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Role of bamboo in environmental conservation and sustainable development

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Abstract

Bamboo, an abundant and versatile plant, has gained recognition as a valuable resource in the context of environmental conservation and sustainable development. The forests of bamboo promote environmental sustainability, biodiversity conservation, carbon sequestration, greenhouse gases mitigation and socio-economic development. Additionally, they act as natural buffers against soil erosion, preventing land degradation and promoting water conservation. They also harbour rich biodiversity and serve as habitats for numerous plant and animal species. Preservation and restoration of bamboo ecosystems contribute to the conservation of endangered species, restoration of degraded habitats, and the promotion of ecosystem resilience. Extensive root system of bamboo helps to stabilize the soil and prevent landslides, proving it an excellent tool for slope stabilization and watershed management. The intercropping of bamboo with other agricultural crops can enhance the agroforestry systems, improving soil fertility and diversifying income options for farmers. Bamboo cultivation and processing provide livelihood opportunities for local communities, particularly in rural areas. It has characteristics like fast growth rate, perennial and well-developed rhizome system that enables regular emerging of new shoots and harvesting that creates a sustainable source of income and employment. Bamboo-based industries such as furniture, handicrafts and textiles offer eco-friendly alternatives to conventional manufacturing processes with promoting sustainable consumption patterns. Moreover, bamboo is increasingly being used as a renewable and eco-friendly substitute for traditional construction materials, such as timber and steel, thus reducing deforestation and minimizing the ecological footprint of the built environment. Different policies and initiatives that promote bamboo cultivation, research, and development can unlock its full potential and contribute to a greener and more sustainable future.

Keywords Bamboo; Environment; Sustainable Development; Conservation; Resilience

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1. Introduction

The confluence of increasing population, land degradation, and environmental pollution places an immense burden on our planet. As the global population expands, so does the demand for resources increases resulting in the exploitation of ecosystems and depletion of finite resources (Ajibade et al., 2021). Urbanization, a by-product of population growth, leads to the encroachment on natural habitats and the fragmentation of ecosystems. Concurrently, land degradation intensifies due to deforestation, unsustainable agricultural practices, and overexploitation, diminishing the Earth's capacity to support diverse life forms (Sanesi et al., 2018; Wassie, 2020). The rise in industrialization and energy consumption, driven by a burgeoning population, contributes to pervasive environmental pollution (Galloway et al., 2008). Air and water quality suffer as pollutants from various sources accumulate, impacting both ecosystems and human health (Bashir et al., 2020). Additionally, the escalating production of waste, including plastic and electronic materials, further exacerbates environmental degradation (Moharir and Kumar, 2019).

Bamboo, a remarkable evergreen perennial belonging to the subfamily Bambusoideae in the family Poaceae, stands out as a powerful force in environmental conservation and sustainable development (Ohrnberger, 1999). They are one of the fastest growing plants on the planet with the special power to reach up to 30 m height and 35 cm diameter. There are 1662 species of bamboo over 121 genera worldwide (Rani et al. 2023a). A total of 36 million hectares, or 3.2% of the world's total forest area, are covered by bamboo stands (Ayer et al. 2023). This study explores the diverse contributions of bamboo to the overall health of our planet. Highlighting its ecological advantages such as promoting biodiversity conservation and carbon sequestration, as well as its crucial role in fostering sustainable agriculture and driving economic growth, bamboo emerges as a pivotal factor in advancing the United Nations Sustainable Development Goals (Fig.1). Notably, it contributes to poverty reduction through bamboo-based cultivation, providing income opportunities at every stage, from harvesting to marketing. Beyond economic facets, bamboo enhances food security with its nutritional shoots, widely consumed in Asian nations. Furthermore, its extracts exhibit medicinal properties, offering a natural shield against various diseases. As a critical component in water management, energy production, and eco-friendly construction, bamboo plays a vital role in addressing climate change challenges.

This paper comprehensively reviews bamboo's ecological, economic, and social dimensions, shedding light on its significant contributions to climate mitigation, biodiversity conservation, and livelihood improvement. It also navigates the challenges and opportunities associated with bamboo cultivation, emphasizing the need for sustainable practices to unlock its full potential for environmental and societal benefits.

