if the load is well distributed. Their main weakness is to deal with unsymmetrical and punctual loads, because the line of moments leaves the "band width" and the curve arch becomes a "straight" line. Another dangerous effect is the buckling sideways, that's why a bridge needs a certain width and diagonal lateral bracing between the arches. A good way to achieve bandwidth in both directions is the "composed curved beam", where several lines of bamboos are gathering in a package, interconnected by hundreds of bolts and dowels.

The composed beam in photo 5 is slightly curved, following the natural curve of a bamboo stem. This project is for a bicycle bridge over a canal in Amsterdam needs 5 composed beams, with a pitch of 60cm in 12 meters. The protection by design consists in a waterproof concrete slab that also functions as the road. The slab is poured on a formwork of "PinBoo", which are glue free bamboo boards made from splits and joined with bamboo dowels.

The same logic is valid for the internal moments of a bridge truss, which is just a curved beam in macro. Small spans can be easily handled with only with trusses. Bigger spans have to be combined with arches to maintain the truss height manageable. The static height of a metal truss should be 5% of its span, but in wood and bamboo a 10% ratio is the thumb rule.

Photo 5: Six curved lines of guadua bamboos are joined to a 12 meter composed beam. The 60 cm pitch is quite powerful, but it will cause a strong reaction in the bridgeheads. The lateral buckling will be controlled by a concrete slab. The connection of the beams with the footing is done with an articulated galvanized steel plate, that allows a reliable fixing on concrete.

The Arch

a. The roman arch and the inverted catenary

Like above mentioned there is a relation between the length, the height and the pitch of a beam. The line of the moments is not precisely similar to a perfect arch, but to a parabola or following the inverted line of an imaginary hanging chain, called a catenary. There is a practical reason to design an arch with a certain "band width", to ensure that the line follows the internal momentum within the limits. These forces are virtually "waving" along the arch, as the life load moves from one riverside towards the other. A bridge allows the division of this arch into an upper and a lower beam, stabilizing themselves mutually with crosses or diagonals. The static height of 2,50m between the belts is enough to allow people walking on the floor beams, where as the upper one supports the roof that protects the building. There are no additional costs for the elevation of the roof, but the extended lifespan pays back your investment immediately.

The extra weight of the roof is a calculable factor and accounts from 2,5% to 25 % of the total dead weight, depending on a wide possible material choice from zinc to tiles. A proper weight of the roof

is a kind of pre-tensioning of the truss and has a positive effect on oscillation and vibration caused by the live load. Heavy bridges a far more comfortable for the user, as the typical dead weight of our colonial style bamboo bridge is around 500kg/meter, which equals easily the required 500kg live load required for footbridges.

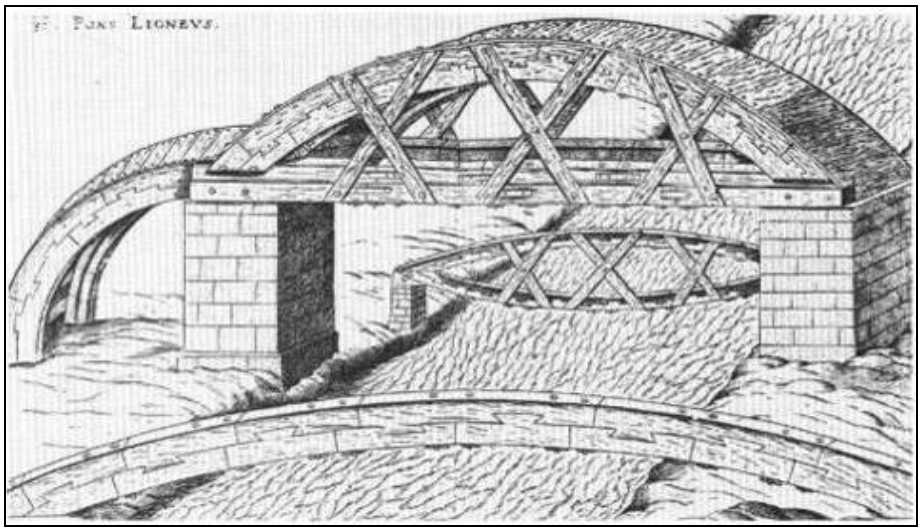

Photo 6: The formwork for the roman arches were composed with beams of short wood. The dented joints are key to neutralize the parallel shear forces of the elements. Bamboo bridges also combine short poles of 4 to 8 meters to ensure uniformity in diameters and wall thickness.

Photo 7: The Bamboo Bridge at the technical University in Pereira (UTP) was built during a one month workshop in the year 2000. The 40 meter bamboo arch stretches over a 4 lane road and has to respect a 5 meter clearance. The load test was done in a moderate progression until reaching 250kg/m2. The arch flexed only 4 cm, recovered 3,8cm, and is stable since then. The permanent deformation of 2mm is caused by the squeezed fibers at the contact zones with each other and with the thread of the steel bolts. The bridge also survived a lateral impact of a drunken truck driver that forgot to close his "bucket".

"Flat" or two dimensional trusses are a good option to enhance rigidity of arches, but it also requires additional collateral bracing between trusses. Whereas at the roof levels we can use "St. Andrews" crossbeams, at floor level I recommend an eight cm thick reinforced concrete slab, which give good comfort to passengers with animals. Collateral bracing is the first step to space frame concepts, that are discussed later.

Architect Simon Velez uses his 14 meter wide roof area to stabilize the lateral forces through three dimensional bracing, which allows maintaining a clear line by the visible distinction between of the arch with it's suspended floor and the complex network of overhead bracing, which prevents the arch from buckling.

Photo 8: Bridge "Jenny Garzón", Bogota 2003, designed by Simon Velez and named after the engineer who investigated the grouted bamboo joints for the ZERI pavilion in Hannover. The bridge has a 46 meter span and shows clearly the arch concept and its suspended floor level.

Suspension Bridges

The problems with buckling are a minor issue in suspension bridges and cable bridges, and only to be considered in the tower design. However wind and traffic can generate strong oscillations that not only challenge the towers, they are also uncomfortable for the user as was recently experienced at the Millennium Bridge in London.

a. The bamboo cable

The external section of a bamboo wall has excellent tensile properties and it can hold up to 2 tons/cm2. It is also very tolerant to torsion which makes it easy to twist into a cable. The upper culm sections are even stronger and more flexible, so even very fine splits can be obtained and twined into ropes, which can be preserved by melting the natural wax during heat treatment. Bamboo cables don't suffer from rust like steel cables in maritime areas, and its humidity uptake is far less than hemp or jute ropes, thus they have been used for centuries in shipping. Tropical bamboos don't have that much wax as subtropical species and they are preserved by smoking with tar. Some species are even named after there extraordinary suitability for rope (bambu tali – Gigantochloa apus) and are found all over South East Asia.

Bamboo rope bridges have been built during centuries, but nowadays the tradition is dying out, as these techniques are now limited to very remote rural areas. But they may be revived in a more technical way, like in laminating techniques as "Advance Bamboo Composites", which uses the tensile properties and may even be worked into beams with unlimited length. A similar technique in the glulam wood industry is called Paralam, but due to the easy splitting of bamboo, these advanced composite bamboo laminates (ABC) or Woven Strand Board (WSB) are much more competitive.

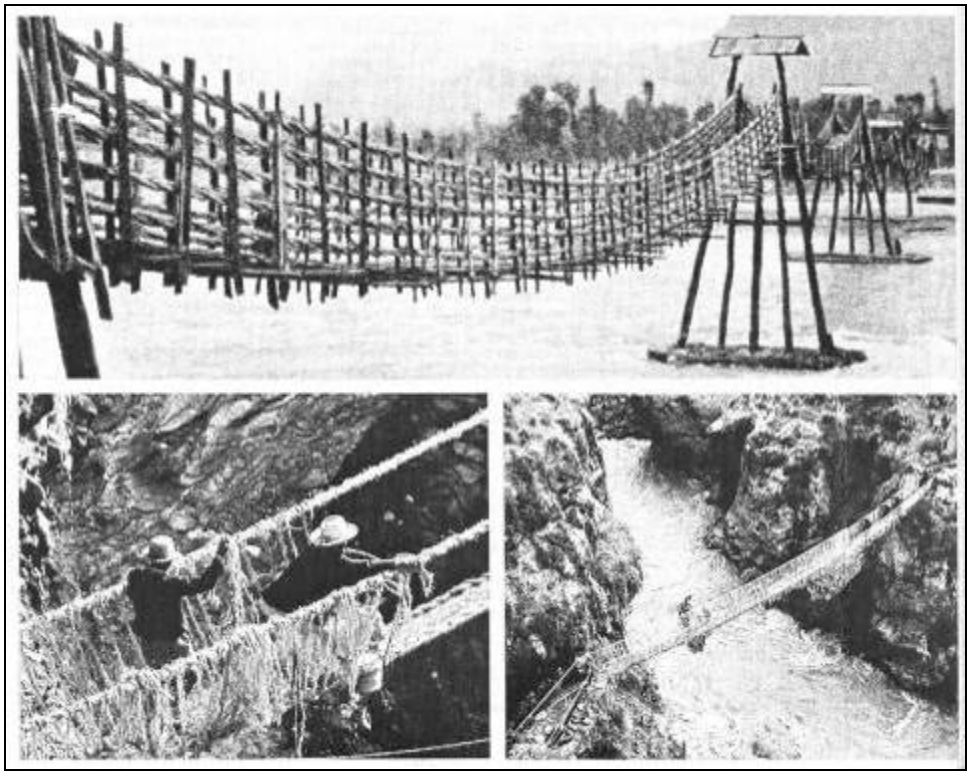

Photo 9: Bridge in Xian, China using cables of woven bamboo splits. The bamboo is a lignified giant within the grass family. In Peru grass cables have been made for thousands of years.

b. The Belt Bridge

Some Bamboos have weaker nodes than others and only distribution can generate homogeneous properties of a laminated beam. The same principle is valid for the composed beams of several poles; - the axial interconnection can be achieved with grouted rebar. The lateral stability has to be ensured by sistering and staggering of the joints as far away from each other as possible.

The tension test of grouted joinery of 12 cm guadua poles, done by Jenny Garzon in 1999, revealed astonishing data with averages between 2 and 3 tons per each grouted node. Applying a security factor of 3, it recommends 700 kg/node for axial rebar, and 900kg for perpendicular bolts (published in Hidalgo, 2003, Gift of the Gods).

The creation of a long bamboo belt bridge, similar to the Rhein - Donau Canal Bridge in Germany (photo 10) is possible, but it has to take in mind the risk of oscillations and the danger of flipping over. There are several examples of bridges in laminated beams and in the near future some laminated bamboo beams can be provided even at competitive prices. The problem of this technology has been the transport of such long elements.

But the belts do no not have to be made exclusively in laminated beams. Natural Bamboo poles can be worked into belts by staggering the poles and using steel rebar. This concept can also be used for tensile roofs over big areas. No example is known so far, but in theory the concept is very promising.

Photo 10: Belt Bridge at the bicycle trail along the Rhine-Donau Canal at the Altmühl, valley in Germany. An about 190 meters long Belt of laminated pine follows the curve of the changing momentum, while it is supported by two towers. The road is the roof which ensures protection by design over the 6 beams of 20 x 60 cm cross-section. The overall length of 190 meters had been delivered in three sections which were glued together in situ with finger joints.

Cable stade Bridge and Cantilever

Where as a suspension bridge is suspended from one long main cable, the cable stade bridges are basically two cantilevered platforms connected in the center of the span. The cables are individually suspended from the tower and can be changed or adjusted. The same principle was used by the natives in Colombia, using the tensile advantages of the natural bamboo.

a. The Páez Bridges in Tierradentro using guadua as tensile elements.

Photo 11: The former bridge of Avirama, Paez, Tierradentro, Colombia, covered a span of 40 meters. Similar Bridges are still found today but they need to be rebuilt every two or three years. Therefore a bamboo grove has been planted close to each site, so spare parts grow meanwhile the out door bridge bamboo decays. The bamboo works tension wise and the poles on each riverside form a partly cantilevered arch for the handrails.

b. The Cucuta Bridge

The archaic concept of using the entire culm in a tensile element and combine it with a arch inspired me to design a footbridge as a sculpture to contrast to a modern concrete nightmare: The fast growing town of Cucuta at the Venezuelan border had just finished a circular road distribution and needed a walkway to cross the 4 lanes. The natural material and its traditional lay out was combined with a modern industrial membrane. The towers had to withstand considerable wind forces on the tent, which were induced by a steel device on top and anchored to the footing by steel cables. The challenge was met by columns with composed columns as a pack of 6 poles forming a pyramid over 4 foundations for each tower. The tension elements are up to 25 meter long sistered culms with steel rebar in 3 grouted internodes each.

Photo 12: The arch is composed by 6 lines of guadua, stabilized by tension beams. The first "Cables" are actually columns under compression, forming a pyramidal tower, which in reality has to respond more to the loads from the membrane, than from the floor. Most of the bridge load is assumed by the arches, - according to the computer model the tension beams are actually mainly decorative.

Membrane constructions have to take in mind the wind force. The sometimes enormous tents can easily convert to sails and develop threatening forces. To avoid this threat, the membrane is tensioned into opposing curves to create an "anticlastic" surface (developed by Frei Otto from Institute for Light weight structures). The membrane is a fiberglass reinforces PVC sheet, coated with Teflon to avoid dust. This technology is still quite new and exclusive, with few professional suppliers. The bamboo bridge now has an extended life expectancy of more than 25 years and an improved reputation where formerly bamboo was considered a poor man's timber. This change will trigger investments in the agro industry and offer a future for this environmental friendly alternative.

Photo 13: The 400 m² membrane allows sufficient weather protection for the bamboo poles. Its cables are actively involved in strengthening the tower and help to support even the floor beam at the center. Although on the photo the morning sun still hits the tower, but the bridge is quite protected by the membrane at noon. The bamboo is painted with an open poring natural oil firnis, which includes UV protection and antifungal agents.

Bridge with form active Surfaces

The anticlastic membrane can also actively integrate into structural duties and not only are the cables on the edge taken into account, but also the glass fiber reinforcement has considerable strength. Rigid screens like walls are also active surfaces, both in compression and tension aspects, but they are usually quite heavy. These concepts are usually found in huge concrete buildings like at airports and convention centers. In the case of bamboo there is a nice option to work with laminated panels (plyboo) or woven strand board panels., Dr. Ing. Rottke developed cupolas with form active screens based on bamboo panels at RWTH University in Aachen, Germany. Other examples of this concept are found in Heino Engel's Book about Structures "Tragwerksysteme".

a. The Bali Bridge

The Bridge at Greenschool in Bali covers a span of 22 meters and was designed by me initially on the base of composed arches. The defense against asimetric cargo was assumed by diagonal tension beams similar to the above mentioned bridge concept of the Colombian natives. The artist John Hardy and his designer Aldo Landwehr wanted to exaggerate the inclination and the length of the

tips, which made a second layer of bamboo necessary to stabilize these long elements. But the resulting rhomboids were still not creating sufficient stiffness of a screen, so a third layer of sticks (traditional roof thatch called alang alang) were attached. The four screens act now as a form active surface and stabilize the form of the arch. No cables were needed at the tips.

Photo 14: The two opposing directions are shown in yellow (Dendrocalamus asper) and in black bamboo (Gigantochloa atroviolecia).

Photo 15: The 22 meter Bridge at "Greenschool" in Sibang, Bali, Indonesia. The two horns are typical ethnic architecture of the Minang Kerbau people from Sumatra and very good for natural air conditioning. The structural concept of the form active surface relies on 4 stiff screens leaning into each other, so the two horns do not require cables to assume the tension of the diagonals.

Photo 16: The two arches are composed by 3 bamboos of *Dendrocalamus asper*, interconected by steel bolts and bamboo dowels. The floor is made from the cracked poles, using bamboo dowels to join about 20 splits each into glue free Bamboo board, called "PinBoo".

Truss Bridges

The Framework of a traditional truss is flat and the elements are arranged in two dimensions that define their forces in vectors on the coordinates X and Y. A simple geometrical method of structural analysis is to visualize the forces in its direction and its size is by drawing vectors. The truss design depends also on the thickness and length of the elements at hand. Civil engineering has developed in the 18th and 19th century, when thick trunks weren't anymore available and the ingenuity of man had to solve the problems of their roofs and bridges with pole diameters that were quite similar to bamboo poles. One of my best books for inspirations is a reprint of a 100 year old handbook for master carpenters (Th. Engelhardt, Leipzig 1900), another one is IL31, Bamboo – Bambus, from Frei Otto's "Institute for Lightweight Structures" at Stuttgart University. His work also started as an investigation about what can be done with the huge amount of small diameter pine trees that resulted from the abundant reforestations during the 60's. Later he observed that pines have the same dimensions as tropical bamboos, but the light and strong bamboo poles were much more appropriate for Light weight construction and an outstanding book on structural concepts in bamboo was written by Klaus Dunkelberg and Eda Schaur.

A lot of wooden trusses have evolved for a great variety of applications during industrialization and became basic knowledge in the formation of civil engineers. Later, as steel became more common and cheaper, steel trusses evolved into their own direction. The WARREN Truss became popular due to the simplicity of tensile connection by Rivets, whereas KING Truss and HOWE were more suitable for wooden joinery, using compression joints for the main forces.

a. KING Truss

The KING Truss owes his name to the center post, like already used in medieval buildings like the 18 meter King truss documented in drawings of the wooden St. Peters Cathedral in 8th century Rome. Nobody knows if the person that baptized the truss did refer to the "Kingpost" as a central element that distributes power… or ….already hanging by his neck…. Both interpretations describe this importance: the truss receives the dead load from the center of tensile beam and transfers it through the diagonals back to the supporting walls. The floor beam has to neutralize the lateral push on the wall by its tensile strength, which is far greater than the sum of the vertical load. This push is absorbed by a joint and must respond to a sufficient parallel sheering capacity and resist the enormous compression through the use of a dense material. Oak was usually the best option as it is a very hard wood (750kg/m3) and has an excellent parallel sheering strength due to its strong radial fibers (about 8kg/cm2 in Engelhardt).

Bamboo does not have radial fibers, nor does is count on sufficient square centimeters and its hollowness does not allow to be squeezed, - apparently a terrible situation. But the cement mortar injection solves this problem and the cylinder transfers the sheer load to the next diaphragm, where fiber cells are interwoven and avoid splitting.

In most bridge cases the bamboo trusses transfer the load of the diagonal compressors directly to the bridgehead, to avoid the above mentioned squeezing of the tension beam. The reaction caused in the footings is similar to the internal momentum of a beam, because the tensile elements of the truss do not absorb any lateral forces. The floor beam's duties are limited to support the gangway and to avoid buckling, but this trick allows us to built bamboo trusses up to 30 meters.

Photo 17: Bridge in form of a "Box". The KING Truss of 12 meters was made in Guadua *chacoensis* en Maceio, Brazil. The style is a true copy of successful systems used in the middle ages and colonial times. Traverses double beams are hanging under the floor, which gives more internal height for the passenger. The crushed bamboo mat called "esterilla" provides the formwork, and the floor belt of the truss confines the limits of the concrete slab, which besides having good abrasive behaviour, also stabilizes against lateral buckling.

Wooden beams jointed by steel bolts generate a serious problem for the engineer as the tempered steel does not allow much bending and has a tendency to break. Wooden beams have a hard inner core and soft tissue outside, which allows bending of the bolts. That can be avoided by "Bulldog" dowels or short sections of steel tubes put around the connecting area, that help to transfer the sheer forces and the bolt is working only in his axial direction, holding the jointed beams together. This technique can't be applied to bamboo although the problem of bending bolts is apparently even worse in round poles. On the other hand Bamboo tubes are more similar to steel tubes, as the outer perimeter of the pole is quite hard and the bolt is working under shear forces instead of bending. For bamboo joinery I recommend 12 mm bolts or threaded rods, preferably not tempered, which have a shear strength of about 2 tons, similar to the load that a 12 cm grouted guadua internodes can withstand. Many clients want to save some money on hardware materials and by two or even three calibers of bolts. This does not only confuse the worker, who does not always understand the loads acting in the particular joint he is working on, it also requires constant supply of not only one, but three types of drill bits, bolts, nuts, washers, wrenches, etc. For seaside projects the minimum requirement is hot dipped galvanized threaded rods, or even better are stainless steel threaded rods.

For minor forces you could apply also bamboo dowels, - like wooden nails have served for centuries and their lifetime expectancy is better than blacksmith iron in contact with oak.

Small bamboo bridges up to 8 meters a truss height of only 80 to 90 cm is required, which allows using a prefabricated King truss for a handrail. The prefab flooring grid of 2,35 cm width does still fit into a Container. A roof can be adjusted by introducing some poles in between the two handrails lines. Many clients don't like roofs, but outdoors bamboo does not last very long, unless it's annually painted yearly with UV protection and mold care.

Photo 18: This small King truss bridge of 6 meters has been installed at the Botanical Garden in Medellín, 2000. It has been pre-assembled and delivered by a small truck; the roof has been thatched locally. "Thermowood" has already a big market, but in Bamboo we still have to investigate to reach reliable preservation. The color is generated by a smoking treatment (pyrolisis), but the traditional Japanese technique is not easy to copy and additional borax preservation is necessary. The diagonal compressors are cut one third of the diameter into the tension beams and transmit the forces into the last nodes, which have to be grouted and its shear strength is also enhanced by two bolts. Note the slight curve of the truss: it's pitch is following the natural bending of the bamboo culm.

b. HOWE Truss

The railway bridges in America brought a lot of innovations in terms of assembly time and conceptual aspects of normed and pre-fabricated pieces for bridges to be built "by the miles". The engineers TOWN and HOWE invented two systems that can be easily applied to bamboo structures, as their elements fit in size with the wooden predecessor. Meanwhile the KING Truss is a framework of only one level, the trusses of Mr. Town and Howe had two or three layers that reduce the buckling of the relatively slim beams.