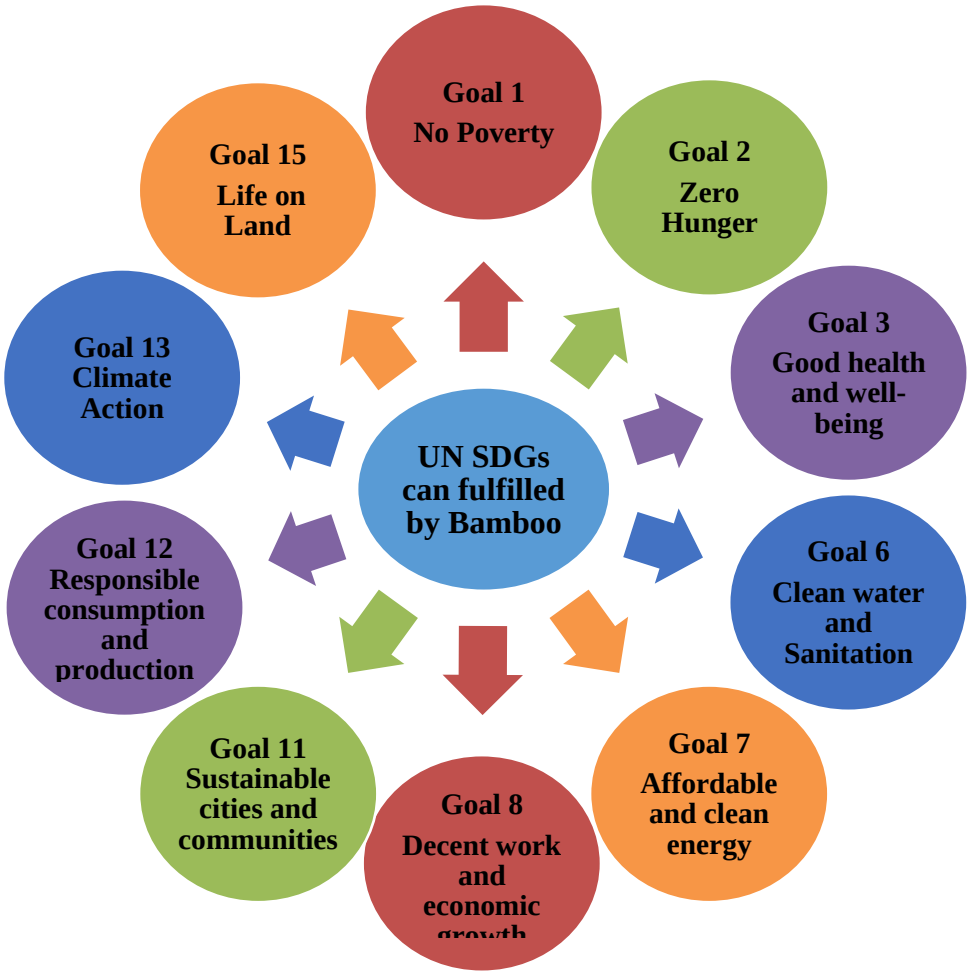

Fig. 1. The United Nation Sustainable Goals that can be fulfilled by Bamboo

2. Bamboo: A key player in SDGs

Bamboo can reduce the poverty by promoting bamboo-based cultivation and restoration which ensures the economic opportunities. Bamboo plantation can be the solid source of income starting from harvesting, collection, processing, manufacturing and trading or marketing. The provisioning services offered by bamboo increase food security for both human and livestock (Paudyal et al. 2022). Bamboo shoots or young culms of the plants are boiled, soaked, cooked, fermented and pickled for variety of dishes considered beneficial and healthy foods due to their high nutrition components such as proteins, carbohydrates, vitamins, fibres and minerals and