The HOWE Truss has shown excellent results in bamboo bridges of 20 to 30 meters, using segments of 5m lengths and 3m heights. This module allows us to apply the normal 6m pole for

diagonals and posts without much wastage, thus optimizing the use of the previously preserved standard poles. The straight bamboo poles in a delivery are chosen for the diagonals and its tension and compression forces, because these vectors are linear. The curved bamboo poles, a gift from nature to the creative spirit, allow bending the bridge truss into a slight pitch upwards. This does not only help aesthetically, more importantly it is a pre tensioning of the structure. All trusses will sink some millimeters when entering service, meanwhile their fibers adjust to each other and against the bolts.

The natural curve of a bamboo pole is less that about 2.5 % of the length and a truss should be similar. A 30m truss should not have more than 1.5 meters pitch. Some arches require a bigger opening below, but a 5 % would be the maximum that could be achieved without intentional cuts or heat bending. Bamboos of more than 10 cm diameter are extremely difficult to bend, even with heat.

Photo 19: This 30 meter bridge in Santa Fe de Antioquia, Colombia was pre assembled completely on a lawn besides the road. The bamboo structure had a weight of 8 tons and a mobile crane simply lifted it onto the bridgeheads. The entire operation only required a two hour road block and the entire bridge project has being finished in one month.

Photo 20: The HOWE concept is a sandwich framework. The tension and compression beams mutually stabilize at the cross over in the center, where usually the worst for buckling occurs. The tension element in the middle layer is bolted in between the outer and inner layer to transfer the forces evenly. The compression beams are cut one-third into the arches and grouted to avoid squeezing. Observe how the traverses are hanging below the floor arch and how the rails under the floor form a "lost casing" with the crushed bamboo mats.

The Space Frame

The structures with vectors in the three dimensions of X, Y and Z can be called space frames and include geodesic domes structures. Its elements work in tension and compression with forces induced through punctual joints. The smallest shapes surrounded by the beams are simple platonic corpuses like tetrahedron or a pyramid. A space frame might need several levels to be determined and rigid structure.

The tetrahedron with 4 Bamboo tubes requires a reliable joint, which conducts the forces from the cortex of the tube towards is axial line. This can be achieved with cement grouting, resins, epoxy glue, sand or milled glass as the infill material. The grouting with the special cement will transfer the load reliably to one axial bolt that is connected to the spherical bowl. This point can be either simply welded or can be a multipurpose solution like the Mero bowl.

Following descriptions on this kind of conical joints, already published by Gonzalez from Costa Rica during his PhD under Prof. Janssen, several approaches have been successful. The Institute for Wooden Structures at RWTH Aachen Prof. Führer and Dr. Evelin Rottke developed with Christoph

Tönges such a conical joint, which cold handle 18 tons of tensile strength, - well the joint worked, but the screw failed. This experience motivated to look deeper into the use of these joints for bamboo Bridges in space frame manner. Another successful joint has been developed by Kool Bamboo.

Photo 21, 22: Very powerful for axial bolts are conical bambú joints and MERO sphere.

Space frame applications on Bamboo Bridges could be similar to examples in wooden engineering over the river Isar in Thalkirchen, Germany. A roadway is supported by these 6 wooden arches; the road is the roof and protects the structure from sun and rain.

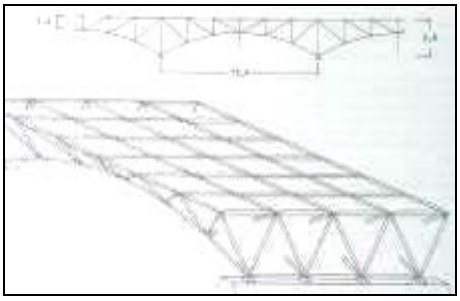

Photo 23, 24: Scheme of the wooden space frame truss over the River Isar, Germany.

a. The project of the bridge over the river Cauca in Popayan.

This Bridge will be a 30 meter space frame in bamboo, combined with 5 packs of bamboo arches (3 lines of guaduas in each) to ensure a live load capacity of 500 kg/m².

The selected guaduas have a diameter between 12 and 14cm and wall thickness of minimum 12mm. The largest elements are 2.4 meters long; the bolts (grade 4) are 18mm thick and transfer the load straight into a 12cm diameter steel sphere. Each cone will be individually examined in a previous load test, numbered and monitored digitally, to substantiate quality assurance for eventual claims.

This joinery technique is very challenging and its development, including the testing facilty, is quite expensive, but it opens the way for mass markets. The same production process for the joint can be

repeated precisely, just the measures of the bamboo pole changes in length or diameter. The cost of the bamboo is quite insignificant compared to the effort on the joints and does almost not influence the cost of the entire element. The bamboo poles need to be perfectly preserved and even receive flame retardant painting. Architects may then order these units by the thousands, just with different lengths. The lay out and planning of such projects can be done already with existing software for space frames in steel. The bamboo element has still to go through official testing for construction material, but at least some prototypes are already there.

In terms of the quantity of bamboo needed per square meter of structure, this system has by far the most efficient use of bamboo and it's very versatile, but it's also the most technical one.

The maintenance or the change of one element is relatively easy, because each element has its own adjustment screw. The cost of the entire system in bamboo is higher than similar existing metal systems on the market. Natural materials need just far more knowledge on selection, preservation and quality control, than industrial processes with galvanized steel tubes. But there is definitely a market where wood and bamboo space frames find their niche. This bridge project could help open the door:

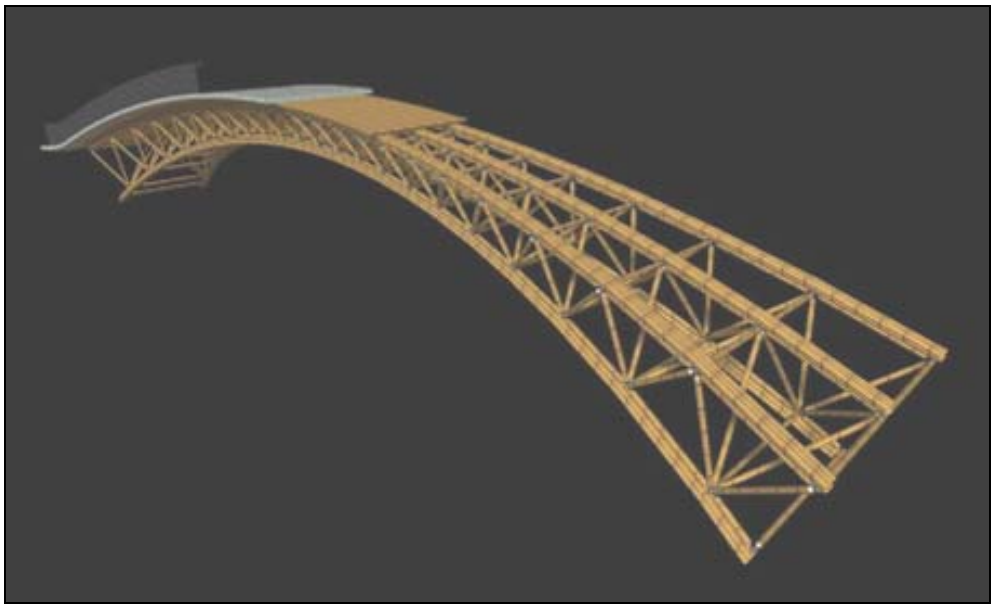

Photo 25: Render of an arched space frame bridge in bamboo. The project of a park along the river Cauca in Popayan including this 30 meter bridge is designed by Architect Valdenebro. It combines the curved space frame with five additional packs of five bamboos. The protection by design principle is the road way, which covers the structure like a roof.

Discussion

In order to compare the construction concepts we need a reference point. The cornerstones of evaluation are the "value", usually expressed in "direct" costs. From there it is not far to compare the level of technical complexity, the need of skilled man power and special tools. Bamboo - at least in the tropical countries - is apparently a very economical raw material, but there are also cost generated through selective harvesting, transport, preservation and installation. The increase technical complexity, guaranty and expected service time is directly proportional to the increase of the cost. These factors influence considerably in the decision of the structural concept to choose.

To give an overview about the above described concepts a table is presented here. Most of the examples have been already realized physically, but the functionality, the span and the weight requirements have not been the same, so is not possible to give a comparison under the similar premises. Also the remoteness and site influences, average time and material requirements have been different, but an average is given by the author's experiences. The table is a baseline for discussions and offers variables for the designer. The concept is graded in 1 to 7 and offers two varieties. The free span between supports or bridgeheads can be from 6 to 40 meters, the required amount of poles and their size gives the total length of bamboo needed. The life time depends on the protection by design and is generally directly proportional to the roof overhang.

The overall goal of the table is to compare the efficiency in the use of bamboo poles under considerations of certain span and load assumptions. The load bearing capacity of bamboo depends a lot on the applied structural concept. Some use the bamboo pole merely by flexion (the beam), some apply the forces perfectly in line with the axis (space frame). In between both extremes we find transitions of different grades, compromising on one hand more poles, on the other more skills.

Qualification of Labor and their related cost are understood as simple workers (W) and skilled carpenters (C), but the required construction time is obviously depending a lot on the span and the site remoteness, etc. The complexity is graded from traditionally simple, to complex and engineered. A few of the outlined 7 concepts have not been worked yet in bamboo, but do exist in wood, which enables us to assume the technical viability.

The logical sequence starts by definition of the concept and its varieties. Than each example is represented by the name of a real existing bridge, most of them have even Autocad plans. Some structural analysis and scaled models are available for future deeper analysis. The span and its width of the bridge allow a certain amount of passengers (a live load of 6 persons per square meter would be 450 kg/m2), which is here assumed with 60% of its official load bearing capacity (4 persons per square meter with 75 kg sum 300kg). The amount of bamboo (handrail included) at the bridge section is shown in relation to the span and the load. The life time of the bridge plays an important role in the bamboo consumption over the years and should justify the investment. The cost is in direct relation to the technical complexity and its need for skilled workers. The final figure should reveal the overall bamboo needed per person and span. This table is just a discussion proposal, based on the experience of the author and has to be checked on other structures.

Table 1: Evaluation of 7 concepts, taking in mind material efficiency, load capacity and life time.

	Concept	Varieties	Example	Span/ load	Bambo ml /span	Life Time	Labor	Pole need/ Pers/ year
1.	**Beam**	a. natural bamboo pole, straight	3 pole packs pure flection	Up to 6 m 1 pers /ml	6 x 6m = 6/ml sp	2 years, no roof	1 day / 2W very simple	36/6/2 = 3 ml/pers/yr
		b. spaced beam, spaced column	2x 4poles spaced	Up to 8m, 4 pers/ml	10 x 8m = 10/ml sp	3 years, board roof	1 day/2W + 1C, simple	80/32/3 = 0,8 ml/pers/y
2.	**Arch**	a. false Arch, woven Arch	Mallorca, Da Vinci	Up to12m 2 pers/ml	20 x 6m = 6/ml sp	2 years, no roof	1 day/ 3W + 1C, tradition	120/24/2 = 2,5 ml/pers/y
		b. roman Arch, composes Arch	In project for Amsterdam	12 x 4,5m 200 pers.	5x6x12m = 30/ml	30 years, road roof	4 weeks/ 2W +2C, simple	480/200/30 = 0,1 ml/per/y
3.	**Suspension**	a. bamboo Cable	Xian, Bali, Peru	≤ 30 x 1,2 m. 60 pers	8x3x30m in slivers?	2 years, no roof	4 weeks ? 10W+ 4C tra	720/60/2 = 6 ml/pers/yr
		b. tensile poles in a long Belt. WSB	Rhein Donau	≤ 30 x 1,3 m. 30 pers	12x8x6m = 18/ml ?	20 years, road roof	8W+ 4C ? engineered	600/30/20 = 1 ml/pers/y
4.	**Cable stade**	a. entire poles as "cables"	Paez	≤36 x 0,6 m. 20 pers	40 poles of 20m.	2 years, no roof	simple, traditional	800/20/2 = 40 ml/pers/yr
		b. Cantilever	Cucuta	≤30 x 3 m 400 pers	40x2x30 m = 80/ml	30 years, membrane	complex, engineered	2400/400/30 =0,2 ml/ps/yr
5.	**Form active**	a. stiff shapes, shells	Bali	≤20x2,5m 200 pers	30x2x22 m = 60/ml	30 years, grass roof	simple, traditional	1320/200/30 =0,2 ml/ps/yr
		b. anticlastic membranes	Partially in Cucuta	Supports center	Towers and floor	30 years, membrane	Complex, engineered	No design yet
6.	**Truss**	a. King Truss	Maceio	≤10x2,5m 100 perso	24x2x14 m= 48/ml.	30 years, tile roof	simple, engineered	672/100/30 =0,2 ml/ps/yr
		b. Howe Truss	Antioquia	≤30x 33m 400 pers	56x2x34 m=56/ml.	30 years, tile roof	Complex, engineered	1800/400/30 =0,15ml/ps/y
7.	**Space frame**	a. space frames with arches	Popayan?	≤ 30 x 3m 400 pers	(25+10) x31m	30 years, road roof	Complex, engineered	1100/400/30 =0.08 ml/p/y
		b. tensegrity Bucky Fuller	?	≤ 30 x 2m 100 pers	50 poles of 6 m	3 years, no roof	Complex, engineered	

According to the hypothetical assumptions of a life time of 30 years and quite high live load capacity, the table shows some astonishing results. Basically all covered bridges need only between 0,1 and 0,2 meter of bamboo per passenger and per year, where as the non protected bridges consume between 2,5 and even up to 40 meters, resulting ten to twenty times more than the engineered bridges.

But it is not the only angle to compare advantages and disadvantages. Each Bridge site already determines a lot of factors, like the soil consistency of the riverbanks, the maximum level of flooding over the past decades, the proximity and the best access to the next roads to get in construction materials, tools or even a crane. If there is no access to a narrow valley, there might be the possibility to install a cable that allows the lifting of the trusses. Other sites require a “false” bridge platform to assemble the truss or to avoid tools falling into the river or the cars on the road below.

Also the average size and the mechanical properties of the chosen bamboo species influence the design. The client might have challenging ideas about functionality or may impose aesthetic preferences.

Some bridges need an official construction permit from city authorities including structural analysis and signed plans by a registered engineer. Building supervisors leave little margin for change or improvisation and are very uncomfortable with unfamiliar building materials. But everybody, client and builder, are identifying themselves with their Bamboo Bridge, so there is always a deal for creative solutions.

Photo 26: The deformation caused by load tests with 55-gallon oil drums (about 200 liters) is registered by a topographer. Later the date is compared with the structural analysis by engineering software. Over the years we have closed in on the gap between these two approaches. Latest tests have confirmed the deformations and recovery predicted by the computer programs. Now we are generally quite close to 0.015 % of the span at tested live loads of 220 kg/m2 (= one barrel/m2). This covers about 50% of the most national norm requirement between 450 - 500 kg/m2. Test on full loads have never performed, as these extremes requirements are for extremely rare situations. Unnecessary extreme testing would eventually cause micro damage in the structure and reduce its overall lifetime. This testing politic has been internationally accepted, even by the German authorities responsible for the structural revision of the Zeri pavilion. 6 load tests have been performed up to now on real existing structures and the data should be compiled and evaluated sooner or later in a professional investigation in order to compare the data between computer simulations and real structures.

.Conclusions

- It does not make sense to compete between concepts, as each one has different advantages that respond to a variety of challenges that can occur in the project. There can also be a combination of concepts. This is needed on one hand to avoid buckling of arches by asymmetrical or punctual loads. On the other hand the arch can be an additional defense line for a truss, just in case one element or a joint fails, due to an accident or lack of maintenance.

- Protection by design using roof and tall footings pay in about 10 times more efficient raw material use, although labor and skill requirements are more challenging.

- Straight bamboo does not exist in nature, and it is a waste of time to ask for a container load of straight and uniform poles. But you can ask for a range of specification like almost straight, or slightly curved, strongly curved, bottom, middle or top section, certain density of mature poles, certain diameters (at the base) and length up to 12 meters. The quality of the selection is up to the provider, but you have a choice. In Colombia and Indonesia there are already about a dozen companies, dedicated to produce good quality and quantity of preserved bamboo poles with those specifications. Most of them have been trained by the author.

- Nature does not limit itself to the straight line of a drawing board. So let's design curves according to the natural bending of bamboo. Curved lines are beautiful, but some architects don't like the triangles. But the diagonal bracing is essential for a truss and can be integrated as lateral confinement, also as ornaments: a lot of common users of a bridge do not understand the crossings of a handrail support and think its decoration.

- Most of the above mentioned construction systems in bamboo are already mature and successfully used for years. They have been refined in terms of simplicity, use of power tools and time efficiency, so there is a base for scheduling their production. Others are still in experimental stage and the first projects are starting soon. The experienced bamboo builder knows his material and will meet the challenges. What we don't know are the costs, but what does it matter to work hard when it comes to discover new horizons.

About the Author

Jorg Stamm has designed and built dozens of houses, schools, community halls and bridges in Bamboo. The variety of construction systems experienced in 15 years since meeting guadua in Colombia stretch from simple post and beam to complex frame works in several layers. He developed a prefabrication method that works with previously selected, preserved and dried poles and brings the actually construction time to a quarter of the commonly used time. The Truss construction itself is usually done on the ground over a pre - established matrix that was planned and drawn in Computer Added Design programs (AutoCad). The matrix follows the 1:25 drawings and the pinpoints important positions with stakes. The assembly is precise to the centimeter and even 40 meter trusses can be screwed together without dangerous scaffolding and complicated leveling. The resulting

truss is very light, as a dry bamboo pole usually weighs only about 20kg, and can be positioned by hand or by crane quite easily into its definite position. The structure is quite identical to the planning, which allows structural analysis based on the same CAD drawings.

Also the preparation of the bamboo poles, their grading, the preservation and drying has been systematically organized. The bamboo goes through this process within two months, before stored properly in a warehouse. This process allows controlling quality and costs. The client can order the necessary poles by the meter like every other modern construction material and cut down construction time. This method converted bamboo construction into a green alternative which is economically competitive and fits into the existing commercial habits of delivery against deadlines.

Due to this achievement he has realized jobs in Europe, America, Africa and Asia with different bamboo species. The ongoing apprenticeship is reflected on one hand in the new techniques applied to fit the diversity of sizes, diameters and consistencies. On the other hand he widened the horizons by meeting impressive ethnic architecture mainly in Indonesia, with its great treasure of styles and functional forms.

The invitation to Bali, by the former Jewelry Designer John Hardy, to built “Greenschool” in Bamboo, was of great importance. Inspired by the potential and the challenge to build exclusively with natural materials like Bamboo, Stones, Mud and Grass he combined these traditional resources with the interesting roof forms. This led to the discovery that these curves are not only creating beautiful light effects, but they are very functional as “form active” structures and useful by their effect on creating draft and natural air conditioning. The design of a 2000 m2 roof for a new factory building was inspired by the silhouette of three volcanoes on the horizon at the background of JH Company. The tree cones of the factory building resemble these volcanoes, including the magma chamber and the crater, which became the skylight over a spiraling internal tower.

Working with more than a dozen local species with different sizes and properties, the design team looked for the options, experimenting with a variety of construction concepts and the possibility to work even with the longest available poles of 20 meters. To avoid unnecessary cuts a 20 preservation tank was built. The long, light, strong and elastic poles offered a surprising quantity of unexpected applications, which were later refined and systemized.

The author did join as a technical advisor some of the investigations on bamboo at the Technical University of Pereira, where selective harvesting, preservation and kiln drying were under his duty. He also wrote a technical booklet on bamboo bridge building, edited by the GTZ-UTP Project.

Important inspiration has been the already mentioned book “Bambus-Bamboo”, IL 31, from Klaus Dunkelberg y Eda Schauer, Frei Otto’s Institute for light weight structures at the University of Stuttgart in Germany. Another important work is Oscar Hidalgo’s “Gift of the Gods”, a Bible in terms of the gathering of a wide array investigations on Bamboo all over the world. Prof. Dr. Walter Liese’s book on “Anatomy of Bamboo Culm” allowed a deep insight into the microscopic world of the structural composition on cellular level.

Photo References

Photos: 3, 6, 10, 11, 23, 24 scanned from: Informationsdienst Holz, Germany, see bibliography

Photo 9: scanned form : IL31 , Stuttgart, see bibliography

Photo 11: scanned from : Guadua, Marcelo Villegas, see bibliography

Photo 14: John Hardy, Bali, courtesy

Render: Arq. Eladio Valdenebro, Popayan, courtesy

The other photos are from the author.

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A Tale of Two Bridges
A Proposal for the International World Bamboo Congress 2009, Bangkok

Mark Emery

It was the best of times, it was the worst of times……

Abstract

This proposal is a subjective portrayal of the construction process of two bamboo bridges that I have helped construct over the past two years. A tale of Two Bridges wishes to reveal the art of Bamboo Bridge building in motion from the perspective of the builder. With the aid of a High Definition video camera I wish to share a personal account, through the ups and downs, of the construction of two bridges.

The two bamboo bridges under analysis include the 30m pedestrian over-pass in the City of Cúcuta, Colombia, and the 30 meter entrance bridge at the Soneva Kiri Resort on Koh Kood island, Thailand. These two bamboo bridges, designed by carpenter Joerg Stamm, modernize indigenous bridge building concepts through the use of well selected, preserved, large diameter bamboo, and utilize modern joinery to maximize load bearing potential. Both bridges were born from a similar conceptual design base although express very different aesthetic outcomes and utilize different structural systems. At a glance one can note this difference between the two bridges; one with a modern anticlastic tent membrane, the other utilizing local ¨sago palm thatching and small bamboo rafters for roof protection. Both Bridges express the clients desire for a representative building that reflects their company's identity

Bending and Joining

The secondary discussion of this proposal will be examining the joinery techniques and explain in laments terms how to unite single bamboo culms to form long complex elements that create structural beams and arches. Herein we examine the differences of working with the different bamboo species endemic to each location; Guadua angustifolia, and Dendrocalamus asper, and explain from the perspective of the builder what it is like working with, and combining these flexible materials with rigid mortar and steel to assemble massive trusses. Through trial and error, discoveries are made and new techniques are born from the workers input to improve process.

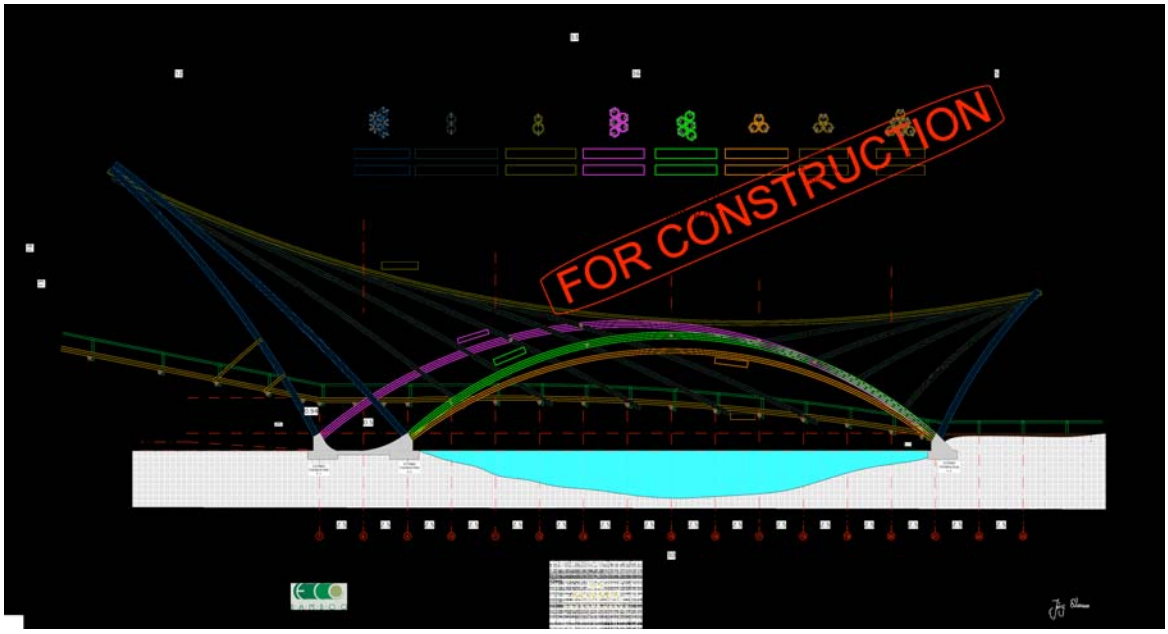
Above- Bridge Cúcuta, Colombia with membrane tarp protecting a symmetrical structure. Below- Model of Bridge at Koh Kood, Thailand currently under construction, to be completed in june 2009. Asymmetrical bridge design with the tension elements radiating from the double footing, whilst at the other end, these apparently similar elements only support the roof structure.

Bending Bamboo. On the left shows huge diameter of the dendrocalumus culm, on the right the smaller but very strong Guadua.

Communication

Communication on the worksite breeds new vocabulary between the workers. To differentiate structural members new descriptive terminology is born: *5-pack, triangular 3-pack, 3-flat-pack, star-pack, and ray beam,* quickly catch on as work site slang to describe the coupling of bamboo poles. These names are used to replace engineering terms such *arch, column, and tension beam.*

Communication from designer to constructor is different in Bamboo buildings as opposed to a conventional building that relies on regularity of the material. A bamboo building maybe only having several fixed reference points for construction from which other points between may vary. AutoCAD is an invaluable tool for the designer, however sometimes with an irregular building material such as bamboo, precise measurements, angle of unions and even where to connect the elements are not apparent until construction. This is why we always explain a design on the worksite with a physical model using round bamboo skewers. This way even the language barrier is surpassed, and an instant understanding of the finished structure is clearly understood by the whole working team.



Construction Drawing of the 30m bamboo Bridge at Soneva Kiri Resort, Koh Kood, Thailand. Shpwn are the "double footing" on the left, and lettered are the "Ray beams" A-L. Above the construction details shows the coupled bamboo elements- Triangular 3-pack, 5-pack, Triangular 6-pack.

The Team Storey

The strong bond between workers created over a 3-month construction period is the parallel storey that is often forgotten in construction. The "team storey" or the personal account of what it is like to build with bamboo is very important, especially for us, the designers of bamboo structures. If you have never made a bamboo dowel with a machete, carved a fish mouth with a chainsaw, or carried a 10 meter bamboo pole on your shoulder, it is even more important for you to listen to the workers say, as their storeys help us to develop a better understanding of bamboo and how to design with it.

Left- Team Koh Kood, Thailand. Right- Giant truss lying damaged on scaffolding after a failed lifting attempt. Photo shows Primary Double footings, and distorted arch's after damage.

With the aid of my HD camera I would like to share the experience of building the bridge on Koh Kood island, Thailand. The mental and emotional process of building a bamboo bridge is unique. Not only is a bridge the pure expression of structural form, it is a dynamic human experience to unite landmass, and the satisfaction of the first crossing from end to end is an incomparable emotion. Without team collaboration, this process would not be possible, and the bridge would simply not exist.

This proposal includes a 10-minute video reel sharing this emotional experience, and explains the crucial steps in mechanical lifting of a bamboo truss, featuring the National example from Koh Kood, Thailand. This dramatic video footage reveals the do's and don'ts of lifting a 7 ton bamboo truss, but more importantly would like to share the emotion and drama experienced in "A Tale of Two Bridges".

About the Author

Mark Emery graduated from the Faculty of Built Environment at the University of New South Wales Landscape Architecture program in 2006. Mark has worked extensively throughout South America, learning the art of bamboo architecture under the supervision of German carpenter and personal mentor, Joerg Stamm. In 2008 Mark established his own design multi-disciplinary practice aligned with an uncompromising philosophy for truthful architecture using sustainable material. His practice, Bambooroo, named after the strongest woody plant on the planet, and as a synonym with the national symbol of Australia the Kangaroo, seeks providing comfortable living with elegant design solutions, whilst exploiting the use of our most precious natural material, Bamboo.

Bamboo as a Material for Housing and Buildings – Indian Experience

Dr.Shailesh Kr.Agrawal
Executive Director, Building Materials & Technology Promotion Council,
Ministry of Housing & Urban Poverty Alleviation, Government of India

Background

Wood has been used for centuries as a common material in construction of buildings and other structures. Similarly, bamboo has also a long and well established tradition for being used as a construction material throughout the tropical and sub-tropical regions of the world.

In the modern context when forest cover is fast depleting and availability of wood is increasingly becoming scarce, the research and development undertaken in past few decades has established and amply demonstrated that bamboo could be a viable substitute of wood and several other traditional materials for housing and building construction sector and several infrastructure works. Its use through industrial processing has shown a high potential for production of composite materials and components which are cost-effective and can be successfully utilized for structural and non-structural applications in construction of housing and buildings.

Main characteristic features, which make bamboo as a potential building material, are its high tensile strength and very good weight to strength ratio. The strength-weight ratio of bamboo also supports its use as a highly resilient material against forces created by high velocity winds and earthquakes. Above all bamboo is renewable raw material resource from agro-forestry and if properly treated and industrially processed, components made by bamboo can have a reasonable life of 30 to 40 years. The natural durability of bamboo varies according to species and the types of treatments. Varied uses and applications in building construction have established bamboo as an environment-friendly, energy-efficient and cost-effective construction material. The commonly used species in construction are Bambusa balcooa, Bambusa bambos, Bambusa tulda, Dendrocalamus giganteous, Dendrocalamus hamiltonii, Dendrocalamus asper, etc.

Bamboo, a highly versatile resource and widely available, is being used as an engineering material for construction of houses and other buildings. A number of small and medium sized demonstration structures have already been constructed during past few years. These have shown very good performance in different climates. In order to propagate use of bamboo in housing and building construction for wider application, awareness and confidence building amongst professionals and householders is required. This calls for organized actions on prototyping, demonstration, standardization aimed at improving acceptance levels and promoting appropriate construction practices.

World-wide availability of Bamboo
(Number of bamboo species and coverage by country, In Asia)

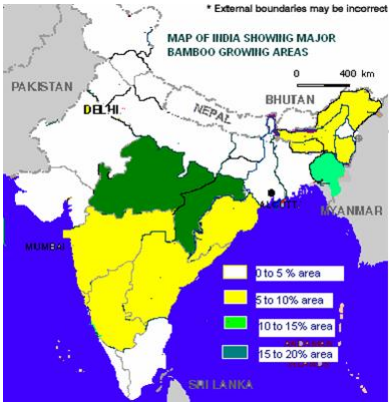
Country/area	Number of species	Area (million hectares)
Bangladesh	33	0.6
China	300	2.9 (only 'Moso')
India	136	9.6
Indonesia	35	0.1
Japan	95	0.12
Malaysia	44	0.3
Myanmar	90	2.2
Papua new guinea	26	N/A
Philippines	55	N/A
Sri lanka	14	N/A
Taiwan	40	0.18
Thailand	60	0.81

Over twenty million tones of bamboo are harvested each year, with almost three fifths of it in India and China. An estimated 25 million people all over the world depend on or use bamboo materials. The table above indicates the distribution of bamboo in Asia. It is also serves to highlight the potential dominance of India with its vast resources and reserves of bamboo in future economic activity and trade.

In India, 28% of area and 66% of growing stock of bamboo in NE region and 20% of area and 12% of growing stock in MP & Chattisgarh.

Availability of Bamboo in India

S No.	State/region	Area %	Growing stock %
1	North East	28.0	66
2	Madhya Pradesh	20.3	12
3	Maharashtra	9.9	5
4	Orissa	8.7	7
5	Andhra Pradesh	7.4	2
6	Karnataka	5.5	3
7	Others	20.2	5



The housing and building construction industry is one of the largest consumers for natural mineral resources and forests. It is increasingly realised that innovative building materials and construction technologies which offer potential for environmental protection, employment generation, economy in construction and energy conservation need to be encouraged as best options to meet the rising demand of housing. Whole of north-east is prone to earthquakes and falls under Seismic Zone V. BMTPC lays emphasis on promoting design and construction of disaster resistant technologies for housing. Construction techniques using bamboo as main material have been found very suitable for earthquake resistant housing. With the constant rise in the cost of traditional building materials and with the poor affordability of large segments of our population the cost of an adequate house is increasingly going beyond the affordable limits of more than 30-35% of our population lying in the lower income segments. This calls for wide spread technology dissemination of cost effective building materials and construction techniques.

Bamboo as a Building and Construction Material

Bamboo is structurally stronger than steel. At the same time, it is light-weight, easily workable, and has vibration damping and heat insulation properties. Structurally, bamboo can find application in three main types of structures: scaffolding, housing, and roads.

Scaffolding

Bamboo is being used for scaffolding in most of the countries where it grows. In fact, despite construction becoming high-rise, bamboo has continued to hold advantages over other materials such as steel, which has entered the scaffolding market recently. Steel scaffolding is available as an industrial product of standardized dimensions that make it quick to erect and dismantle. Moreover, steel can be used at least 50 times more than bamboo, which can be used five to ten times at most depending upon the load of the construction. In this respect, bamboo scaffolding needs some technical upgrading.

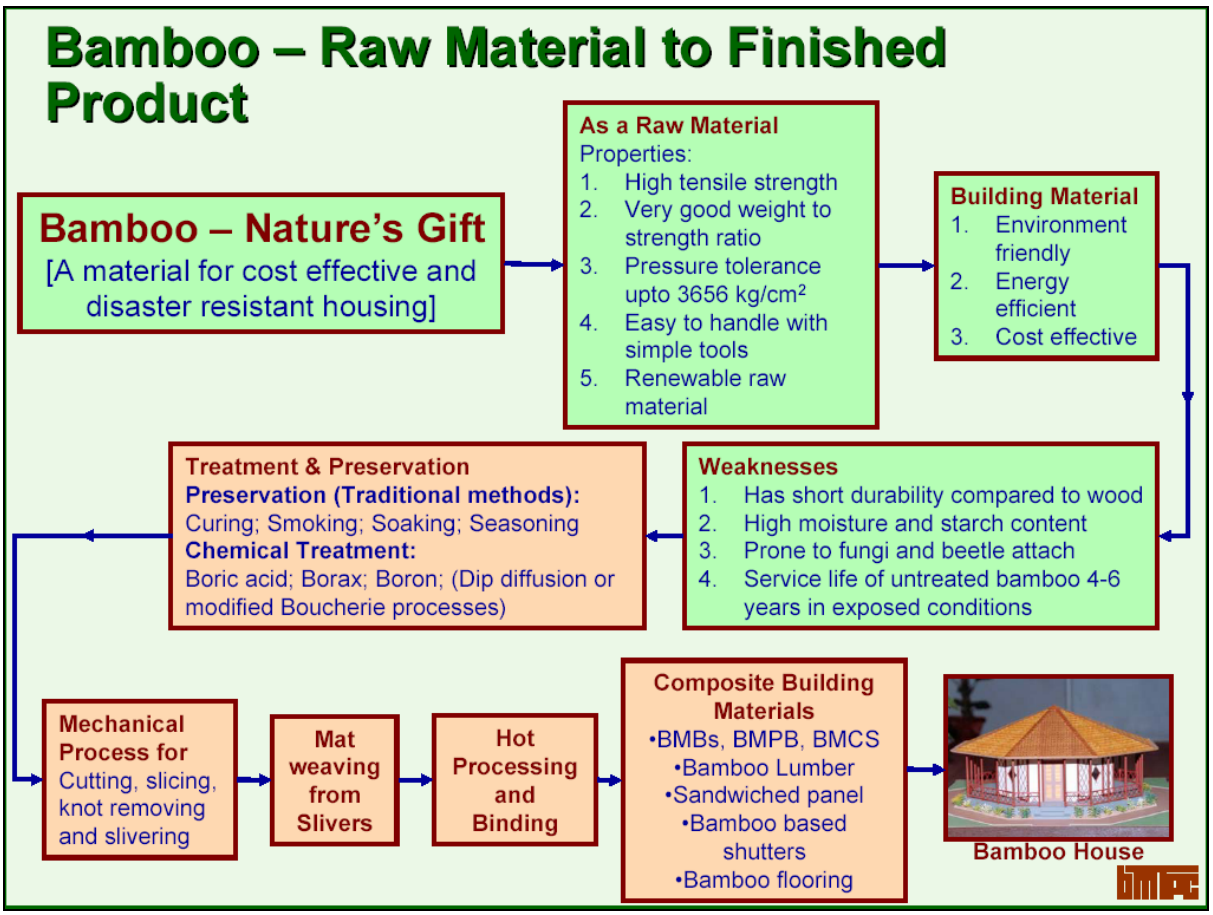
However, bamboo is a preferred scaffolding material because its flexibility in the variety of lengths that it can be cut into, the lower investments that contractors need to make in the scaffolding stocks (bamboo costs just 6 per cent of the price of steel for similar quantity of scaffolding) and the ease with which it can be set up and dismantled. It is the preferred scaffolding option even in developed countries such as Hong Kong and continues to be used for the majority of high-rise buildings in these countries

In India too the usage of bamboo for the purpose of scaffolding is on the higher side. There is virtually no value addition on the raw bamboo used for scaffolding purposes.

Bamboo – a Housing material

In a structural application, bamboo rounds are used to create roof support systems. These systems include a prefabricated triangular truss comprising units eight metres long. A truss can be carried by four people, and deflects only 2.5 cm along its entire length. It is covered with bamboo boards, lath and plaster to create a

waterproof roof. This system utilises bamboo rafters with bamboo boards, which are plastered on both sides, and fired clay tiles are used to waterproof.



Floor:

Bamboo flooring and bamboo board are newly developed interior designing material made using modern scientific methods from superior quality bamboo. Bamboo flooring is an attractive alternative to wood or laminate flooring.Bamboo with a wall thickness of culm of at least 11 mm is suitable for making floorboards. The process of making bamboo strip flooring consists of the following steps:

- Hollow bamboo of a minimum thickness of 11 mm is sliced into strips.
- These strips are milled to a thickness of 7 mm. They are then boiled to remove the starch and treated for anti-moth, anti-mildew, etc.
- The strips are then dried and carbonised (if required).
- The dried strips are now milled to 5 mm thickness.
- These strips are now glued and laminated into solid boards under high pressure, which are then milled into standard strip flooring profiles.

The machinery and equipment required for manufacturing bamboo flooring can be imported from Taiwan, though some is available locally as well.

Floors can be made out of flattened bamboo, woven bamboo mats or split bamboo.

As reinforcement:

There are four categories in which the use of bamboo has been made:

1. Bamboo fibres in cement mortar for roofing sheets
2. Split bamboo as reinforcing bars in concrete
3. Bamboo as a form work for concrete
4. Bamboo as a soil reinforcement

For Roofing:

Bamboo Mat Corrugated Roofing Sheet has been developed by BMTPC in close collaboration with Indian Plywood Research and Training Institute (IPIRTI) Bangalore, India. It is made from woven bamboo mats.

For Walls:

Woven bamboo mats are used to make walls in countries such as Bangladesh and India. Vertical whole or halved culms and flattened bamboo strips are also used for making walls. Walls can be made with bamboo as a minor component and mud as a major one.

For Doors and windows:

Bamboo can be fashioned artistically to make doors and windows.

BMTPC's Initiatives in Promotion of Bamboo in Housing & Buildings

The Building Materials & Technology Promotion Council (BMTPC) under the Ministry of Housing & Urban Poverty Alleviation, Govt. of India is actively involved in development of bamboo based technologies and to promote these technologies in the North-Eastern Region including other bamboo growing areas, by encouraging commercial production of bamboo based products, construction of demonstration houses and setting up of Bamboo Mat Production Centres for processing of bamboo, etc.

Bamboo Mat Corrugated Roofing Sheets

The BMTPC in collaboration with Indian Plywood Industries Research & Training Institute (IPIRTI), Bangalore, have developed a technology for manufacturing of Bamboo Mat Corrugated Sheet (BMCS) which is durable, strong, water-proof, and decay-insect-fire resistant. The commercial production has been started at Byrnihat, Meghalaya. The product has been accepted by the consumers and is becoming increasing popular as a roofing option in the north east part of the country. It is estimated that in full capacity this unit will generate livelihood for nearly 7000 women/men (through mat weaving) in rural regions where bamboo is abundantly grown.

Bamboo Mat Corrugated Ridge Cap

BMTPC in collaboration with IPIRTI, Bangalore, has also developed a technology for manufacturing of Bamboo Mat Corrugated Ridge Cap for roofing. The Technology is ready for commercialization.

Construction of Demonstration Structures

BMTPC has constructed 24 demonstration structures in Mizoram, Tripura, Nagaland and Meghalaya using bamboo based technologies. These include Houses, OPD buildings, Library buildings, Picnic huts, Schools, etc. The cost of construction using conventional technologies in these areas is around Rs. 800/- per sq ft. This is considerably reduced using bamboo based technologies and the cost of construction achieved is Rs.315 to Rs.622 per sq.ft. for different types of structures. The specifications used are:

(a) Treated bamboo columns and beams,
(b) Ferrocement walls on bamboo grid reinforcement,
(c) Treated bamboo trusses, rafters and purlins,
(d) Bamboo mat board in wooden frames for door shutters,
(e) Bamboo Mat Corrugated Roofing Sheets,
(f) IPS flooring, etc.

Development of Technology for Construction of Two Storey Bamboo Housing System

A technology for construction of two storey bamboo housing system has been developed and a demonstration house has been constructed at the campus of IPIRTI Bangalore. At each stage of house construction various elements were tested and models of such elements were made before the actual construction was carried out.

Design and Development of Pre-fabricated Modular Housing System

BMTPC has undertaken Design and Development of pre-fabricated modular housing system using bamboo and bamboo based composites in collaboration with IPIRTI, Bangloare. A model design of pre-fab double walled bamboo composite house attached bath and kitchen having size 20’ x 24’ x 8’ was developed. This system will enable application of bamboo composite building materials in pre-fabricated houses. These types of houses can be constructed quite quickly for immediate and long term rehabilitation for post disaster relief.

Bamboo Mat Production Centres

BMTPC alongwith Cane & Bamboo Technology Centre (CBTC) in cooperation with State Governments, is establishing Bamboo Mat Production Centres in the States of Assam, Tripura, Mizoram, Meghalaya and Kerala. The main objectives of Bamboo Mat Production Centres are to provide uninterrupted supply of bamboo mats to the manufacturing units of bamboo based building components for increasing the productivity, quality, to provide training in mat production process and to create employment opportunities.

The Council has established such Bamboo Mat Production Centres in Tripura, Mizoram, Meghalaya and Kerala.

BMTPC and CBTC are also providing training on bamboo mat production to the artisans from each Bamboo Mat Production Centres. The production capacity of each production centre will be 300 mat per day. It is estimated that

the each Centre will be able to produce the mat at the rate of Rs.35 per mat and would be able to sell at the rate of Rs.45 per mat. This provides employment generation of nearly 150 women/men per day i.e. 45,000 women/men days per year per Centre. Besides the above, the Centres can also generate income by supplying bamboo sticks made out of bamboo waste, to the artisans for making handicraft items. The mats produced by Bamboo Mat Production Centres are likely to utilized by various manufacturers who are producing Bamboo Mat Corrugated Roofing Sheets and Bamboo Mat Boards.