very low fat are commonly used as food in Asian nations (Nirmala et al. 2018; Wang et al. 2020; Joshi et al., 2023). By sustainable agriculture, improved nutrition and food security ensures the food for all and can end hunger and also ensures healthy life for all the age groups. The extracts and components of these leaves also exhibit antioxidant, antibacterial, anti-inflammatory, anti-helminthic, antidiabetic and antiulcer properties which prevents the humans from diseases. (Indira et al. 2023; Nirmala et al. 2014). Bamboo forest ensures the availability and sustainable management of water and sanitation for all. It provides the excellent source of renewable energy especially through bamboo charcoal and provides smoke free fuels. Bamboo waste chipped or pellets can be used as fire generator through gasification. It is a superior raw material for biofuel. Bamboo promotes sustained, sustainable economic growth, full and productive employment and decent work for all. The role of bamboo in providing affordable strong, practical, cost-effective, eco-friendly building materials is well recognized. There are excellent opportunities for sustainable, climate-smart construction. It is a wonder plant; every part of the bamboo can be used for manufacturing and it is one of the important sustainable and environmentally responsible raw materials with a smaller carbon footprint. Climate Action aims to improve and strengthen the resilience and capacity to adapt the climate-related risks and natural disasters. Bamboos are an excellent option for adaptation to climate change effects as it acts as a giant carbon sink, and its durable products, which store carbon and a healthy grove of bamboo can generate about 35% more oxygen than an equivalent biomass of trees. Use of bamboo protects, restore and promote sustainable use of terrestrial ecosystems, manage forests, combat desertification, halt and reverse land degradation and limits biodiversity loss. There is immense potential for cultivating bamboo to restore degraded lands and promote disaster risk reduction (DRR). The mountain Gorillas, lemurs, Red Panda, Giant Panda, bears and mountain tapirs and frogs, and many other species depend on bamboo forests

3. Bamboo in Environmental Conservation

Bamboo provides a wide range of regulating services such as carbon storage and sequestration, restoration of degraded land, flood and erosion control and sediment retention (Mishra et al. 2014; Paudyal et al. 2022). It has the ability to grow in variety of soil and climatic conditions that makes it an idea crop for the purpose of agroforestry systems. Bamboo's ability to grow in a variety of soils and climatic conditions makes it an ideal crop for use in agroforestry systems. It can be intercropped with other crops providing a range of benefits such as reduction in soil erosion and improving soil fertility (Tewari et al. 2015). Deep root system of bamboo makes it an effective tool for the conservation of water, reduce the water loss from soil and decrease the

risk of flooding (Jeffery et al. 2023). These deep roots also make it a potent candidate for use in the phytoremediation of contaminants that have leached to depth of the soil profile and cause the soil pollution (Rani et al. 2023b; Lathwal et al., 2023b).

3.1. Carbon Sequestration and Climate Change Mitigation

Forest is the largest carbon inventory and deposits 1146x1015 which contributes 56% of the total carbon inventory of the terrestrial ecosystem. Bamboo forest is the important part of the forest ecosystem and known as an important carbon source and carbon sink on the earth (Seethalakshmi et al. 2009; Zhou et al. 2011). Currently, India is the 4th leading emitter of CO_2 next to China and USA (Gupta and Paul, 2019). The contribution of India's global energy use will be 11% by 2040 from 6% in 2015. Bamboo has large CO_2 sequestration potential, as it has unique feature of fast growth and high annual regrowth after harvesting (Song et al. 2011). The process in which plant capture carbon dioxide through photosynthesis and transform the gas into solid biomass is one of the best options for decreasing the total amount of CO_2 in the atmosphere and thus mitigate the climate-change scenarios and afforestation/reforestation CDM (Jijeesh and Seethalakshmi 2009). Bamboos have extensive underground rhizome and root systems which can live even up to 100 years (Sudhakara and Jijeesh 2015).

Houdanon et al. (2018) reported 106.36 t/ha carbon storage in *P. pubescens* in Japan and 165.1t/ha in *P. bambusoides* recorded by Isagi (1994). In India, 37 species of *Bambusa* genus are found which are grown in different locations and climatic conditions (Sharma and Nirmala 2015). The estimated carbon storage in aerial biomass of *B. cacharensis*, *B. vulgaris* and *B. balcooa* is 54.7 t/ha,128 t/ha, and 65.3 t/ha respectively reported by Dwivedi et al. (2018). According to the IPCC, global warming is unequivocal, with evidence from increases in average air and ocean temperatures, melting of snow and ice and sea level rise (Singh and Singh 2012). In order to avoid the most damaging effects of climate change, it is estimated that global levels of atmospheric greenhouse gases (GHGs) need to be stabilized at approximately 445-490 ppm CO_2e (CO_2 equivalent) or less. Forests will have a central role in meeting this target (Eliasch 2008). India is the most vulnerable countries with respect to global warming (Dwivedi et al. 2019). The country has a target of reducing its emission intensity of GDP by 33–35% from 2005 levels before 2030 (Shukla et al. 2017). Bamboo can effectively provide financial gains and adaptation to climate change at the village levels. It also helps in climate change mitigation at the global level because of its multiple uses and suitability to diverse conditions. *B. vulgaris* forest reserve in the Moulvibazar district in Bangladesh was estimated for total

carbon sequestration and found 52.96 tons/ha in plantation and 24.71 tons/ha in soil (Sohel et al. 2015). Bamboo cultivation requires little fertilizer and pesticides, which makes it an economically favourable crop (Vanlalfakawma and Tripathi 2018).