Bamboo – More Than An Alternative

Bamboo has so far not been regarded as a substitute for wood. An analytical look at the applications for which wood is being used and the usage of bamboo indicates that it is possible to use bamboo for all the applications for which wood is being used. The usage of bamboo has in fact been established conclusively for categories that consume larger volumes of wood, namely, paper pulp, plywood, construction and furniture.

There are preconceived notions about the technical capability of bamboo. These have hindered the adoption of bamboo as a wood substitute. The wood industry is not able to visualize bamboo as a process-friendly material that can peeled. It also considers bamboo to be susceptible to fire, water and termites.

The Bamboo, if used efficiently, shall lead to the following in the interest of the nation and masses:

- *Enterprise Development*
- *Training for skill upgradation*
- *Employment generation*
- *Conservation of forest timber*
- *Bulk utilization of bamboo*

VOLUME 11

In Partnership for a Better World (INBAR)

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Preface

Walter Liese
Session Chair

The Session Chair had his first contacts with bamboo in 1951. Trials were done to use its culms as pit props in German coal mines for the rare timber, but bamboo failed under pressure by sudden collapse. A closer contact began in 1957/58, with an FAO assignment for bamboo preservation in India. Since then, a greater number of consultancies were undertaken in numerous countries, beside the official functions as Professor of Wood Science at Hamburg University, with the main research beginning in 1963 on wood structure, deterioration and protection. After official retirement in 1991, the bamboo mission could be intensified with research, consultancies, and publications; for example, two INBAR-edited books.

As President of IUFRO (International Union of Forest Organizations) from 1977-1981, the moderate interest of the International Development Research Centre (IDRC) of Canada was intensified to lead to cooperation, and finally, to the creation of the International Network for Bamboo and Rattan (INBAR).

The five papers of this Session will give an overview about INBAR's mission, its achievements and further responsibilities for the wise use of bamboo.

-The potential of bamboo to contribute to sustainable development and environmental protection at the local, national and global level can only be realized if all actors work together.

-Facilitating a network for partnership and collaborations is one of the main tasks of INBAR, cooperating with other international Agencies, like FAO, ITTO, UNDP, CIFOR.

-The session will present examples of how such partnerships and collaboration facilitated by INBAR cooperate at different levels, and for different purposes.

-It is most fitting to have the Session, Partnership for a better World, at the end of this very inspiring conference just before we will wrap up and to illustrate the global potential of bamboo, there will be the declaring of the

WORLD BAMBOO DAY.

18 September.

Resilience Thinking Implications for Reconfiguring Bamboo Management and Governance

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Abstract

The preparedness and resilience of bio-productive agro-systems to face current challenges is reconfiguring 21st century visions of sustainable development. 'Complexity science', has evolved over the past century replacing the equilibrium view encompassing concepts such as 'carrying capacity'. Bamboo grows within a complex adaptive system, managed within dynamic social-ecological systems. The social-ecological system, highlights that the delineation of social and ecological systems is arbitrary. Sustainable development is increasingly perceived as a process involving aspects of evolutionary and co-evolutionary change. The ability to enhance resilience depends on the dynamics of the biophysical system and institutional organizational and governance processes that enable adaptive co-management of ecosystems. A major challenge to bamboo management and other bio-productive systems therefore is to maintain the resilience of the system in the face of change.

This study considers three different models which are cross-cutting across the 'three pillars' of sustainability: society, environment and economy, they are forest certification, Conservation Agriculture (CA) and a livelihoods approach. Experts have warned against having new blueprint approaches, but instead forming a patchwork of approaches to suit situational contexts. There are potential arenas for learning which arise from Forest Stewardship Council (FSC) Principles and Criteria (P&C) even if the primary goal of a non state market driven mechanism is not effective. FSC potentially plays a role in advocating forms of adaptive co-management. CA provides many learning opportunities for bamboo to transform management practices to sustainable resilient ecological systems. Moreover the livelihoods model provides a framework for understanding the need for diversity, not just biologically, but economically. Together the frames can go some way towards reconfiguring bamboo management and governance within resilience thinking.

Introduction

The preparedness and resilience of bio-productive agro-systems to face current challenges is reconfiguring 21st century visions of sustainable development. Sustainability has been one of the most widely used buzzwords since the late 80s (Scoones 2007a), however there have been shifting visions of the interpretation of sustainable development. The most widely popularized definition defines sustainable development as 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs' (Brundtland 1987). Many contemporary scholars envision sustainability not as a fixed ideal (Cary 1998) or

outcome (Stagl 2007) but an evolutionary (Cary, 1998) or co-evolutionary process (Noorgard 2000) of social-ecological systems (Berkes and Folke 1998), involving reinterpretations of management and knowledge systems (Cary, 1998). Future sustainability therefore is part of co-evolutionary interactions within complex adaptive systems (Rammel 2007a). When facing the complexity of evolutionary systems analysis many scholars have highlighted the need for novel combinations of existing tools and methods rather than completely new methods (Giampietro 2004), through a mosaic of approaches to sustainable development (Stagl 2007; Rammal et al 2007b).

The need to reassess the bamboo management toolkit arises from the current challenges facing bamboo management in China. These are intensive harvesting, an increase in monocultures with associated biodiversity loss, excessive tillage, and chemical residues (Fu and Lou 2002; Lou et al. 2008), erosion and depletion of soil nutrients (Saxena et al. 2002; Zhou et al. 2006; Jiang 2007). This is not to say that *all* bamboo in China is unsustainably managed, however as China is the model of bamboo development (FAO 2008), this is a trend that is being followed as areas become more developed. This need is becoming more acute as the IPCC report identifies that climate is changing with ramifications for both human and non human systems (IPCC 2007). In 2008 the worst snow disaster in 100 years hit China**,** killing more than 100 people**.** The Chinese government pledged $1.2 billion to rebuild homes, farms and help those in need (Ho 2008). Large areas of bamboo forests were lost, particularly within monoculture stands, causing significant loss of livelihoods. The bamboo farmers are particularly vulnerable due to managing bamboo under high yielding regulations for high economic gains (GB 2006).

According to Diamond (2003) past societies collapsed due to a lack of environmental governance. Vulnerability therefore needs to be understood in the context of political and economic systems that operate at national and international scales (Wisner et al. 2003). The shift to considering socio-ecological systems(rather than just ecological) has triggered the emergence of analytical frameworks like socio-ecological resilience, adaptive co-management, and adaptive governance, all of which can be related to matters of institutional function (Galaz et al. 2007; Leach and Smith 2007).

This paper intends to address the implications of considering resilience in the practice and governance of bamboo management. Three current niche models will be assessed which advocate ‘sustainable development,’ those of Forest Stewardship Council (FSC) certification, Conservation Agriculture (CA) and the livelihoods model developed by the UK Department for International Development (DFID) in an attempt to consider holistic arenas for brokering knowledge. The paper aims to highlight the potential for adaptive and transformative systematic change.

Theory

The modernisation of bamboo management institutions is key to meeting policy challenges and realising opportunities of bamboo management. Institutions can be defined as societal rules or the human constraints that govern political, social or economic exchange (North 1990). The literature of socio-ecological systems provides a valuable framework for thinking about new or transformed institutions for bamboo management. Key concepts

within this literature are Complex Adaptive Systems (CAS), resilience thinking, as well as approaches to brokering learning, primarily transformative change.

Complexity theory, rather than an equilibrium view, underpins the socio-ecological approach (Scoones 2007b). For example under the equilibrium view bamboo management focuses on annual allowable cuts, however studies in India found that the retention of the protective covering of the axial branches was more important than annual allowable cuts (Prasad 1985). In contrast to equilibrium, the notion of a complex adaptive system (CAS) views sustainable development as a dynamic process of reciprocal feedback between the social-ecological system (Berkes and Folke 1998), with external 'social' and internal 'ecological' aspects of an integrated system (Folke 2005). A CAS approach is important for natural resource management systems in order to emphasise that structures adapt to changing external environments over temporal scales. Sustainable development is increasingly perceived as a process involving aspects of evolutionary and co-evolutionary change (Rammel et al.2007a). Sustainable development is about creating and maintaining our options for various co-evolving elements of social-ecological systems. (Folke et al. 2004; Stagl 2007)

Crucially the distinction between adaptation and resilience in socio-ecological systems thinking draws attention to the distinction between reactive policy and policy which is robust to changing circumstances. The recent snow disasters and current state of intensively managed forests in China is proof that bamboo policy has been largely reactive to changes in circumstances. A major challenge to bamboo management and other bio-productive systems is to maintain the resilience of the system in the face of change. Resilience is defined as the capacity of a system to absorb disturbance and undergo change whilst retaining fundamentally the same functions, structure, identity, and feedbacks (Folke 2006).

Leach and Smith (2007) argue that the ability to enhance resilience depends on the dynamics of the biophysical system and institutional organizational and governance processes that enable adaptive co-management of ecosystems. Central to this process will be transformative learning. Adaptability is the capacity of actors in a social-ecological system to manage resilience in the face of uncertainty. In contrast, Walker et al. (2004) define transformability as the capacity to create a fundamentally new system when ecological, economic, or social conditions allow. Transformative change can occur as a result of three key events: ecological crises, shifts in the social components of the system, such as in social values or resources (Folke et al. 2004) or economic or political change (Olsson et al. 2006). Two significant areas of learning present themselves with bamboo management to create an arena for change, through experiencing crisis and niche adoption of practice (representing potentially both social and economic change).

Crisis can act as a catalyst for learning (Westley 1995). The majority of breakthrough thinking is the result of a response to crisis (Stagl 2007). After the worst snow disaster for 100 years in China, farmers began to realize how vulnerable their bamboo stands were without the support of trees. Monoculture areas too are experiencing higher frequency of pests and diseases, therefore providing learning through 'crisis.' Resilient system preparedness is advocated rather than learning being attributed solely to natural disasters; this is where niche practices play a significant role.

Niche-based approaches explore problem framings and search for solutions (Smith 2007). Against this backdrop three niche approaches will be considered in this study, namely the Forest Stewardship Council (FSC) bamboo

certification and Conservation Agriculture (CA) for bamboo as well as the importance of considering the diverse livelihood options will be addressed within the framework of the DFID model. Strategic niche management is concerned with two processes: the quality of learning, and the quality of institutional embedding. Learning can be limited to the technical performance or extend to complementary infrastructures. If a broad network of users and outsiders utilise the framework, then the niche may contribute to the formation of a new regime (Smith 2007).

To be effective, practitioners must engage with different systems and problem framings. This practice-based perspective accommodates plurality of approaches addressing uncertainty and complexity and does not seek to define a single model (Schön and Rein 1994). Dynamic social, technological or environmental systems must be understood in relation to both their structures and their economic, institutional or ecological functions (Thompson and Stagl 2007). Bamboo management however is further complicated by the 'frame of reference' being blurred. Although managed under forestry laws, classified as a Non-Timber Forest Product (NTFP) under FSC, a tree for the Clean Development Mechanism (Widenoja 2007) and advocated as horticulture by Indian bamboo experts, the lack of consensus highlights the pressing need for plurality of approaches, to borrow from forestry, agriculture and livelihoods development. Three models will be addressed under the banner of 'the three pillars of sustainability': society, environment and economy.

Bamboo Certification: Society?

Forest certification is a non state market driven mechanism (NSMD) (Cashore et al. 2007) encompassing the three chambers of environment, society and economy akin to the three pillars of sustainability. The feasibility and need for certification has been researched (Buckingham 2007; Lou et al. 2008). Bamboo FSC certification is currently established in areas of Zhejiang however global bamboo certification programmes have faced various efficacy issues due to finance, capacity and local comprehension of schemes, a lack of market drivers, administration challenges and predominance of certification bodies being overseas (Buckingham et al. 2009). Although the FSC Principles and Criteria (P&C) have been developed for China, it remains to be seen whether a system created for sustainable forest management can be adequately translated into bamboo management.

Although there are administrational challenges associated with certification, it also provides arenas for change in operational management. Two approaches that arise from the certification assemblage include 'adaptive co-management' and the Modular Implementation and Verification (MIV) approach. Adaptive co-management refers to the multilevel and cross-organizational management of ecosystems (Olsson et al. 2004). Fundamentally co-management is not merely about resources; it is about managing relationships (Natcher et al. 2005), thereby the certification assemblage could potentially provide an arena for change within operational approaches; the P&C have guidelines for management plans, monitoring and assessment, tenure and laws, community relations and workers rights, exceeding a beyond a narrow environmental stewardship agenda.

In order to audit multifaceted dimensions across the social and environmental spheres, the MIV was developed and approved by FSC in 2005 as a stepwise, modular or phased approach to forest certification. The aim of the approach is to identify and understand the root causes of why certain modules require improvements, not just isolate gaps (Nussbaum 2003). WWF and IKEA first developed the MIV approach as a manageable toolkit separating legal, technical, environmental and social components. The five subcategories divide the FSC P&C.

What is potentially transformative about MIV in terms of policy is that it isolates strengths and areas for intervention. In sum, bamboo certification can provide opportunities within the social sphere to build the institutional framework.

Bamboo Agro-ecology: Environment?

Bamboo requires a reconfiguration of bamboo management practices which focus on environmental stewardship for resilience. The efficacy of FSC standards is currently inconclusive, however agro-ecological alternatives which have emerged as a response to the second-generation impacts of the Green Revolution emphasise pathways of change which work with natural systems (FAO 2008), different from traditional practices. One institutional agricultural practice that has been adopted by farmers for 10 000 years is tillage (FAO 2008). An agro-ecological approach that opposes this traditional practice is Conservation Agriculture (CA). CA has three basic principles defined as minimal soil disturbance (no-till) and permanent soil cover (mulch) combined with rotations (Hobbs 2007). Residue retention and reduced tillage are both conservation agricultural management options that may enhance soil organic carbon (SOC) stabilization. The dynamics of Soil Organic Matter (SOM) are influenced by agricultural management practices such as tillage, mulching, removal of crop residues and application of organic and mineral fertilizers (Chivenge et al. 2007). Conservation agriculture has emerged as a new paradigm to achieve goals of sustainable agricultural production.

The biggest challenge facing CA is overcoming the past mindset whereby agriculture is nearly synonymous with the practice of cultivating the soil (Abrol et al. 2006).Tillage disrupts the soil pores left by roots and microbial activity. The bare surface exposed after tillage is prone to breakdown of soil aggregates, reduced infiltration of water and increased run-off, leading to soil erosion. When the surface dries, it crusts and forms a barrier to plant emergence. The bare surface after tillage is prone to wind erosion. Figure 2 demonstrates the negative effects stemming from inappropriate tillage practices. CA increases biotic diversity in the soil as a result of the mulch and reduced soil disturbance. It also produces higher surface soil organic carbon than when soils are tilled (Hobbs 2008).

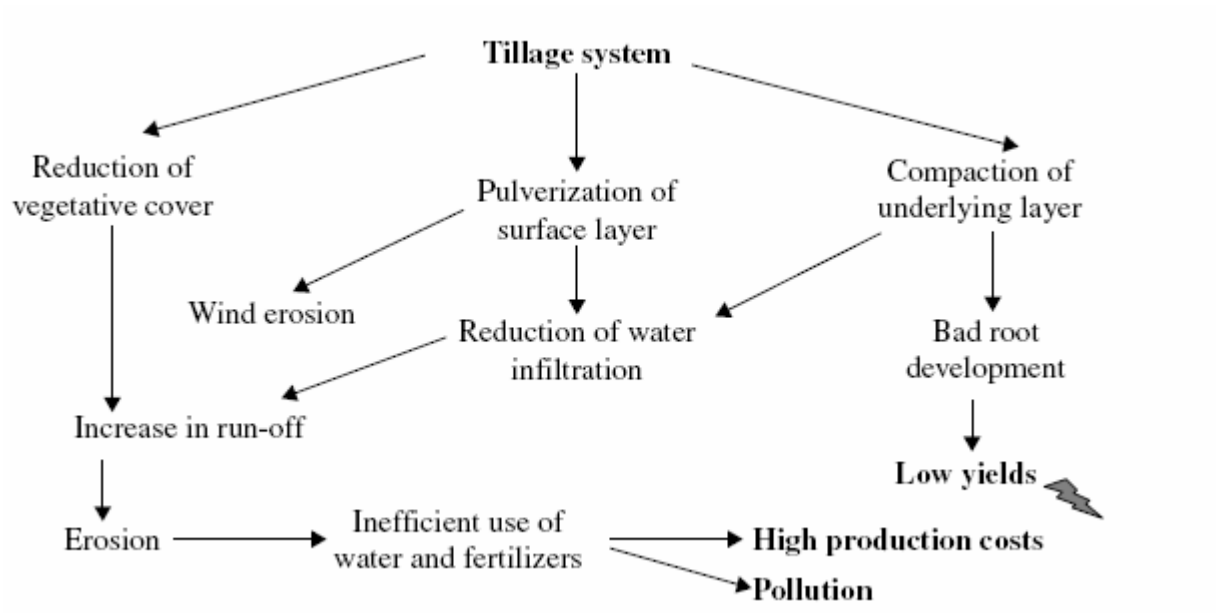

Figure 1: The effects of inappropriate tillage practices (Hobbs 2007)

CA techniques could be used for bamboo management in China. Soil degradation is one of the key problems that has arisen in recent times, particularly in the high intensively managed bamboo areas in Zhejiang. Bamboo farmers have reported digging and tilling the land and removing forest cover to create more efficient monocultures. As the first principle of CA, no till forms the corner stone of CA, however permanent soil cover and combined cropping also constitute important contributions to a robust agricultural system. Bamboo in India has already been seen to benefit from various intercropping techniques, the most famous of which is in Tripura. In 1996, bamboo was planted in India on degraded brick mining land. Within 5 years the ground water level rose from below 40 metres to 33.7 metres, the microclimate improved and 70% of the migrant labourers returned to their village communities to be involved in agro forestry (INBAR 2003).

Bamboos advantage of shallow roots, creating an opportunity for growth on marginalised lands, also presents challenges regarding the intensification of bamboo management. Deep roots are needed to enable the supply of water for transpiration. As a grass, 44% of root biomass occupies the top 10cm of soil and 75% within the top 30cm, unlike temperate and tropical trees, whereby 26% of root biomass constitutes the top 10cm and at least 78% the top 50cm (Bonan 2002); without trees bamboo lacks water for transpiration. Moso rhizomes extend to 20cm or 30cm (Jiang 2007). Moreover with the shallow root systems on often sloping land, bare land and unsustainable tillage, use of chemicals and lack of other forms of protective vegetation reduce the resilience of the ecosystem.

Bamboo as an integrated management activity in a livelihoods model: Economy?

The niche approaches discussed thus far concentrate on societal elements and environmental stewardship. Although forest certification aims to operate in niche markets as a NSMD, the efficacy to produce price premiums and economic benefits are yet to be seen, therefore the economic benefits need to be considered in robust policy instruments. Studies have found that in China bamboo is often managed as a 3 month activity (Buckingham 2008), moreover in India bamboo is managed as part of a horticultural system. Livelihood models would therefore provide useful guidelines for the matrix of approaches in order to create a holistic resilience framework for bamboo management.

Recognising and understanding the dynamics of the livelihoods process is fundamental for any analysis of resilience. Carney (1998) considers a livelihood sustainable "when it can cope with and recover from stresses and shocks and maintain or enhance its capabilities and assets both now and in the future, while not undermining the natural resource base." The structure of people's livelihoods and diversity in assets varies greatly, as do the effects of external influences upon them (Soussan et al. 2000). Figure 3 illustrates the DFID livelihood model which shows the social-ecological interconnectedness and need for diversity in approaches. This can be used as a model for learning for bamboo management through considering the internal and external forces. External forces beyond the control of farmers include the social, economic, political, legal, environmental and institutional dynamics of their local area, the wider region, their country and, increasingly, the world as a whole. Taken together, the threat of external shocks and trends directly affect the decision making environment and the outcomes of livelihoods, and provide the vulnerability context.

Rennie and Singh (1996) identify the responses of such threats as either adaptive strategies (where a household consciously adopts a process of change in response to long term trends) or coping strategies (short-term responses to immediate shocks and stresses). In these, the household will seek to deploy their different assets to best effect within their often limited range of choices. Although the livelihoods model isolates areas beyond the control of farmers themselves, it also identifies areas for policy change, since the institutional context in which the livelihood model operates is key to enhancing the resilience of the system and reducing the vulnerability within the system. Therefore when considering bamboo management, a narrow view of only enhancing bamboo management expertise should not be taken, bamboo management should be approached as one of a set of diverse livelihood options.