3.2. Soil Erosion Control and Watershed Management

Worldwide more than 10 million hm^2 of world's arable land is lost per year. 75 billion metric tons of soil is lost from the land and causes 400 billion US$ damage around the world per year (Pimentel et al. 1995). The bamboo forest soil has a high anti-scour and anti-erosion ability. It is valuable for controlling soil erosion, watershed protection and can be used as a timber substitute in the forest ecosystem. Bamboo grows well on steep hillsides, road embankments, gullies, or on the banks of ponds and streams. *B. blumeana* and *P. pubescens* was introduced by Brazilian for controlling soil erosion, preventing nutrient loss and improving soil structure (Benzhi et al. 2005). Bamboo roots and rhizome forms the closely woven mat which are effective in holding the soil. Many studies reported that around 80% of the rhizomes and roots were present in the upper 0-30 cm soil layer and serve best in controlling soil erosion. In Nepal, Moso bamboo was successfully established on the degraded site of Dhaneshwor Baikiwa community of mid hills and suggested the promising species for ecological restoration and reclamation of degraded lands (Ayer et al. 2023). Jha et al. (2019) found that bamboo plantations in the hilly region of India significantly reduced the soil erosion and increased soil organic matter content. Similarly, in China, Zhao et al. (2023) reported that bamboo plantations reduce the soil erosion by 85% in the Loess Plateau region. These studies, along with others, demonstrate the effectiveness of bamboo in controlling erosion and conserving soil (Jeffery et al. 2023).

Bamboo species of *Sasa* and *Indocalamus* distributed 1000m high from sea level in Hakone-yama Mountain of Japan and resulting in reduction in water and soil loss. It is reported that the *Guadua* bamboo in Colombia is one of the bamboos that prevented the millions of tons of mountain soil from reaching the ocean bottom (Van Dam et al. 2018). Benzhi et al. (2005) demonstrated that *Pleioblastus argenteostriatus f albostriatus*, a dwarf bamboo had a higher ability of anti-scour and anti-erosion due to its well-developed rhizomes and root system. The index of anti-scour ability and anti-erosion for the dwarf species are 1.404 and 1.413, respectively, 40% and 34% higher than those in larger sized *P. pubescens*. By retaining soil particles through a complex network of roots and rhizomes, bamboo forests regulate floods and landslides (Paudyal et al. 2023). During flood periods, the fibrous mass of roots binds the soft

banks and the thick culms arrest strong currents. Bamboo is commonly used in bioengineering when stabilizing slopes, conserving soil, and preventing erosion on slopes in Nepal (Ayer et al. 2023). The efficacy of bamboo as a soil binder was successfully used in Puerto Rico. A sympodial bamboo species, *B. vulgaris* revetment was constructed at adjoin experiment field at Mayaguez Federal Experiment Station to avoid the damage of trial crops by river. In China, about 90% of bamboo forest naturally occurs in the headstreams of rivers, lakes and reservoirs or along the banks (Benzhi et al. 2005). The department of interior has used planting of bamboo (*B. vulgaris*) with considerable success to maintain fills and steep road embankments (Anonymous 1997). It develops large thick clumps, makes a rapid dense growth, and planting material has been readily available. The presence of bamboo clumps or forests are thought to be an efficient mechanism to prevent erosion and soil mass loss on slopes (Tardio et al. 2018).

3.3. Land rehabilitation

Bamboo's deep root systems also have the ability to grow in degraded or contaminated land making it a viable tool for water conservation, land restoration and rehabilitation (Li et al. 2021; Bian et al. 2023). In India, Bamboo species were used to rehabilitate soil under an INBAR project, which was degraded due to brickfield mining near Allahabad. Farmers of Jabalpur, Madhya Pradesh of India were willing to plant *D. strictus*, *B. bambos* and *B. nutans* on farm bunds and degraded lands even if that were non-productive. Bamboo seedlings were intercropped with either maize or soybean. The bamboo species were intercropped with maize and peanut in Thailand (Anonymous 1997). The project of bamboo-based technologies funded by IDRC in India to rehabilitate the land was successfully proved that using a soil, sludge and fly-ash combination successfully cultivated the bamboo and restore the degraded land because of its maximum biomass production per unit area and unit time (Anonymous 1997). Bamboo leaves and other plant materials can be used as green manure to improve the nutrient content of the soil (Jeffery et al. 2023).

3.4. Biodiversity Conservation

Long-term processes such as soil formation and retention, habitat supply, nutrient cycling, and oxygen generation are the examples of habitat services. Bamboo forest found to have a positive impact on biodiversity, offer excellent habitats for a variety of species (flora and fauna) serving as a habitat for a variety of wildlife species because of the abundance of bamboo foliage (Xu et al. 2020). The combination of these benefits makes bamboo a potent tool in conservation efforts and its cultivation can help to preserve natural habitats and biodiversity. The animals

also consume the young leaves and shoots or bamboo foliage (Chuchón et al. 2021). Paudyal et al. (2022) reported that in South Asia, bamboo forests serve as home for the different species of animals, including elephants, wild cattle (*Bos gaurus* and *B. javanicus*), various type of deer (Cervidae), leaf monkeys, pigs (Suidae), rats and mice (Muridae) and squirrels (Sciuridae). In Nepal, these bamboo forests are home to red pandas (*Ailurus fulgens*) and many endangered species of the country (Ayer et al. 2023). Sharma et al. (2014) found that in pre- and post-monsoon seasons, bamboo was the primary food source for red pandas in Rara National Park. Bista et al. (2022) proposed the development of bamboo plantations and the regulation of bamboo harvesting to help the survival of red pandas in their natural habitat and currently threatened by bamboo mortality. Shrestha et al. (2021) also concluded that bamboo cover was significant for the occurrence of red pandas. Therefore, the loss of bamboo habitat due to various anthropogenic causes could affects the survival of red pandas and other wildlife (Li et al. 2015). A study by Reid et al. (2004) indicated a positive relationship between bamboo cover and species diversity. Despite this evidence, bamboo forests are considered to be of lower value compared to natural forests in terms of providing biodiversity services (Paudyal et al. 2019).

Apart from these, bamboo serves as a nesting site for birds. In Sumber Kendedes region, Rohman et al. (2020) observed that 15 species of birds use the bamboo as a preferred site for building their nests. The conducted study also provides the valuable insight into the relationship between bamboo and bird species which highlights the ecological significance and versatility of the bamboo. Bamboo forests can provide habitat and food sources for beneficial insects such as bees and butterflies. These insects contribute to pollination, which is essential for the growth of many plants, including those that help improve air quality by absorbing pollutants. Conservation efforts are essential for maintaining a healthy and thriving ecosystem that supports a diverse range of species and contributes to the overall health and wellbeing of the planet.

3.5. Air and Water Quality Improvement

Bamboo's ability to sequester more carbon dioxide from the atmosphere through photosynthesis helps to reduce the overall concentration of green-house gases and improves the air quality. Simultaneously, it releases more O_2 and provide healthy life for the living beings. Bamboo foliage act as natural filter for airborne particulate matter. It can trap the dust, pollen and other small particles which causes the air pollution. Morina et al. (2013) introduced *B. bissetti* to the urban areas of Belgrade to improve the air quality that was degraded by heavy

traffic. They observed that dust was adsorbed on the leaves and reached upto 10% of the leaf d.wt. Extensive dense rhizome system of bamboo help to stabilize the soil and prevents its erosion. Control in soil erosion limits the sediment runoff that can carry pollutants such as heavy metals, fertilizers and pesticides into the nearby water bodies. Bamboo also has the ability to uptake excessive nitrogen and phosphorus and heavy metals (As, Pb, Cr, Cd and Ni) from the soil and wastewater bodies. Removal of these nutrients leads prevention of the water pollution, eutrophication that can harm the aquatic ecosystem. Bamboo charcoal is used in water purification from centuries. Porous structure adsorbs impurities, odour and chemicals from the water and improve the taste and quality of the drinking water.