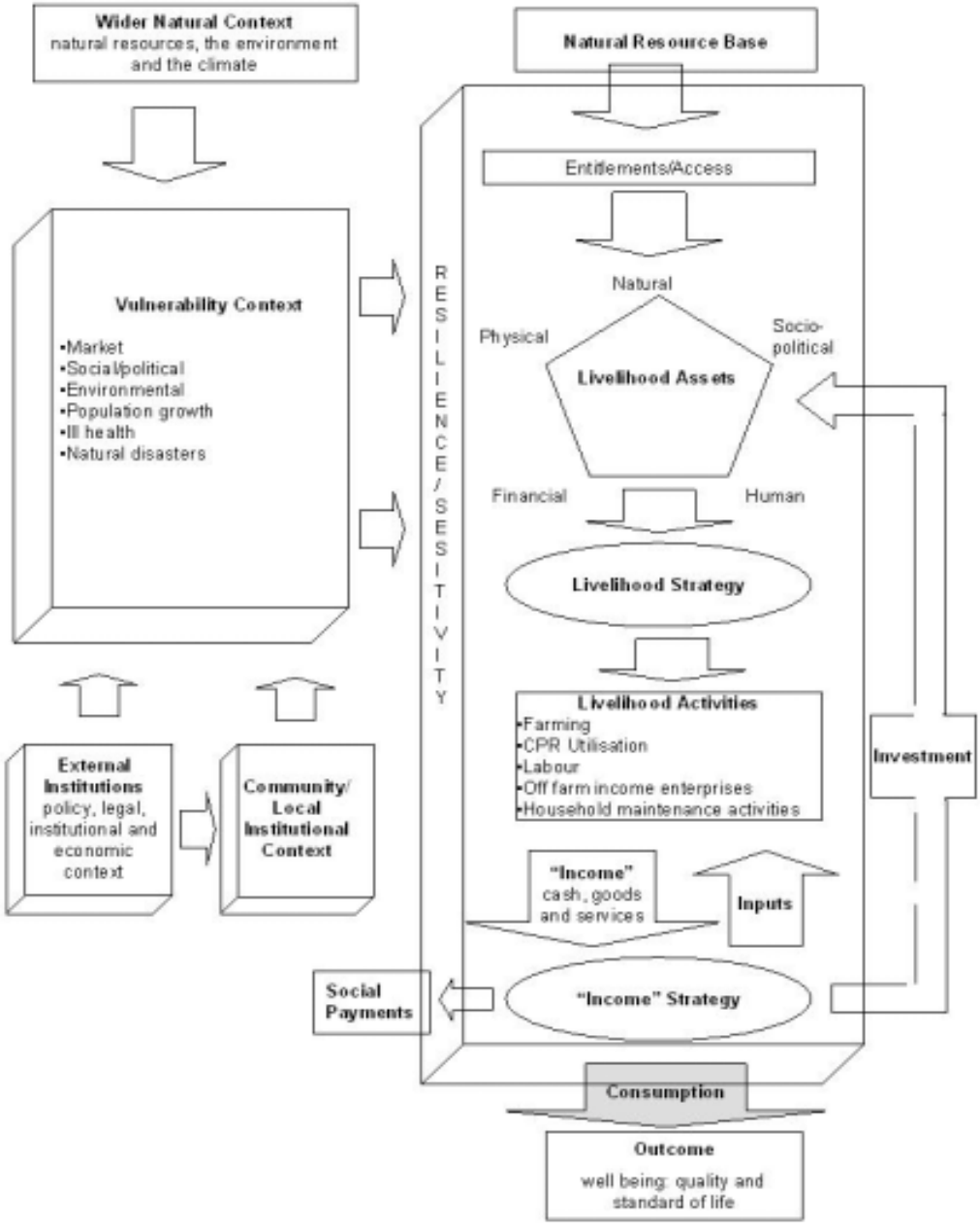

Figure 2: The livelihoods model (Soussan et al. 2000)

Conclusion

The need to reassess the bamboo management toolkit arises from the current challenges facing bamboo management in China such as intensive harvesting, an increase in monocultures with associated biodiversity loss, excessive tillage, chemical residues, erosion and depletion of soil nutrients. These challenges have been further exacerbated by the recent snow disaster in 2008 whereby bamboo farmers, particularly in monoculture stands, suffered significant losses. A major challenge to bamboo management and other bio-productive systems is to maintain the resilience of the system in the face of change. The modernisation of bamboo management institutions is key to meeting policy challenges and realising opportunities for bamboo management.

This paper has considered three policy instruments that could be applicable to assist sustainable bamboo management: forest certification, conservation agriculture and a livelihoods approach. These options present just three of the possible approaches towards an integrated approach to 'the three pillars of sustainability' through the environment, society and economy. Experts have warned against having new blueprint approaches, but instead forming a patchwork of approaches to suit situational contexts. It is acknowledged that other policy instruments such as carbon storage could also contribute to the socio-ecological dimension, however for the purpose of this paper a number of learning outcomes have been identified from the three models.

There are potential arenas for learning which arise from the Forest Stewardship Council (FSC) Principles and Criteria (P&C) even if the primary goal of a non state market driven mechanism is not effective. FSC potentially plays a role in advocating forms of adaptive co-management, moreover the Modular Implementation and Verification approach identifies strengths and gaps for enhancing policy. The second instrument, CA provides many learning opportunities for bamboo to transform management practices to sustainable resilient ecological systems. Moreover the livelihoods model provides a framework for understanding the need for diversity, not just biologically, but economically. Together the frames can go some way towards reconfiguring bamboo management and governance within resilience thinking.

The paper has highlighted the important role played by institutions to recognize the need to adapt systems to resilience with the aim to eventually move to transform systems rather than react through adaptation. Bamboo management operates within Complex Adaptive Systems (CAS) which are constantly co-evolving within social-ecological systems. Niche systems have the potential to transform to regimes if practices are widely adopted therefore such schemes act as pilots for practices. It remains to be seen whether there can ever be a perfect fit between governance and biophysical systems. Social and biophysical systems are not merely linked but interconnected. Institutions and policy prescriptions that fail to acknowledge this tight interconnection are likely to fail. (Galez et al 2008). Crucially the distinction between adaptation and resilience in socio-ecological systems thinking draws attention to the distinction between reactive policy and policy which is robust to changing circumstances. With the challenges posed by climate change there is a need for proactive rather than reactive policy.

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Global Bamboo Trade and the New HS Codes

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Abstract:

Due to the deterioration of global environment and pressure on the supply of timber resources, bamboo has garnered more and more attention from both producer and consumer countries throughout the world. Bamboo industry and trade contribute greatly to the global economy and trade. This study used UN Comtrade data to analysis the global trade status of bamboo products. The global trade statistics of bamboo products with different UN codes system before and since 2007 were compared and bamboo trade data in EU and China in different coding system were analyzed. The total global export and import trade value of bamboo products continuously increased in the past decades. The main bamboo products in the global market are bamboo for plaiting, mats and screens, basketwork, furniture and seats, charcoal, plywood and panels, and bamboo shoot products. Most of bamboo products were traded within and between Asia and Europe. China, EU, USA, Japan and other Asian countries with bamboo resource are the major traders of bamboo products in the world. More efforts need to be made to further add new HS Code for bamboo products and the quality of global bamboo trade data should be improved through the international cooperation on information exchange and data research.

Keywords: Global trade, Bamboo products, HS codes

As one of the most important non-timber forest resources, bamboos are found in Asia, Africa and Latin America. Bamboo products have a great potential in European and North American markets (Jiang 2002). Bamboo is a good timber substitute and processing and utilization of bamboo resources have drawn more and more attention from producer and consumer countries throughout the world due to pressure on the supply of the world's timber resources (Wu 2009). Trading in bamboo products, from raw materials to value-added products, from shoot to furniture, from charcoal to flooring, has potential to contribute greatly to the global environment, its economy and market.

HS Codes of Bamboo Products

The Harmonized Coding System (HS) is a 6-digit commodity classification system developed in the 1980s by the Customs Cooperation Council, later renamed the World Customs Organization (WCO) (Lobovikov 2003). There were 9 HS codes for bamboo, of which only 1 code was given to bamboo products specially, that is "bamboo for plaiting" and the rest 8 codes were not differentiated from the codes of wood products or other similar materials. For example, bamboo shoot products are not distinguished separately from a big variety of the

traded vegetables. Additionally, these traditional codes included only traditional bamboo items, such as bamboo for plaiting, plaited products, furniture and shoots and didn't reflect developments of industrial bamboo commodities such as bamboo flooring, panels, boards, pulp and paper, fabrics, charcoal and shoots (Wardle 2003).

With the aim of improving the quality of bamboo trade data, INBAR and the United Nations Food and Agriculture Organization (FAO) helped to develop 9 new, 6-digit codes for bamboo and 2 for bamboo and rattan furniture and seats to reflect the revolutionary changes in the bamboo industries over the preceding 10-15 years. These were formally approved by WCO in 2005, and have been effective since 2007(table 1).

Each code should collect minimum US$50 million annual trade according to HS requirements (WCO 2002). The present HS system has 12 codes for bamboo, covering 5 categories and 8 chapters, among of them 10 codes for bamboo, and 2 codes for mixed bamboo and rattan. At present, most bamboo products, both newly developed products, including pulp and paper, bamboo panels, charcoal and traditional products, such as basketwork, mats and screens, and preserved bamboo shoots, are listed in individual categories. However, the codes still need improvement. Some products (e.g. bamboo panels, bamboo shoot other than preserved bamboo shoot, handicrafts, etc.) end up listed in inappropriate product categories or not differentiated from other similar products (Jiang 2007).

Table 1 Harmonized System (HS) codes for bamboo

Codes in 2007		Codes before 2007	
Codes	Code description	Codes	Code description
# Bamboo raw materials			
140110	Bamboo for plaiting	140110	Bamboo for plaiting
		140190	Veg. materials used for plaiting(incl. bamboo)
# Bamboo plaited products			
*460121	Bamboo mats and screens	460120	Mats and screens(incl. bamboo)
*460192	Bamboo plaits and plaited prods	460110	Plaited products(incl. bamboo)
		460191	Plaits and plaited prods(incl. bamboo)
*460211	Bamboo basketwork	460210	Basketwork(incl. bamboo)
# Bamboo industrial products			
*440210	Bamboo charcoal		
*440921	Bamboo shaped products		
*441210	Bamboo plywood		
*470630	Bamboo pulp		
*482361	Bamboo paper articles		
# Furniture and seats			
*940151	Bamboo and rattan furniture	940150	Furniture (incl. bamboo)
*940381	Bamboo and rattan seats	940380	Seats(incl. bamboo)
# Bamboo shoots			
*200591	Preserved bamboo shoot	200590	Preserved vegetables(incl. shoot)

Note: * new codes effective since 2007; # headings for description purpose only in this paper.

The revision of bamboo codes reflects the rapid development of the global bamboo industry and the increasing trade of bamboo products. It also indicates that bamboo products and trade have been drawing attention both from producer countries and consumer countries.

An Overview of Global Bamboo Trade

Although the new codes for bamboo and rattan commodities have been in effect since 2007, to date the UN database for commodities hasn't yet completed data transition and adjustment. Thus the following analysis on the global bamboo trade is still based on the original four categories, nine 6-digit codes before 2007.

Commodity Composition of Global Bamboo Trade

According to UN Comtrade data (UN 2007), the global export trade value of product sectors including bamboo was US$ 6.99 billion in 2007, of which the trade value of raw materials, plaited products and furniture and seats were mixed with products made of rattan and similar materials and the export trade value of preserved bamboo shoots was mixed with other preserved vegetables. The export trade value for raw materials, plaited products, furniture and seats and peserved vegetables and shoots were respectively US$ 0.13 billion, US$ 1.96 billion, US$ 2.62 billion, and 2.29 billion, 2%, 28%, 37% and 33% respectively of the total (Table 2).

Growth of Global Trade of Product Sectors including Bamboo in 1995-2007

The total export trade value of product sectors including bamboo increased to US$ 6.99 billion in 2007 from US$ 3.89 billion in 1995, with an average annual growth rate of 6%. Products exports grew substantially, of which furniture increased fastest, up from US$ 0.90 billion to US$ 2.24 billion between 1995 and 2007 with an annual average of growth rate of 11%, followed by preserved vegetables, mats and screens with the growth rate of 8% (Figure 1).

Table 2 Global trade of product sectors including bamboo in 2007

Unit: million USD

		Import		Export	
		Value	Proportion	Value	Proportion
140110	Bamboo for plaiting	134	0.02	53	0.01
140190	Veg. materials used for plaiting	93	0.01	74	0.01
Sub-total of raw materials		227	0.03	127	0.02
460110	Plaited products	0	--	0	--
460121	Mats and screens	362	0.05	465	0.07
460211	Basketwork	1887	0.25	1424	0.20
460191	Plaits and plaited prods	64	0.01	70	0.01
Sub-total of plaited products		2313	0.31	1960	0.28
940150	Furniture	2069	0.28	2240	0.32
940380	Seats	618	0.08	378	0.05
Sub-total of furniture and seats		2687	0.36	2618	0.37
200590	Preserved vegetables	2283	0.30	2288	0.33
Sub-total of shoots		2283	0.30	2288	0.33
Grand total		7510	1.00	6992	1.00

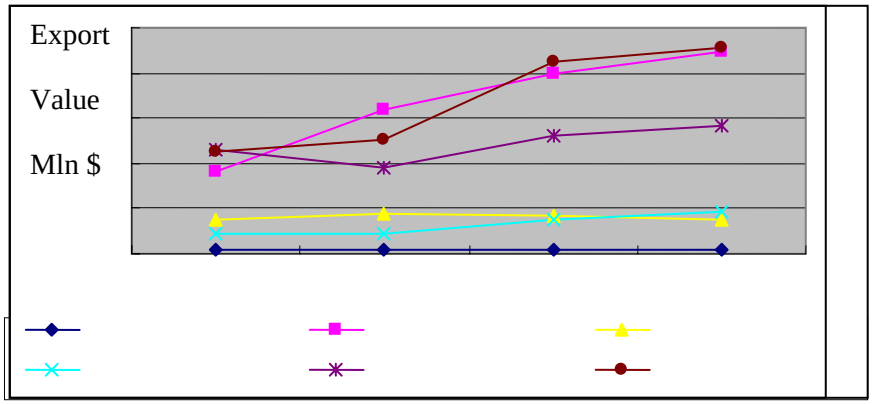

Figure 1 Global trade of product sectors including bamboo in 1995-2007

Trade Flow of Product Sectors including Bamboo Trade in 2007

According to UN Comtrade data, China, Indonesia, EU, the Philippines and USA were the top five exporters of product sectors including bamboo with market shares of 38%, 10%, 9%, 2% and 2% respectively in 2007 (figure

2). EU, USA, Japan, Canada and Singapore were the top five importers, responsible for over 59% of the total imports value of bamboo products, including raw materials, plaited products, furniture and seats.

According the data analysis, China was the largest exporter of raw materials with a value of US$ 37 million in 2007, nearly 30% of the total export value. EU was the largest importers of raw materials with a value of US$ 68 million, 30% of the total import value of materials. China, Indonesia, the Philippines, Hong Kong and USA were the top 5 exporters of plaited products including basketwork, mats and screens and EU, USA, Japan, Canada and Korea were the top 5 importers. China, EU, USA, Thailand and Malaysia were the top five exporters of furniture and seats, USA, EU, Canada, Japan and Singapore were the top five importers of furniture and seats.

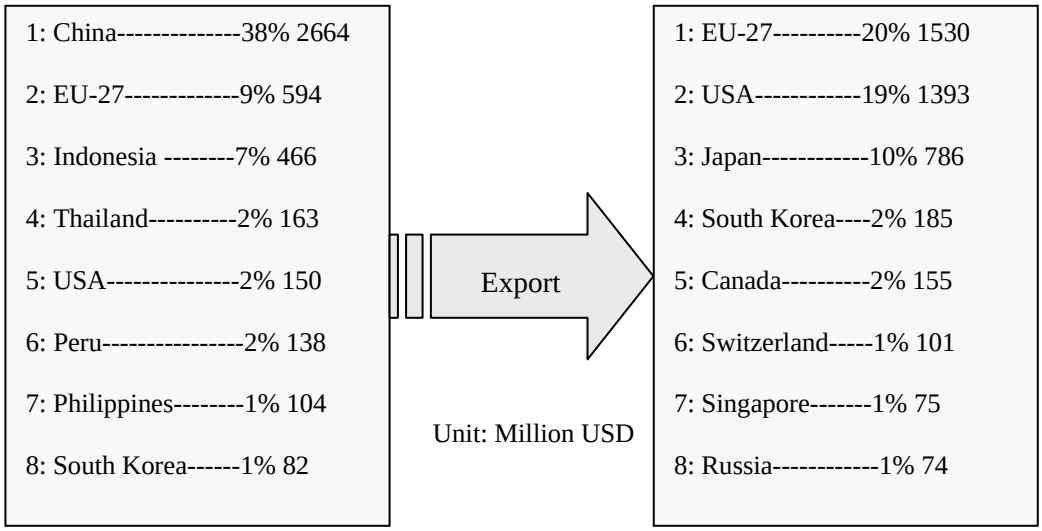

Figure 2 Top traders of bamboo products in 2007 with codes before 2007

Global Trade with New Codes

In cooperation with the International Tropical Timber Organization (ITTO) and European Forest Institute (EFI), the International Network for Bamboo and Rattan developed the Bamboo and Rattan Trade Database from 2003, based on UN Comtrade data, utilizing the Harmonized Commodity Description and Coding System (HS) used by World Customs Organization (WCO) (INBAR 2007).

Trade Statistics for Global Bamboo Trade

Bamboo trade data, partly using the new codes, was updated in the global bamboo and rattan trade database (INBAR 2007). The total export value using the new codes in 2007 was US$ 2.15 billion, which was a lot less than the data according to the code system before 2007 and obviously indicated that the updating has not been completed, and that the new codes are more accurate for some specific codes and products, such as preserved

bamboo shoots. The export trade value for bamboo raw materials, bamboo plaited products, bamboo industrial products, furniture and seats, and bamboo shoots were US$ 0.06 billion, US$ 0.55 billion, US$ 0.67 billion, US$ 0.65 billion and US$ 0.23 billion respectively, representing proportions of 3%, 25%, 31%, 30% and 11% of the total (Table 3).

The data with new codes in 2007 reflected a more accurate and proper composition and proportion of main bamboo products in global market, although the current bamboo products trade statistics still misestimate global bamboo trade as furniture and seats share codes with rattan and some bamboo products are not classified from wood and similar materials. In addition, a considerable proportion of national bamboo trade data is not stated, as many countries have not started using the new codes or have not completed transfer and updating according to the new codes.

Meanwhile, data statistics in regional or national level are usually more accurate and reliable, and are updated very timely. Analysis on the trade data of EU, the largest importer and China, the largest exporter bamboo products in the world, will be made in the following paragraphs in order to clarify the trade situation of bamboo products, using different trade data sources, including UN Comtrade data, EU trade statistics and trade data of China's Customs.

Trade Statistics for Bamboo Products in EU

As the largest importer and the third largest exporter of bamboo products in the world, EU used and developed its commodity codes within the framework of UN coding system and updated timely. There are 13 codes for bamboo products in EU coding system, of which one extra code was given to bamboo shoot other than preserved bamboo shoots (EU 2008). According to EU trade statistics, the total trade value of bamboo products in EU decreased from 2007 to 2008, of which the export value decreased from US$ 108 million to US$ 79 million and the import value decreased from US$ 612 million to US$ 466 million. N.B. It should be noted that these figures are for import and export into and from the EU as a single unit, and do not include the import and export between EU countries As the largest importer of bamboo products, the total import value in 2008 was US$ 466 million, of which 9% was for bamboo raw materials (US$ 44 million), 6% for bamboo shoot (US$ 26 million), 11% for bamboo industrial products (US$ 51 million), 27% for bamboo plaited products (US$ 129 million), 22% for furniture (US$ 105 million) and 24% for seats (US$ 111 million). As a significant exporter, the total export value of bamboo products from EU in 2008 was US$ 79 million, of which 55% were furniture and seats, 24% for bamboo industrial products, 11% for bamboo shoots, 7% for bamboo plaited products and 3% for bamboo for plaiting.

Table 3 Global export trade value of bamboo products in 2007

Unit: Million USD

Codes	Bamboo products	Data with old codes	Data with new codes	Data difference
140110	Bamboo for plaiting	53	55	2
Sub-total of bamboo raw materials		127	55	-72
460211	Basketwork	1424	289	-1135
460121	Mats and screens	465	230	-235
460192	Plaits and plaited prods	70	28	-42
Sub-total of bamboo plaited products		1960	547	-1413
440210	Bamboo charcoal	--	58	58
440921	Bamboo shaped products	--	298	298
441210	Bamboo plywood	--	248	248
470630	Bamboo pulp	--	62	62
482361	Bamboo paper articles	--	3	3
Sub-total of bamboo industrial products		--	669	669
940151	Furniture	2240	333	-1907
940381	Seats	378	320	-58
Sub-total of furniture and seats		2618	653	-1965
200591	Preserved bamboo shoots	2288	227	-2061
Grand Total		6992	2151	-4841

A comparison of trade value of bamboo products based on UN Comtrade data and EU trade statistics in 2008 was made to address the data differences by different data sources (table 4). As shown in table 4, there was a data difference between UN Comtrade data and EU trade statistics, of which UN Comtrade data overestimated US$ 28 million of the export value of EU in 2008 and US$ 5 million of the import value in 2008.

Trade Statistics for Bamboo Products in China

As the largest exporter of bamboo products in the world, China developed it national 8-digit codes within the framework of UN coding systems. Up to 2007, 26 codes had been set for bamboo products in China, of which 5 individual codes are given to bamboo shoot products, 8 codes to various bamboo panels, 6 to other industrial bamboo products, including bamboo charcoal, chopsticks, sticks, pulp and paper, 4 to bamboo plaited products, and 2 to furniture and seats (mixed with rattan) and 1 to bamboo raw materials (China's Custom 2008).

The total export value of bamboo products from China in 2008 was US$ 1.36 billion, of which 14%(US$ 193 million) was for bamboo shoots, 44%(US$ 594 million) for bamboo plaited products, 3%(US$ 35 million) for furniture and seats, 24%(US$ 324 million) for bamboo flooring, 4% (US$ 56 million) for other panels, 8%(US$ 105 million) for chopsticks and sticks, 2%(US$ 33 million) for bamboo for plaiting and the rest 1% included bamboo charcoal, pulp and paper articles(Zhang 2009). The total import value of bamboo products in China in 2008 is about US$ 16 million, of which 50% was for pulp and paper articles, 21% for raw materials, 7% for furniture and seats.

Table 4 Trade value and composition of bamboo products in EU in 2008

Unit: Million USD

Code	Products	Import		Export	
		UN data	EU data	UN data	EU data
140110	Bamboo for plaiting	46.4	43.76	2.46	2.32
Sub-total of bamboo raw materials		46.4	43.76	2.46	2.32
460211	Basketwork	38.69	36.49	1.85	1.75
460121	Mats and screens	15.39	14.52	0.97	0.92
460192	Plaits and plaited prods	82.19	77.52	2.8	2.65
Sub-total of bamboo plaited products		136.27	128.53	5.62	5.32
440210	Bamboo charcoal	8.45	7.97	1.45	1.37
440921	Bamboo shaped panels	38.61	36.42	6.86	6.47
441210	Bamboo plywood	3.05	2.87	8.85	8.35
470630	Bamboo pulp	0.23	0.22	0.12	0.11
482361	Bamboo paper articles	4.16	3.92	2.86	2.69
Sub-total of bamboo industrial products		54.5	51.4	20.14	18.99
940151	Furniture	118.1	111.4	5.44	5.13
940381	Seats	111.15	104.84	40.52	38.22
Sub-total of furniture and seats		229.25	216.24	45.96	43.35
200591	Preserved bamboo shoots	27.59	26.03	9.61	9.06
Grand Total		494.01	465.96	83.81	79.04

Although the new codes were developed for more bamboo products, the current UN Comtrade data still overestimates and misestimates the actual trade situation. A comparison of trade statistics in China in 2008 based on the data of UN Comtrade coding system and Chinese national codes showed the trade data differences with new codes for bamboo (table 5). Data difference of the total export value of China in 2008 between UN Comtrade data and Chinese national data was about US$ 316 million, which mainly came from bamboo shoot products other than preserved bamboo shoots, bamboo plaits and plaited products, bamboo chopsticks, sticks and sculpture. Obviously, it showed that some very important bamboo products with a big trade market have not been classified in appropriate categories in UN Comtrade data and further adjustment should be done for the 6-digit HS codes of bamboo products.

Conclusions and Recommendations

Importance of Global Bamboo Trade

As the most important non-timber forest product resource, bamboo is closely bound up with the life and existence of 1.5 billion people around the world, benefiting not only the producer countries but also the consumers in many developed countries. Global bamboo trade over recent decades has increased continuously, both in terms of the total value of exports and imports and the number of exporters and importers of bamboo products. The main bamboo products in the global market are raw materials, traditional plaited products, further-processed products, furniture and bamboo shoots. Asian countries with abundant bamboo resource and traditional bamboo industry are the major exporters of bamboo products in global market, especially China, which dominates the exporting market with a very significant market share. EU and USA contribute to the exporting market greatly as well, with their advanced processing technology. EU, USA and Japan are the top importers of bamboo products, either raw materials, or traditional products and value-added products.

Necessity of Additional New HS Codes for Bamboo Products

UN Comtrade data has almost separated the main bamboo commodities from rattan and many wooden products and more accurately captured key bamboo trade flows since 2007, and would be

Table 5 Export trade value of bamboo products in China in 2008

Unit: million USD

Code	Products	UN data	China's data	Data difference
14011000	Bamboo for plaiting	33.59	33.14	0.45
Sub-total of bamboo raw materials		33.59	33.14	0.45
44021000	Bamboo charcoal	7.24	5.26	1.98
44092110	Bamboo flooring	-	324.33	-324.33
44092190	Bamboo shaped products	329.34	5.03	324.31
44121011~1099	Bamboo plywood	72.2	51.32	20.88
44190032	Bamboo chopsticks	--	75.50	-75.5
44219022	Bamboo sticks	--	29.92	-29.92
44201010	Bamboo sculpture	--	11.03	-11.03
47063000	Bamboo pulp	3.29	3.72	-0.43
48236100	Bamboo paper articles	0.01	0.04	-0.03
Sub-total of bamboo industrial products		412.08	506.16	-94.08

46012100	**Bamboo mats and screens**	**195.06**	**330.56**	**-135.50**
46021100	**Bamboo basketwork**	**189.50**	**222.49**	**-32.99**
46019210/9290	**Plaits and plaited products**	**13.85**	**41.04**	**-27.19**
Sub-total of bamboo plaited products		**398.41**	**594.09**	**-195.68**
94015100	**Bamboo and rattan seats**	**17.79**	**13.79**	**4**
94038100	**Bamboo and rattan furniture**	**22.43**	**20.99**	**1.44**
Sub-total of furniture and seats		**40.22**	**34.79**	**5.43**
07099010	**Fresh bamboo shoots**	**-**	**5.17**	**-5.17**
07119031	**Salted bamboo shoots**	**-**	**11.23**	**-11.23**
07129010	**Dried bamboo shoots**	**-**	**13.51**	**-13.51**
20059110	**Preserved bamboo shoots**	**161.54**	**145.74**	**15.80**
20099190	**Other preserved bamboo shoots**	**-**	**17.72**	**-17.72**
Sub-total of bamboo shoots		**161.54**	**193.37**	**-31.83**
Grand Total		**1045.84**	**1361.56**	**-315.72**

the best available source of information to monitor the commodity composition, dynamics and prices of global bamboo trade. However it is still insufficient and needs to be further improved. For example, bamboo furniture and seats still share codes with rattan, and many important products are still classified in other categories without specific codes, such as bamboo chopsticks, craftwork as well as some new products including bamboo fiber and chemical products. Therefore, efforts to add new HS codes for bamboo products should be made and promoted with the cooperation of WCO, INBAR and relevant countries.

International Cooperation on Trade Codes and Data Quality of Bamboo

The production and consumption of bamboo products major is concentrated in Asia and Europe. The related trading countries have better developed commodity codes for bamboo products. For example, the 8-digit codes in China increased from 12 to 25 in 1992-2007 with which more and more bamboo products classified from wood, vegetables and similar materials in China's Customs codes. As one of the key importers of bamboo products, and especially as the largest importer of bamboo shoots, Japan has well developed bamboo HS codes (Wardle 2003) with individual codes for bamboo shoots, chopsticks, charcoal, etc. To improve the quality of present trade data of bamboo products, international cooperation on code and data research should be further enhanced in line with national trade status. A new HS codes proposal in future to WCO could be drafted based on a survey of national HS codes, especially with comments and experiences from the top traders. But countries need to exchange information on national bamboo trade statistics in order to improve their own bamboo HS codes and research trade on bamboo products simultaneously.

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Bamboo Biomass Energy –A Partnership between Ghana, Ethiopia, China and INBAR

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Abstract

The African continent increasingly depends on firewood and charcoal for cooking and heating homes. In 2000, nearly 470 million tonnes of wood were consumed in homes in sub-Saharan Africa in the form of firewood and charcoal, more wood per capita than in any other region in the world. Moreover, more than 1.6 million people, primarily women and children, die prematurely each year worldwide (400,000 in sub-Saharan Africa) from respiratory diseases caused by the pollution from such fires.

Ethiopia and Ghana are two African countries where the majority of households rely on wood-based fuels as the primary energy source for domestic cooking and other productive activities. Ethiopia's energy sector depends heavily on traditional firewood and wood charcoal, which account for more than 90% of final energy consumption. Similarly in Ghana, firewood and wood charcoal account for more than 78% of all primary energy consumption. These levels of consumption are highly unsustainable, with use of firewood and wood charcoal emerging as a main contributor to deforestation and air pollution.

Bamboo-based firewood and charcoal are suitable alternatives for wood-based firewood and charcoal. Because bamboo has advantages like self regeneration, sustainability of supply, environment friendliness etc; and bamboo charcoal has high heating value, which is suitable for household energy source.

This paper outlines an EC-funded project: Bamboo as a sustainable biomass energy. In this project INBAR will work in partnership with FEMSEDA and EREDPC in Ethiopia, with FORIG and BARADEP in Ghana and with Nanjing Univeristy in China and introduce and develop bamboo biomass energy technology, especially bamboo charcoal technology, for Ethiopia and Ghana.

The project action has strong potential for further replication in sub-Saharan Africa, Asia and Latin America countries, which are dependent on wood-based fuels for cooking and heating homes.

Keywords: Bamboo Charcoal, Bamboo Firewood, Biomass energy, Partnership

Introduction

In industrialised countries, wood-based fuels have long been replaced by more efficient and convenient sources of fuel. However, in developing regions, less able to afford and access alternative sources of energy, wood has remained a dominant fuel. The African continent increasingly depends on firewood and charcoal for cooking and heating homes. In 2000, nearly 470 million tonnes of wood were consumed in homes in sub-Saharan Africa in the form of firewood and charcoal, more wood per capita than in any other region in the world.[1] Moreover, more than 1.6 million people, primarily women and children, die prematurely each year worldwide (400,000 in sub-Saharan Africa) from respiratory diseases caused by the pollution from such fires.

Ethiopia and Ghana are two African countries where the majority of households rely on wood-based fuels as the primary energy source for domestic cooking and other productive activities.[2] Ethiopia's energy sector depends heavily on traditional firewood and wood charcoal, which account for more than 90% of final energy consumption. Similarly in Ghana, firewood and wood charcoal account for more than 78% of all primary energy consumption.[3] These levels of consumption are highly unsustainable, with use of firewood and wood charcoal emerging as a main contributor to deforestation and air pollution.

In Ethiopian and Ghanaian rural areas, firewood is the preferred form of domestic energy, largely because it does not require complex and expensive equipment. In addition, it can be procured often at no greater cost than collecting and preparing it. However, burning of firewood is inefficient and results in the emission of pollutants, such as carbon monoxide, methane, nitrogen oxides, benzene formaldehyde, aromatics and respirable particulate matter. Wood charcoal production is a profitable source of income for many urban and rural communities in Ethiopia and Ghana. Ethiopia produces approximately 3.2 million tonnes of wood charcoal per year, while Ghana produces 1.4 million tonnes of wood charcoal. The majority of this charcoal is produced at the household level or by micro and small enterprises (MSEs). While wood charcoal produces fewer emissions than firewood, production techniques are often highly polluting and lead to major deforestation. Deficiencies in current charcoal technologies and production skills result in poor quality products, high carbon emissions, leakages and high resource wastage.

Ethiopia's forest cover decreased from 4.2% in 2000 to 3.5% in 2005, with an annual rate of depletion of 141,000 hectares, and this trend is continuing. If this trend persists at its current rate, the forest area in the country will be reduced to less than 7 million hectares (ha) by 2020. In 2005, annual withdrawal of wood from forests was 111 million cubic metres.[4] Ghana's total forest cover decreased from 37% in 1993 to 24% in 2005 (5,517,000 ha), with an annual rate of deforestation of 115,000 hectares, and this trend is persisting. About 90% of Ghanaian wood-based fuels are obtained directly from natural forests and the savannah woodlands. From 2000-2004, annual withdrawal of wood from forests was 25-28 million cubic metres.

Constraints on the supply of electricity, which is only accessible to a very limited number of urban households, coupled with the high cost of commercial fuels, further increases the demand for biomass fuels. Today, firewood and charcoal production in both countries is responsible for deforestation, emissions and indoor air pollution. The demand for wood as biomass for firewood and charcoal making in both countries represents a serious environmental threat, which is expected to remain unchanged for many decades to come. This relentless demand is influenced by low household incomes, urbanization, and the growth of informal sector activities. Due to

increasing scarcity of wood resources and cumbersome policy regulations, demand for firewood and charcoal will vastly outstrip supply in many parts of Ethiopia and Ghana.

The International Energy Agency (IEA) predicts that by 2030 biomass energy in Africa will still account for an estimated three quarters of total residential energy. If correct, these estimates underline the urgency of facilitating a sustainable alternative biomass to replace wood biomass. The need for alternative energy sources, which are both sustainable and widely accessible to the urban and rural poor, requires urgent action. In China, India, Vietnam and Thailand, bamboo has been shown to serve as a viable and more sustainable alternative biomass fuel. Due to its extremely fast growing properties, woody nature, high-tensile strength, and carbon sequestration rates, bamboo is an ideal sustainable alternative biomass fuel. Bamboo can be selectively harvested annually for 2-4 year old culms, whereas timber forests require on average four to six decades to regenerate, with the exception of eucalyptus and prosopsis. Bamboo is comprised of cellulose, hemicellulose, lignin, potassium, silicon, phosphate[5] and extractive materials such as, carbohydrates, fat, protein, nitride etc. In addition to these components, there are some metallic elements with little content such as copper, iron, calcium, magnesium, and manganese. The cellulose content of bamboo is similar to any softwood. The resource's lignin content falls between that of a softwood and hardwood, and is higher than grass. The ash content of bamboo is 3 to 4 times more than wood.[6]

Bamboo-based firewood is cleaner and produces less pollution than wood firewood. Bamboo culms are more porous compared to timber. This leads to less wastage as the entire bamboo resource can be burned, resulting in less pollution. Bamboo charcoal produces fewer emissions than wood-based fuels and prevents deforestation. The surface area pores of bamboo charcoal are up to 500 m2 per gram compared to wood charcoal with only 100 m2 per gram. Bamboo charcoal has excellent properties for water purification, three times more than wood charcoal. Bamboo charcoal has a calorific value of 26-29 MJ/kg, equivalent to wood charcoal. Bamboo charcoal briquettes enhance the energy output of charcoal, as they burn through gasification from the inside outwards. Normal wood charcoal burns through direct combustion, which is inefficient, because it burns from the outside inwards. In addition to energy loss, direct combustion also produces larger amounts of waste gases, which are toxic and cause respiratory diseases.

Therefore, the project described in this paper aims to promote the production and consumption of bamboo firewood and charcoal, which, due to its cleaner processing technology, drier nature, and sustainable resource base is thought to be an attractive and sustainable alternative for wood based biomass derived energy sources.

The project's overall objective is to increase the use of bamboo as a source of energy for the poor of Ethiopia and Ghana thereby providing a more sustainable, environmentally friendly and economical alternative to firewood and wood charcoal.

The specific objectives are:

(1) to develop over a four year period the bamboo resource base in Ethiopia and Ghana so that the appropriate varieties are available for long-term firewood and charcoal use;

(2) to develop over a four year period a small-scale private bamboo firewood and charcoal sector to ensure appropriate supply for target populations;

(3) to put into place the institutional support needed for bamboo to be widely adopted as each country's primary source of energy for the poor, through development of appropriate policies, capacity building and awareness raising.

INBAR's partnership with Ethiopia, Ghana and China for the project implementation

Ethiopia and Ghana:

Ethiopia's bamboo resources amount to 1 million ha and constitute 7.7% of the country's total forest cover.[7] Ghana has approximately 300,000 ha of bamboo resources, which cover 5% of the country's total forestland. The availability of bamboo resources in both countries makes bamboo a viable biomass alternative for energy. Bamboo is one of the fastest growing plants on earth, which makes it a quickly-renewing and sustainable source of biomass for the poor. Bamboo charcoal's heating value is over 30,000 joules per gram, offering comparable heating properties to wood charcoal for cooking and heating.[8] In Ethiopia, the average annual dry bamboo culm increment is 10 tons/ha and thus it is possible to harvest over 10 million tons annually of dry bamboo for biomass energy. With a 30% bamboo charcoal yielding rate, sustainable harvest of bamboo resources could potentially provide 3.3 million tons of bamboo charcoal annually; it is possible, therefore, that bamboo charcoal could potentially replace all wood charcoal production. Ghana has a strong potential to produce 0.9 million tons of bamboo charcoal on a sustainable basis with a 30% yielding rate, so bamboo could potentially replace 64% of the country's wood consumption for charcoal production.

China:

China is one of the countries with richest bamboo resource and has over 500 bamboo species and 4.86 mil ha bamboo forest. Its annual output is over 7 billion EUR in bamboo sector. China has a long history on bamboo cultivation and sustainable management of bamboo forest and bamboo has been widely used in environmental protection, livelihood, economical and social development. As an alternative of wood charcoal, bamboo charcoal has been produced in China and its annual production is over 100,000 tonnes. The experiences on bamboo biomass production and bamboo charcoal production as well relevant energy saving stove technology and bamboo charcoal briquette technology are shared with the partners in Ethiopia and Ghana through study tours, training, technology transfer, publications etc.

INBAR's global experience:

INBAR and its partners in Asia have demonstrated that bamboo charcoal is a viable alternative to wood for fuel and charcoal used for cooking and heating. Such projects have proven that through capacity building and training activities, wood charcoal producers can easily shift to produce bamboo charcoal. INBAR partners in China and India, where bamboo plantation management and charcoal making technologies are the most advanced in the world, are actively involved in the organisation's charcoal projects in Asia and Africa. Bamboo

charcoal is produced through controlled burning of bamboo in improved traditional charcoal making kilns, low technology metal kilns and brick kilns. Since 2002, *INBAR* has developed and field-tested technologies that make it possible to produce large quantities of bamboo charcoal at the community level. These activities stimulate local production, enabling households to access and consume affordably priced, sustainable bamboo firewood and charcoal. Drum kiln technology has also been developed to produce bamboo charcoal briquettes, commonly used for heating and cooking, and capable of burning for approximately 2.5 hours. This results in low emissions of greenhouse gases. Wastage can also been reduced, as the surplus material from other bamboo based projects is used to produce charcoal.

For many years, INBAR has been working closely with local government institutions to promote bamboo for livelihood and economic development and environmental sustainability in both Ethiopia and Ghana. For instance, in 2003, INBAR began working with the Ghanaian government and local partners to develop a National Bamboo Strategy. Since 2005, INBAR has supervised a Common Fund for Commodities (CFC) project for East Africa, which encompasses the development of an Ethiopian National Bamboo Strategy in collaboration with Ethiopian government agencies. The long-term objective of the project is to promote the development of sustainable production and use of bamboo products in East African countries, with a focus on markets as the driving force behind such sectoral development. In both 2005 and 2006 INBAR has organized a 2-month training workshop on bamboo cultivation and utilization in Ethiopia, with support from the Chinese government. From 2007 to 2009, the Global Non-Timber Forests Products Partnership Programme (NFTP-GPP), coordinated by INBAR, has been implementing an International Fund for Agricultural Development (IFAD)-funded project "Assessing and Developing Replicable Methodologies and Approaches for Sustainable Charcoal Production for Livelihood Development, Rural Energy Security & Environmental Protection". The project is focussed on sub-saharan Africa and aims to help develop charcoal production into a sustainable option for addressing rural poverty and rural energy security, while contributing to environmental protection.

INBAR is the project's main implementing agency. The project is executed with four main local implementing partners, EREDPC and FeMSEDA in Ethiopia and BARADEP and FORIG in Ghana.

The project will also draw on the expertise of universities, research institutions, NGOs, and the private sector in the implementation of capacity development and awareness creation components.

INBAR and local project partners will establish five pilot demonstration sites showcasing effective, adaptable models for bamboo firewood and charcoal production. The demonstration sites are the way in which the Action will promote replication of appropriate technologies, with models to illustrate different aspects of bamboo for firewood use and charcoal production. Activities at the demonstration sites will focus on sustainable management of the resource base, and optimal resource management. International and national policy consultants and trainers will implement certain project components in their respective areas of expertise. These include bamboo charcoal briquette production and use, bamboo best cultivation practices and marketing strategies.

The project seeks to overcome the challenges identified below, which, if not addressed, will result in an unsustainable reliance on wood-based fuels.

1. Current unsustainable use of wood as biomass for firewood and charcoal making
2. Major negative environmental consequences of increased wood charcoal production (deforestation, reduction of carbon sequestration, loss of biodiversity and desertification)
3. Inefficient and wasteful wood-based fuels production
4. Poor marketing and inadequate regulation of the wood-based fuels energy industry
5. Prohibitive policies and regulatory mechanisms that support inefficient wood-based fuel activities
6. Lack of technologies and incentives to develop sustainable energy from biomass

The project will address these challenges through: a) improving the production of fuel from existing bamboo resources, through better sustainable management techniques and plans and an increased use of bamboo charcoal where appropriate, b) establishing pilot sites to demonstrate best bamboo as firewood practices, innovative construction and operation technologies for bamboo charcoal production, and bamboo firewood and charcoal energy saving stove technology, thereby successfully transferring and introducing bamboo technologies to meet local energy needs, c) creating the right climate for profitable and sustainable bamboo firewood and charcoal production and use, through enacting sound policy recommendations and a national marketing strategy, d) hosting workshops with key stakeholders and establishing village level bamboo charcoal MSE associations, which will create dialogue between government, industry, MSEs and civil organisations, e) implementing training and demonstration events for policymakers, local energy development personnel, local households, and MSEs, which will build the capacity of target groups and beneficiaries to replace wood with bamboo for firewood and charcoal production, f) publishing best practices and technologies, which will lead to increased awareness of the benefits of bamboo firewood and charcoal.

Expected results

This 4 year project expects to achieve the following results:

- **Result 1: A sustainable local resource base for bamboo will be in place in both Ethiopia and Ghana, sufficient to supply households and small enterprises to substitute bamboo for firewood and charcoal.** Local infrastructure to ensure a sustainable local resource base for bamboo firewood and charcoal production in Ethiopia and Ghana needs to be established. The project will ensure local infrastructures exist to promote a sustainable local resource base for bamboo through the development of inventory analyses for bamboo resources in Ethiopia and Ghana and the introduction and propagation of five bamboo species suitable for firewood and charcoal in both countries. Indicators for achieving this result include two inventory analysis reports, successful introduction, propagation and cultivation of five bamboo species at the Action's bamboo nurseries, and their seedlings planted in the Action's pilot sites.
- **Result 2: An increased number of local households will use bamboo as their energy source and an increased number of micro and small enterprises (MSEs) will produce bamboo charcoal.** The project will build the capacities of local households and target MSEs to replace wood with bamboo for firewood and charcoal production. The main indicators for achieving this result will include at least 20,000 households using bamboo for firewood, 13,000 households in Ethiopia and 7,000 households in Ghana; at

least 7,000 Ethiopian households and 3,000 Ghanaian households using bamboo charcoal; at least 1,000 MSEs, 700 in Ethiopia and 300 in Ghana, using bamboo for charcoal production.

- **Result 3: Both governments will have issued policy recommendations, and at least one national level MSE association in each country will be in place.** The project will develop policy recommendations on community-based bamboo firewood/ charcoal production through central government level discussions and seminar. These recommendations will be disseminated through workshops that bring together stakeholders of all kinds and at all levels. The project will also support the establishment of two bamboo charcoal MSE associations, one in Ethiopia and one in Ghana, and help set up a long-term plan for how to maintain each association after the project is over.

Possibilities for replication and extension of the project outcomes

Replicability is at the heart of the project action's design. The project's overall objective is to increase sustainable use of innovative biomass energy options in Ethiopia and Ghana for local populations in order to meet everyday energy needs. As such, the activities are seen as a first step to gain and apply knowledge on bamboo as renewable biomass energy in these socio-economic and agro-ecological areas. The project will demonstrate and disseminate best bamboo firewood and charcoal production technologies and develop policy recommendations and institutional support mechanisms necessary to enable bamboo for firewood and charcoal production to be undertaken economically, effectively and in a sustainable manner by local households and charcoal producing MSEs. The real key to the project's long-term success is in helping the Governments of both countries to mainstream the idea into the relevant policy framework, without which it cannot be adopted on a countrywide scale within the existing energy, forestry and environmental programmes. The various activities of the action have been designed to build upon and complement one another to achieve this replication. At the national and local level, the beneficiary-driven-ness and integrated involvement of Government, local households and MSEs, and forestry research centres will ensure strong ownership of the activities and will enhance the opportunities for replication to other urban cities and rural villages.

The involvement of INBAR and project partners, who will provide technical and marketing support for existing wood charcoal MSEs to replace wood with bamboo for charcoal production, will clearly demonstrate the income generation possibilities for using bamboo charcoal technologies, thus encouraging members of other cities and villages to participate and replicate these experiences. The environmental, technical, and socio-economic benefits will be documented and made widely available elsewhere as adaptable models. Development of supportive policy recommendations will facilitate greater uptake of the technologies and practices at provincial and national levels, and awareness raising of high-level decision-makers will foster effective replication at these levels. Involvement of stakeholders from all levels in the project steering committee will ensure dissemination of positive experiences within the mandated networks of these organisations and bodies.

The project has strong potential for further replication in sub-Saharan Africa, Asia and Latin America countries, which are dependent on wood-based fuels for cooking and heating homes. The overall objective is also highly relevant to neighbouring sub-Saharan African countries, such as Kenya, Nigeria, Mozambique, Tanzania, Uganda and Sudan, where there is clear need to adopt sustainable energy resources in preference to firewood,

which is responsible for significant deforestation, emissions, and indoor air pollution. Bamboo resources are also locally available in these countries. The results are expected to form the basis for an innovative biomass solution for sub-Saharan Africa's energy crisis in these countries, where, like in Ethiopia and Ghana, many households depend on wood-based fuels to meet their everyday energy needs.

The project will thus serve as a model for replication in these countries. Results and lessons learned in obtaining those results will show how access to information and know-how, institutional support systems for bamboo firewood and charcoal production, adequate communication among government, and civil society, MSE capacity building, adequate national marketing strategies, can ensure sustainability, supply and use of bamboo as biomass fuels. Results could also be replicated in Asian and Latin American countries as well other African countries where unsustainable use of wood-based fuels persists and bamboo resources are locally available.

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Philippine Bamboo Innovation in Partnership with INBAR

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Summary and outcomes

The Community Enterprise Development Project, coined Design Center Philippines, was undertaken to investigate and implement new ways and processes of producing bamboo components and products with village level production as its focus. Thus, the project veered away from the use of heavy capital investment in machinery. Instead, thermo setting resins like polyester resins with fiberglass mats and hemp were introduced and integrated into the usual village outputs of bamboo culm slats, split halves, and woven mats to take these products into a different level of higher value products welcomed by furniture makers and home builders alike for use in resorts and natural homes in the Philippines and around the world.

The main research outcome are grouped into 12 process innovation technologies which open new and infinite possibilities for designers working with bamboo to benefit the rural poor who have been left behind in the 21st century. These innovations are:

Using Bamboo Woven Mats

1. One layer bamboo strips, woven into structural shapes such as baskets and furniture leg components, woven on desired moulds, then released, and laminated one side with fiberglass, make structurally sound seats, chairs and hollow furniture components of all sizes and shapes. This technology innovation opens a variety of ways bamboo can be shaped into furniture and home accessories for functional use.
2. One layer bamboo strips are woven into fiberglass chair molds, leaving the fiberglass mold inside and injected with polyester resin to bind the two making beautiful woven chairs of any size and shape structurally sound. A series of chairs were made to illustrate this.
3. Two layer woven bamboo mats sandwich with fiberglass woven mats and polyester resin were molded into one piece all woven bamboo mat stackable chairs, seats and backs replacing molded plastic chairs, seats and a multitude of containers;
4. Intricately woven and colored open weave bamboo mats were sandwiched between 2 fiberglass woven mats to make into light diffusers woven and decorative skylight roofing sheets. This technology opens a multitude of possibilities for lighting fixtures, diffusers and bathroom wall tiles;
5. One layer closed weave finely woven bamboo mats were laminated with fiberglass mats and polyester resin and shaped into counter tops for bathrooms and kitchen; the same technology uses the closely woven fine bamboo mats as table tops, and decorative wall panels and opens the door to a multitude of home accessories.

Using Bamboo Rotary sliced Veneer promoted by the Department of Science & Technology of the Philippines

6. Rotary sliced bamboo veneer strips were cut to desired widths and shaped into honeycomb core boards and honeycomb furniture components using polyester resin. Endless housing structural components and furniture configurations can be made with this technology especially if used with even cheaper environmentally sound glues found in India coming from cashew.
7. Rotary sliced bamboo veneer strips used in the past for panel facing or pressed into mat bowls, trays, plates, and spoons were stripped into 2 inch widths and laminated successfully with polyester resin to any length and shape to form structurally sound furniture components replacing steel and wood. This opens immense possibilities for bamboo in furniture bringing it to the 21st century. Two types of prototypes were produced to illustrate this: stools and stackable chairs.

Using Thin-walled Bamboo culms

8. Thin walled bamboo culms are split into 3 parts and laminated back to back with resin and hemp into thin lightweight furniture components structurally sound. This opens large possibilities for designers to use bamboo in furniture. Two types of prototypes were made to illustrate this: a series of folding chairs with canvas and stackable chairs with woven mat seats.
9. Thin walled bamboo components are split into 2 parts, crushed, bent and laminated back to back with polyester resin and fiberglass mats to make into structural building and furniture components. Here again infinite possibilities have opened to designers in using bamboo for furniture and building components. Two types of prototypes were made to illustrate this: outdoor lounging chairs and floorboards for decks.

Using Typical Bamboo Slats

10. Bamboo slats were assembled into 1.2 m x 1.2 m panels held together with paper then laminated with polyester resin into 10 mm plywood boards to avoid warp age. This enables the village workers to supply finished flooring material to the market without heavy investment in machinery.

Glues

11. The use of polyester resin with fiberglass woven mats or hemp in these processes brings the component to the outdoors. The initial trials were not sound. Repetitive experiments perfected the proportions, combinations and processes used. Other thermo setting glues that are cheaper should be looked into especially those coming from India.

Finishing

12. The use of stop sag with gel coat resins as clear putty or fillers and gel coat as clear primers for finishing bamboo is a breakthrough in finishing technology for bamboo products. It not only brings the product outdoor but brings the quality level of the product into the high end market. Many techniques and processes were tried over and over again to finally determine how to finish bamboo properly.

Penetrating wood stains are sprayed on to color the bamboo after the primer. The gel coat is again sprayed on top on the color to seal it. Then a mat finish polyurethane coat is sprayed for the final coat. This finish puts bamboo at par with all high end wooden furniture.
Note 1: Spray painting should be done using air operated piston pump compressors and airless spray guns to get the proper thickness per coat of application. Otherwise the resins need to be diluted and are not that effective outdoors. Lack of access to such equipment during prototyping prevented us from testing the product under different harsh weather conditions. We have however tried the unit in a demo and tested the usage of paints. It is less durable than half of conventional standards.

Note2: we have not yet been successful in finding color fast stains to withstand the tropical sun. More experiments still need to be conducted.

Though more studies are required to be undertaken to commercialize the production of these technologies, attached drawings give one an idea of products that can be developed along the lines of furniture alone.

In addition to the innovations presented, a drum pyrolyzer with 40% recovery was fabricated in collaboration with the Cottage Industry Technology Center and Forest Products Research and Development Center to turn bamboo waste into charcoal. This has helped every household engaged in bamboo production to turn 70 kgs of waste every week into 240 pesos, adding to their income stream.

The Context

In Abra, Philippines, the number of households involved in commercial use of bamboo is around 1524, with 930 households concentrated in 18 villages (6 municipalities). This amounts to about 4572 people assuming that per household 3 people are actively involved in the industry.

Each household generates around 70 kgs of bamboo waste every week producing bamboo furniture and barbecue sticks for the local market. Turning the waste into charcoal to add to their income stream was priority.

Most of these producers would supply the export market through traders in the past. However with China's entry into the market, most export orders stopped due to China's ability to provide the world with high quality commercially produced bamboo products at the right price. In addition, these producers have been left behind by the 21st century as new innovations in materials like plastic, having low maintenance and all weather qualities, have taken the place of indigenous materials like bamboo and rattan with look-alike products catering internationally to resorts, spas and outdoor furniture.

However, with problems arising from global warming, much interest has been aroused again on sustainable materials such as Bamboo. People are beginning to ask again if the materials used are sustainable. With this opportunity at hand, the task was to investigate new ways of how bamboo products could be produced in village level workshops at the right price for the 21st century market - taking advantage of the boom in resorts and return to natural homes. In the province of Bohol alone, known for its eco tourism, ten thousand resort rooms need to be built till the year 2010. At current cost of one million pesos a room, this translates to 10 billion pesos

for one province alone in the Philippines. There are at least nine other similar destination provinces being sold by the Department of Tourism. The other markets with bright future are school desks and classrooms.

Craftsmen from other parts of Asia and Africa are feeling very similar problems and opportunities. Thus it was thought that new processes need to be found to keep bamboo craftsmen busy in the 21st century and the Philippines was in the best position to do so.

The decision to conduct the research in the Philippines is threefold: the Philippines international leadership position in design excellence; its technical expertise in developing new products and processes with focus on indigenous materials; its experience using village level workshops for its export industry.

Scope of Replication

The innovations in this study were designed to rely on the village craftsmen for most of the primary processes with exception of veneering. It also relies on the village craftsmen for producing the mats in mass with the help of patterns and moulds. It also continues to rely on the bamboo producers to cut, split, and strip bamboo culms to desired component specifications.

These components are brought to a factory in the midst of a village cluster where they undergo curing, veneering, crushing, bending, drying, lamination, and some finishing and assembly. The factory's clients are different furniture makers, home builders and home depots that in turn assemble, finish, and deliver the final product to their clients/outlets.

At the center of these operations is a core group whose function it is to continuously market, research and develop new products and processes through the collaboration of the village craftsmen, the factory, and the furniture/ home designers + makers. External collaboration shall be provided by Suppliers of different materials and equipment, the Local Government Units and Indigenous Institutions, the Bamboo Industry Cluster Committee and the Philippine Bamboo Network.

Main Players

a. The Bamboo Producers + Harvesters + Carriers
b. The Village Craftsmen
c. The Factory (a partnership of InHand Abra and InTechDev)
d. The Home accessory + Furniture makers and Home + Resort Builders
e. Home Outlets + Building Contractors and its Clients
f. Suppliers of Glues + Resins + Moulds + Equipment
g. Provincial Bamboo Industry Cluster Committee (PBICC)/ Philippine Bamboo Network
h. Local Government Units and Indigenous Institutions

Scaling Up

A factory in the midst of a village cluster, equipped with the right equipment such as curing, cutting, and veneering equipment, presses and moulds, and finishing equipment. These can be scaled up depending on the type of products it needs to do and market requirements per Region.

Scaling Out

Bamboo village craftsmen exist in every Region in the Philippines doing similar bamboo products. Depending on a Region's requirements, a factory brought in the midst of a village cluster could replicate similar or the same products through the collaboration of the bamboo producers, village craftsmen, the factory and the furniture makers/ home builders/outlets. Equipment can be fabricated or funded with the collaboration of the Technical Education Skills and Development Agency, the Department of Science and Technology and the local government units as in the case of their collaborated efforts to fabricate more drum pyrolizers in Abra after the successful demonstration of the first unit.

Main Technical Components of the Program

a. Process design – designing processes with focus on the village craftmen capability to produce products for the 21st century market at the right price, quality and time. This necessitates collaboration among the bamboo producers and craftsmen, a technically capable factory which can operate at village level and furniture makers and home builders who market their own products to the 21st century market.
b. Product design +Prototype – fast prototyping technologies linked to market requirements
c. Mould design + execution – efficient and cost effective mould materials and production
d. Material Preparation + Weaving on Moulds or following Patterns - computer aided programs to produce patterns from 3 d drawings.
e. Veneering + Drying + cutting – veneering and drying equipment to prevent mould and cut veneer strips into specified widths and lengths.
f. Glues + Resin Lamination – environment friendly thermosetting resins and needed fibers for maximum strength.
g. Connectors + Hardware + Assembly – bamboo, because of its nodes, unlike wood is never the same and difficult to mass produce.. thus assembly becomes a challege.
h. Dyes + Paints + Resins + Painting Equipment – color fast dyes for the tropical weather; colorless resins top coats to help keep colors fast and moisture out; airless spray paint equipment that allows the thick application of the resin.
i. Charcoal drum pyrolyzers – efficient recovery of waste material at village level.

THE INSTITUTIONAL CONTEXT

In 1988, InTechDev Systems, InHand Abra and the National Livelihood Support Fund collaborated to bring development in the province of Abra thru a seed project using thin walled bamboo which was then abundant in the province, and developed by Intechdev into bamboo plywood panels with trade name "plyboo". The project was paralyzed in 1989 due to the earthquake that devastated the province cutting off the raw material supply. Despite that, the panels were continually being promoted, tested and used successfully in a low cost housing model - the Pinatubo House in 1990. The supply problem was never resolved and finally dwindled when the bamboo in the uplands flowered a few years later mothballing the project altogether in 1996 for lack of material supply.

InHand Abra then concentrated on working with village craftsmen to scale up their facilities and know-how. These village craftsmen are presently very successful on their own and their facilities demonstrating 'industrialized-handicraft' seen in the town of Bumagcat, Tayum. However, few have followed their footsteps as the exports orders for craft items slowed down since the emergence of China in the industry. Seeing that a return to industry was a key factor to develop the bamboo industry, InHand Abra represented by Carmelita Bersalona partnered with INBAR to get funds to restart the plyboo project in Abra and became the **A**ction **R**esearch **S**ite (ARS) of INBAR in the country.

Carmelita Bersalona, began to assist INBAR in its livelihood projects in Africa and India in the year 2005. It began to dawn on her that the problems of craftsmen in third world countries was universal – the craftsmen received less than a dollar for a day's work, unable to sustain their own needs, yet, at the same time, their products were priced high compared to that of China's. It seemed clear from her visits to other countries that setting up common facility centers alone was not the answer to alleviate the problems of the craftsmen.

In 2005, InHand Abra and Intechdev jointly wrote a proposal to ITTO to investigate new ways of producing bamboo products for the 21st century market with focus on village level workshops and craftsmen. The proposal was approved but no funding was available. In 2006, funding from IFAD through INBAR for InHand Abra to finally start the much needed investigation and study of new processes began. Medilen Singh of Intechdev partnered with InHand Abra to direct the process and development of process innovations.

On the other hand, through the management of InHand Abra, the INBAR **G**lobal **M**arketing **I**nitiative (GMI) Design Centre has collaborated with the *Department of Science and Technology* to develop other bamboo processing technologies. For example, the Design Centre, working in tandem with the *Forest Products Research & Development Institute*, has contributed towards the development of bamboo charcoal and veneering technologies. In collaboration with the *Philippines Textile Research Institute*, the Design Centre has also developed bamboo fibre processing technology, which can be applied to furniture making. All these have been used by Intechdev in its process innovations.

PROGRAMME IMPLEMENTATION

The challenge was to find appropriate methods to enable bamboo producers to continue with their craft but at the same time answer the needs of the local and international market in the 21st century.

The idea was to let go of the notion that more machinery meant better products.

The Philippines has the highest cost of electricity in the Region and supply is not stable in poor communities. Also, producing weather resistant products meant the use of resins for glueing and protection.

A trip around the various research and development agencies of government showed the problem of using stripped bamboo for lamination. Failure was in the glue line despite the use of polyurethane glues due to the absence of appropriate processes. Standard thickness of bamboo strips was critical to the process for proper

bonding. Also critical was the use of proper jigs and clamping system. The down side also was the cost of polyurethane glues which sell at 800 pesos a liter.

To test different resins, woven mats were used to make into waterproof boards and furniture. Polyester resins proved to be the best suited but not friendly to the environment but the aesthetic results were wonderful. However, future collaboration with the manufacturer resulted in environmentally friendly resins that are water based. The first board produced was left outdoor for 2 months for testing. The only thing that changed after 2 months was the color of the bamboo mat that was dyed. Polyester resin proved to work well with bamboo. It is the most inexpensive of thermo setting resins. It sells at 127 pesos a liter. The board may be used for ceiling diffusers and as a substitute to bathroom tiles and kitchen countertops. If we find a UV protective treatment to keep the colors fast despite the light, the board can be used as roofing sheets for certain areas like patios.

An alternative to using bamboo strips for furniture component is the use of rotary bamboo veneer and at certain cases combined with sliced bamboo veneer. Rotary cut veneers come in standard thickness and pliable enough to be shaped into different forms. However, it has a limitation on length, 57 cm., but can be stripped with paper cutters and taped to desired lengths.

The resin is mixed with a hardener and brushed onto the strips. The strips are laid into desired moulds or jigs and clamped manually. The outer strips may be made of a sliced veneer so as not to show the joints of the veneer taped together. The setting of the resins is completed within 20 min and removed from the mould. The piece is then weather resistant as it is sandwiched in resin. The piece is allowed to cure overnight then sanded and finished with polymer gel coatings or clear polyurethane paints. Parts maybe welded together also using the resin instead of metal hardware. The process is simple but requires highly precise craft skills that may be learned.

Another process innovation is the utilization of bamboo with 3.5” diameter and more than ¼” thickness and with long internodes. The bamboo culm is cut into cylinders according to specified sizes, scraped, split/ripped and planed into desired width and thickness and laminated back to back with polyester resins to desired shapes clamped in moulds. Preparatory to lamination, heat bending is done then clamped till cool for the required shape to stay. For its seat and back rest, crushed bamboo or laminated woven bamboo/fiber mats are utilized.

The production process of bent bamboo furniture was refined and proper jigs and moulds developed and tested on new designs for patio furniture. These were exhibited during the International Bamboo and Rattan Exhbition in Guangzhou, China on September 22-24, 2007.

Crushed bamboo laminated back to back into decking boards using resin and fiber mat in between was very successful. After 3 months of water test, the glue line held nicely. However, during the test against severe tropical sunlight, the bamboo cracked at the surface within a week much like pine wood decking boards do. The thinly coated resin surface gave in and peeled off. We need to apply the resins properly with airless spray units to get the required thickness on the surface before doing further tests again. If it persists, then the thing to do is to use oil based weather resistant coatings like xyladicor to protect the bamboo decking boards from the weather, and repaint every 3 years.

Impact

The Process innovation of combining bamboo veneer, bamboo splits, crashed bamboo and polyester resin, brings bamboo into the garden furniture category and building materials resistant to weather. It allows for indoor and outdoor use of the furniture and building components which is the clamor of the market today for aesthetics and easy maintenance. It will allow bamboo to compete with imitation bamboo and rattan furniture for outdoor using aluminum and plastic fiber imitations. Not only is bamboo used for esthetic purposes but is also used for structural purposes with respect furniture and building components. It does away with metal for structural components.

The process innovation will also provide the Bamboo Industry in the Philippines with a chance to develop and grow using the process to supply the furniture makers with components they need to compete internationally.

Constraints Faced During the Program Implementation

Internal

- Workplace was too small and affected by changing weather;
- Equipment such as dryers, presses, cutting tools and proper painting equipment were lacking or make shift;
- Jigs were temporary and made of wood;
- Pace was slow as each experiment went through tests before proceeding to next phases.
- Each phase went through as series of trial and error procedures for process elimination as there were no models to follow.

External

- Lack of color fast dyes
- Lack of technical data on resins and glues
- Lack of inexpensive glues in the market especially thermosetting glues
- Lack of equipment facilities to rent such as new types of airless painting equipment necessary to test the weather resistant qualities of the products.(Because of this lack, we are unable to test whether our present coatings can withstand the severe heat of tropical sunlight and continuous rain and heat conditions)
- Lack of testing equipment to expedites test results such as the effect of UV rays.

Further Research Needs

For furniture and building materials, the production processes still need to be refined with proper presses, jigs, moulds, spray equipment and knock down hardware developed and tested before actual building of prototype house can take place. Its outcome will be the final costings and equipment listing before commercialization of these processes can take place.

Target Group

The projected commercialization of the bamboo furniture at the village level using the new innovations shall involve 96 households from two weaving villages of La Paz (Mudeng and Udangan) with an average annual income of Php 34800 and 59 households from the village of Bugbog, Bucay and Bumagcat, Tayum which has some basic machines and tools for semi-processing of bamboo. The bamboo producers of Tayum earn an average annual income of Php 79500 which is attributed to semi-mechanized production. The indigenous peoples of Licuan-Baay and Sallapadan will be tapped to supply crashed bamboo.

The Gender Dimension

In every household at least one woman is involved in the production of bamboo components. Historically, the women of the household hold the purse. She markets the products and manages the income of the household. Thus, in this case, at least 155 women will be involved at the village level.

In the factory, most of the workers in the assembly section will be women earning at least minimum wage.

Accessibility

The innovations made in this action research will be learned and demonstrated in the factory to be established in village clusters. It will be open to INBAR's network of member countries.

Institutional Sustainability

The factory will operate directly at the community level. It will buy the products from the craftsmen, therefore, it needs to set up and train them well with respects processes and equipment if it wants quality products delivered at the right price. The factory will be a joint venture of Intechdev and InHand Abra in partnership with INBAR - one having the expertise of technology transfer, the other, community development.

Dissemination Pathways

Communication Strategies at the Village Level

1. Collaboration with the Provincial Bamboo Industry Cluster Committee (PBICC) which plans, coordinates, implements and evaluates programmes that strengthen development of the bamboo sector. The PBICC,chaired by the Provincial governor and co-chaired by the Department of Environment & Natural Resources and the Department of Trade & Industry, draws membership from a wide range of government, technical and financial institutions. Members of the PBICC include the Department of Agrarian Reform, the Technical Education Skills & Development Agency, the Department of Labor & Employment, the Technology Livelihood Resource Development Center, the Department of Science & Technology, the Cooperative Development Authority, the Department of Local Government, the Land Bank of the Philippines, the Department of Education and Culture, and the Abra State Institute of Science & Technology. As of 2007, the PBICC has increased its membership with municipalities engaged in bamboo production and, or processing now being represented.

2. Coordination with indigenous leaders/institutions and local government officials on policies related to bamboo harvesting and infrastructure development

3. On site consultations including design clinic

4. Training cum production schemes

5. Provincial and regional trade fairs

6. Communication through SMS messages and email

Communication Strategies at the National and International levels

1. National and international trade fairs

2. Collaboration with government agencies :

a. the Department of Science and Technology to produce a number of new bamboo processing technologies. For example, working in tandem with the Forest Products Research & Development Institute, it has contributed towards the development of bamboo charcoal

b. the Philippines Textile Research Institute, the bamboo fibre processing technology applied to furniture making

c. the Department of Trade & Industry on new product designs that will increase access to growing domestic and international markets; marketing research by the Bureau of Domestic Trade, which supplies designers with details on the latest consumer trends and material developments; new product designs to be exposed to markets through the Center for International Trade & Market Exposition.

3. ECO Network compose of individual designers, social enterprise developers, manufacturers, and exporters bridging community producers with technology, design and market.

4. Philippine Bamboo Network, Philippine Bamboo Foundation and other NGOs in the development of the Philippine Bamboo Industry.

The Bamboo Sector as an Effective Stakeholder Network and the Role of INBAR

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Introduction

Bamboos grow naturally in almost all tropical and sub-tropical countries, except those in the Persian Gulf, North Africa and the Sahel, and extend well into the temperate zones of each hemisphere. Many societies have developed integrally with bamboo, and the ubiquity and utility with which bamboo is relied upon by people in over half the nations of the world for varied aspects of their lives is well documented. Cultures have evolved with bamboo, and it has been a significant contributor to the development of civilization.

With perhaps a billion of the world's population relying on bamboo in some way or another for some aspect of their lives or livelihoods, the vast majority of those poor and in developing countries, the opportunity that bamboo offers to improve their situations by building on inherent bamboo skills and knowledge is huge. Already, innovation of products, policies and support structures have led some countries, particularly China, and to a lesser extent India, Colombia and the Philippines amongst others, to develop thriving commercial bamboo sectors that employ millions of people.

Because of the versatility of uses of bamboo wood, the production chains of bamboo for different products often involve a range of people at different stages, each stage a different processing step, and each step involving value addition by the producers, and hence income generation. As a result the value chain of bamboo products is very pro-poor. Even with products that are finished in large factories, much primary processing is required and is usually done by the farmers that grow and harvest them or in their communities, which not only benefits the processors, but is usually cheaper for the factory owner as they can work with semi-processed materials. A production chain can thus involve many stakeholders, from individual farmers to NGOs supporting their work, funding agencies such as banks, commercial companies, government agencies from forestry departments to ministries of commerce, chambers of commerce, fair trade groups, all of which have varying roles within it.

The environmental benefits of bamboo in relation to coping with climate change are presently very topical - annual non-destructive harvesting of bamboo means that the canopy is retained over the soil and permanently and significantly reduces soil erosion, whilst providing a predictable supply of wood for income generating activities. Bamboo's very rapid growth rate means it sequesters carbon rapidly, though the extent to which this happens needs further research (Liese, in press). Most high-value bamboo products have a long life, and the carbon can be captured and held for many decades. As an alternative to timber wood, using bamboo would help

reduce the destruction of forests, particularly tropical forests - activities which in themselves release large amounts of carbon.

At the Conference on "Climate Change, Global Risks, Challenges and Decisions" in Copenhagen in March 2009, noted Climate Change specialist Prof. John Schellnhuber said: "We are facing the MAD challenge: Mitigation, Adaptation and Development" (see http://climatecongress.ku.dk/). He argued for holistic approaches, not marginal changes, that actively involve developing countries – and the vast majority of these already have bamboo. The inherent ability of bamboo to combine protection of the environment with income generation ensures it is a strong candidate for contributing to these holistic integrated development systems that will be necessary for dealing with the MAD challenge. At the same time, researching and implementing holistic development systems can only be successful through a partnership approach.

INBAR as a networking agency

A good partnership brings together organizations and individuals with similar goals but different and complementary skills, which ensures more effective and efficient progress towards their common aims, and enables them to learn together, and from each other. Partnerships are often formalized by an MoU indicating a general agreement to work together, or by a contract in order to implement a project or other activity. In the latter case, careful inclusion of appropriate technical, national/local support, field implementation, innovation, marketing, training organizations (amongst others) at appropriate levels – international, national, local or community – can build strong links that increase local and national capacities to implement the project, to continue its development or adapt it for broader uptake after the project has finished.

The different levels of knowledge and awareness of what bamboo can do across the world is vast. INBAR often finds that when we bring people from countries with untapped bamboo-based development potential to China to see the bamboo value chain, or to our Action Research Sites in Asia, Africa or Latin America, they are amazed at the possibilities bamboo has to offer. Unless specific action is undertaken, ideas and innovations tend to remain where they originate and with the people who originated them. This is to be expected particularly in the case of new products where many have a financial value. Clearly sharing of information across boundaries, be they national, cultural, economic or social, is an essential first step to enabling decision makers to decide whether and which bamboo-based solutions to trial in their own regions. Linking appropriate partners to the decision makers and the implementers to help them achieve their bamboo-based aims is the second step, and providing guidance and assistance to enable them to achieve these aims is the third.

Recognizing the essential need for sharing and enhancing existing skills and experiences from the very diverse backgrounds from which they come in order to grow the world's bamboo sector, INBAR was established to act as the hub of a network of bamboo expertise, implementation, adaptation and adoption organizations and individuals. This confers certain advantages, responsibilities and ways of working on INBAR. Firstly, networks, and the partnerships that develop from them, enable learning and innovation amongst their members – sharing of information and skills increases the abilities of members, and builds stronger partnerships between them. This leads to increased mutual trust and support that strengthens the network, including sharing information that would not otherwise be shared. Finally, networks and partnerships lead to an increased capacity to manage

change by the members and empower them to deal with the broader, more complex issues that affect their common interests (Svendsen and Laberge, 2007).

Over the years INBAR has formally partnered (ie by MoU, contract or similar agreement) well over 200 organizations, companies and individuals for its work, and worked informally with many more. Our mailing list includes over 5500 institutions and individuals throughout the world. As a hub, INBAR aims to collate and provide up-to-date information on all aspects of bamboo-based development to the world community, and we are continually working to improve our information services. INBAR coordinates a range of training and awareness- raising activities, focusing on its abilities as a global networking organization to share skills across national and continental boundaries. INBAR also needs to lead the development of innovative bamboo-based solutions to poverty and environmental amelioration, and runs Action Research Projects to do this. Not only do they trial the production of bamboo products in different locations, with different bamboo species, under different environmental, social and market conditions and different levels of policy support and investment, but they also trial different partnerships and show how they can work for sustainable development. INBAR shares the experience gained to guide and help other members of the network achieve similar success.

INBAR's partners

The world's bamboo sector is very diverse. Within the sector, different sets of stakeholders have different demands, and so INBAR works to develop sub-networks where appropriate, sometimes thematic, sometimes geographical, that bring like-minded stakeholders together. In general our main groups of stakeholders can be categorized as:

- The approximately one billion rural poor people who depend in some way or another on bamboo for some or all of their lives and livelihoods
- The governments of INBAR's member countries and, by default, all their citizens (ie. over 3 billion people)
- The consumers of bamboo products throughout the world
- Actual or potential investors in the bamboo sector
- Bamboo innovators and implementers
- The world's development community

INBAR has developed formal structures for some of its partnerships:

Membership

Membership of INBAR is open only to sovereign states registered with the United Nations. Nine states signed INBAR's establishment treaty in 1997, and presently 34 states have acceded – 10 in Asia, 13 in Africa, 9 in Latin America, one in North America and one in Oceania. Membership of INBAR confers certain advantages on these states, but also requires their commitment to helping INBAR develop for the good of their own citizens. Representatives of the Member Countries meet once every two years as the INBAR Council to review INBAR's progress and take decisions about its future.

Affiliates

INBAR's affiliates scheme, with about 170 members, is regarded as a second tier of membership, and is open to individuals and organizations alike for a small fee. It offers a range of benefits to members. The scheme in Latin America is particularly successful, and acts as a network of geographically and culturally-similar partners, sharing a common language.

Partnership programmes

INBAR runs three thematic programmes and also three special partnership programmes – the NTFP Global Partnership Programme (NTFP-GPP), the Global Bamboo Housing Programme (GBHP) and the Global Rattan Programme (GRP). These are multi-level partnerships that work with stakeholders ranging from governments (eg. for policy, investment) to NGOs (eg. for community training or access to common-use processing facilities). They work by either encouraging formal membership of organizations in the partnership, and/or by being open to individuals and institutions via memberships of online discussion groups.

The NTFP-GPP was established under the aegis of the Global Forum on Agricultural Research in 2005 and currently has 22 members, including the governments of India, Mozambique and Ecuador, SNV - the Netherlands Development Organization, the Asian and Arab Networks for Sustainable Agricultural Development, and a range of NGOs and companies. Its goals are ensconsed in the Marrakech Declaration, and it aims to promote collaborative efforts, synergies and economies of scale to address strategic NTFP research and development issues of global relevance in order to contribute to achieving the Millennium Development Goals. Projects to date have included evaluations of NTFP potential in Mozambique and reviews and policy work of charcoal production and use in Africa. The NTFP-GPP helps the INBAR network to learn from other NTFPs, and the NTFPs represented by the GPP members learn from INBAR's network to improve their effectiveness.

The Global Bamboo Housing Programme aims to promote and develop appropriate sustainable housing solutions using bamboo. With a global need for 4000 new houses every day, pressure on timber and the rising costs of mineral-based raw materials, the programme and its partners have demonstrated bamboo as an effective alternative resource for construction in a number of countries in Asia, Africa and Latin America. The programme has trained hundreds of house constructors, fostered innovation of new housing construction systems using engineered bamboo, and developed support systems such as standards for building with round-pole bamboo that can be used to develop national legislation that provides a legal framework for builders of bamboo houses. With its partners it has innovated a prototype refugee shelter from bamboo in Ghana, and built emergency shelters in Sichuan after the earthquake in 2008. The programme has organized two international workshops on housing and has organized a highly acclaimed design competition (see Xiao *et al.* 2008; Paudel *et al.* 2008). The programme presently supports projects to develop modular bamboo housing production facilities in Nepal and Ethiopia, to develop pre-formed bamboo components and relevant policy supports in India, and has started working on bamboo housing more widely in East Africa. Its thriving Google group is a forum for discussion and exchange amongst individuals and institutions, with well over 150 members.

The Global Rattan Programme commenced in 2008, and has a specific aim to foster links between Asia, Africa and Latin America. Currently it runs its first project in Ghana. It is presently an informal network, and not

directly relevant to bamboo, expect for the fact that in a significant number of countries the bamboo and rattan sectors are very much intertwined.

As part of its core activities, INBAR runs to develop innovative and sustainable solutions to environmental degradation, poverty and fairer trade with bamboo, in partnership with a wide range of expert organizations and individuals. Project partners are a.o. multilateral agencies, funding agencies, government departments, NGOs, research and development agencies, community-based organizations, and marketing organizations.

Impact of INBAR's work

INBAR's work aims to contribute to the United Nations Millennium Development Goals, particularly MDG 1 (eradicate extreme poverty and hunger), MDG 7 (ensure environmental sustainability) and MDG 8 (develop a global partnership for development). To ensure that INBAR works effectively, INBAR developed four strategic goals in 2006 that it aims to achieve over the following decade (INBAR, 2006):

1. An expanded, highly effective network of committed stakeholders (MDG 8)
2. Better ways and means of livelihood development, particularly in rural areas (MDG 1)
3. Increased and more effective conservation of the environment and of biodiversity (MDG 7)
4. A better and more innovative market environment, providing fair global-to-local and local-to-global trading systems for income generation (MDG 8)

INBAR with its partners is making good progress towards realizing its goals.

MDG 1: Eradicate extreme poverty and hunger

<u>Directly improving the lives of thousands of people in Asia, Africa and Latin America in development projects</u>

INBAR and its partners work with a small but representative sample of the rural poor in our field projects to develop replicable and adaptable development models with bamboo and rattan that can be scaled up and applied more widely. We have helped thousands of men and women in the Action Research Sites earn incomes from bamboo, and have developed a Global Marketing Initiative to promote better products that meet international market demand, to help increase the benefits they accrue from their work (eg. see Ramanuja Rao *et al*, in press)..

<u>Helping innovate bamboo technologies and products with market potential</u>

INBAR and partners have fostered the development of a wide range of new products, and the systems used to produce them, including flat-pack bamboo furniture, bamboo crisps, stylish round-pole furniture, mass produced incense sticks and commoditized bamboo laths and slats, all of which meet market demand, or open up new trading avenues.

Training over 6000 people in bamboo production and processing

INBAR run training courses with partners in all developing continents. Many trainees use their new skills to establish businesses or take jobs in the sector. Courses targeted towards government decision-makers have encouraged some of them to develop national bamboo-based development programmes and projects in their own countries.

MDG 7: Ensure environmental sustainability

Demonstrating bamboo for rehabilitating degraded lands and preventing soil erosion

The bamboos that INBAR supported the NGO "UTTHAN" to plant on land severely degraded by mining for brick making in Allahabad, India raised the water table by 7m in five years. In only two years bamboo plantations in China reduced soil erosion by 75% whilst providing incomes to local people who processed them for sale (see Kutty and Narayanan, 2003).

Evaluating the state of the World's bamboo resources

INBAR and FAO have agreed to include bamboo in FAO's pentennial Forest Resources Assessment, which will give a more accurate picture of the state of the world's bamboo forests. We estimated global bamboo species diversity and highlighted threatened habitats and species with UNEP(see Bystriakova *et al* 2002).

Demonstrating new conservation techniques

With local partners in Sichuan, Yunnan and Hunan provinces in China, INBAR has innovated new conservation techniques for endangered bamboo stands that improve productivity whist protecting the forest, and together we are developing a management standard to enable replication.

MDG 8: Develop a global partnership for development

Facilitating development of national and local institutional support systems in nine countries

Through our development projects we have fostered the development of bamboo based NGOs in INBAR member countries, such as Ecuador, Ghana, India, Tanzania, Ethiopia and Mozambique and helped facilitate government bamboo initiatives in India, Ghana and Mozambique that are now leading the development of the sector in these countries.

Developing standardized customs codes for more accurate reporting of bamboo and rattan trade, and an online trade statistics database

We worked with the World Customs Organization and other partners to produce bamboo specific categories and codes that are being used to track international trade more accurately since 2007. The INBAR online bamboo and rattan trade database provides easy access to the data.

Developing building codes for bamboo structures

Bamboo building codes for round pole houses have been adopted by the International Standards Organization and provide a basis for developing national legislation for bamboo buildings (see Anon, 2004). The GBHP is presently working on similar codes for engineered bamboo buildings.

Promoting commodity-based development

As the International Commodity Body for Bamboo and Rattan of the Common Fund for Commodities, INBAR facilitates the development and implementation of many bamboo commodity-based projects that help our member states develop bamboo and rattan as viable market-based options.

These achievements would not have been possible without the networking approach. We like to believe that the work done together not only has had real impact in the communities and on the environment, but that it also has grown all the partners involved, helped partners to learn from each other, and made all better at doing development with bamboo. Further development of the network is essential, as more and more organizations are seeing the possibilities of bamboo. Meetings such as the World Bamboo Congress are excellent opportunities to re-connect with many partners, to link in with new ones, and we look forward to working in an even more close partnership with the bamboo sector, not least so we can respond effectively to the MAD challenge.

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Bart DEWANCKER, Toshiichi KUSABA The preservation of bamboo forests undertaken by NPO Kitakyushu Biotope Network Group in Kitakyushu, Japan.	Bart Dewancker Associate Professor The University of Kitakyushu Hibikino 1-1 Wakamatsu-ku 808-0135 Kitakyushu Japan bart@env.kitakyu-u.ac.jp
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Shozo Shibata Succession of Bamboo (Phyllostachys bambusoides Sieb. et Zuc.) Riparian Forest Vegetation after Gregarious Flowering	SHIBATA, Shozo (Dr. Agr.) Professor Field Science Education and Research Center (FSERC) Kyoto University TEL:+81-(0)75-753-6442 FAX:+81-(0)75-753-6451 EMAIL:sho@kais.kyoto-u.ac.jp
Kananbala Sarangthem Cyanogenic Glycosides in Bamboo Plants Grown in Manipur, India.	Dr. Kananbala Sarangthem Assoc. Prof., Dept. of Life Sciences, Manipur University, Canchipur - 795003 Manipur, India kananbala_s@rediffmail.com
Keshab Shrestha The First Report of Flowering and Fruiting Phenomenon of Melocanna baccifera in Nepal	Keshab Shrestha Natural History Museum Swayambhu Kathmandu Nepal keshab_shrestha@hotmail.com
S. Pattanaik and J.B. Hall Species Relationships In Dendrocalamus Inferred From Aflp Fingerprints	Swapnendu Pattanaik Scientist, Rain Forest Research Institute (ICFRE) Jorhat, India. swapnen@yahoo.com J.B. Hall Director, Postgraduate Studies, School of the Environment & Natural Resources Bangor University, United Kingdom
Yoko Hisamoto and Mikio Kobayashi Flowering gene expression in the life history of two mass-flowered bamboos, Phyllostachys meyeri and Shibataea chinensis (Poaceae: Bambusoideae)	Yoko Hisamoto United Graduate School of Agricultural Science, Tokyo University of Agriculture and Technology, 3-5-8, Saiwai-cho, Fuchu, Tokyo, 183-8509 JAPAN da07953001@cc.utsunomiya-u.ac.jp Mikio Kobayashi Department of Forest Science, Faculty of Agriculture, Utsunomiya University, 350, Mine-machi, Utsunomiya, 321-8505 JAPAN
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Abhinav Kant Micropropagation protocol for Melocanna baccifera using nodal explants from mature clump	Abhinav Kant Research Scholar Tissue Culture Discipline Forest Research Institute Dehradun, India Email: akant23@gmail.com
Celso B. Lantican Bamboo Propagation: Practical Experiences of Some Private Nursery Operators in Laguna, Philippines	Celso B. Lantican President, Bamboo Network of the Philippines Retired Professor and Former Dean UPLB College of Forestry The Philippines cblantican@gmail.com
Sheena Haorongbam, David Elangbam and C. Nirmala Cyanogenic glucosides in juvenile edible shoots of some Indian bamboos	Nirmala Chongtham Department of Botany Panjab University, Chandigarh, India e-mail: cnirmala10@yahoo.com
C. Nirmala, Abdulminam Hussein Ali , Badal T, M.L. Sharma In-vitro organogenesis and simultaneous formation of shoots and roots from callus in Dendrocalamus asper	Abdulminam Hussien Ali Ho. no. 212 sec 11 A Chandigrah, India. masaowdi_67@hotmail.com
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Gladys Muivah, Rashmi Verma & I.Usha Rao Allelopathic effect of Parthenium hysterophorus L. on germination and growth of seedlings of Bambusa bambos (L) Voss and Dendrocalamus strictus Nees	Gladys Muivah, Rashmi Verma & I.Usha Rao Department of Botany University of Delhi Delhi-110 007 India E-mail: usharaolab@yahoo.com
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Th.Brojendro Singh Bamboo – A Renewable Natural Resource And Valuable Raw Material Of Cottage Industries	D.M. College of Science Manipur India drthbrojendro@gmail.com
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