3.6. Litter accumulation

Bamboo creates a lot of biomasses, up to 10 ton/ ha or more each year mostly in the form of foliage. Bamboo leaves usually fall when they are between 12-18 months old, and they are quickly replaced with new leaves (Banik 2015). Benzhi et al. (2005) demonstrated that *P. pubescens* produces the most litterfall during two periods, i.e. during April to May and November. The annual litterfall of *D. latiflorus* forest with a density of 825 culms/ha is measured to 3.6-3.9 tons/ha (Vanlalfakawma 2014).

3.7. Moisture retention

The thick leafy blanket of the bamboo also assists the earth to absorb and retain moisture more efficiently and reduce the rate of evaporation. Leaves being organic matter also helps to enhance the organic content of the soil. Bamboo litter has a high-water retention capacity as it can hold 2.75 times more of its d.wt.). The litter of *D. latiflorus* stand with a density of 825 culms/ha has the capacity to absorb the moisture 2.7-2.9 times of its dry weight (Vanlalfakawma 2014). The maximum water-holding capacity of *P. pubescens* forest mixed with *Cunninghamia lanceolata* could be 21.29 tons/ha much higher than that for pure *C. lanceolata* forest, which is measured to be 7.37 tons/ha (Zhou et al. 2018). Canopy of bamboo stands can intercept up to 25% of rain through fall, value much higher than those for conifers and pines

4. Bamboo's contribution to sustainable development

Bamboo is also known for its wide range of uses, including construction (used as a scaffold, wall fencing, flooring, roofing, and furniture), paper production, methanol production, medicinal products and textiles (Kaur et al. 2022) (Table 1.)

4.1. Economic impact and income generation

India is struggling economically in pursuit of all-round development of its huge population under the poverty line. Economically, bamboo can be used in a wide range of industries, including construction, textiles, paper production, and furniture manufacturing. Furthermore, bamboo can be grown and harvested quickly, making it a sustainable and renewable resource. Bamboo can also be used to improve the livelihoods of smallholder farmers who can use bamboo to produce a variety of goods for sale in local and international markets. Bamboo products have significant international demands with USA and EU accounting for 80% of total bamboo imports at present, most of it originating from China (Dwivedi et al. 2019).

Bamboo can also be used to create jobs in rural areas and improve the local economy. It is relied on heavily by some of the world's poorest people, and can be a significant pathway out of poverty (Kuehl 2015). For example, a conservative estimate indicates that there are 5.6 million people working in China's bamboo sector, 80% of whom are working in forest cultivation (Yiping et al. 2010). Case studies on 'bamboo counties' in Eastern China demonstrate the important role that the development of the bamboo sector can have significant contribution in reduction of rural poverty, maintaining high levels of rural employment. Impact assessments of INBAR project communities in northern India show that bamboo-based interventions have high value-addition through enhancing incomes, generating extra rural employment and empowering women in their communities (Rao et al. 2009). Currently bamboo contributes to between 4-7% of the total tropical and subtropical timber trade (Nath et al. 2018). The successful use of bamboo in a wide range of different products demonstrates the high potential for bamboo as a sustainable 'potential key substitute for timber, cotton, construction material and edible products' (Kuehl et al. 2013). New generations of bamboo products with longer lifespans have been developed recently (Nath et al. 2020). These innovative products offer prospects that sequestered carbon can be stored for a longer period.

The influence of dwarf bamboos on tree regeneration and hence stand development may also be temporally variable. Dwarf bamboos have a unique life history: they flower and dieback over wide areas every several decades, regenerate from seed, and grow vegetative until the next flowering period (Taylor et al. 2004). The sudden decline of the bamboo cover after a flowering event may trigger a pulse of tree regeneration, and bamboo die-off is thought to be an important process regulating tree seedling establishment and forest stand development (Pfadenhauer et al. 2020). Synchronized tree regeneration has been observed both beneath forest and canopy

gaps after bamboo dieback (Franklin and Bowman, 2003). Silva et al. (2020) added that due to its composition of various carbohydrates, such as simple sugars, starches, hemicellulose and cellulose, and low levels of protein and lipids (less than 2–3%), bamboo has the potential to be used in the food industry and biotechnology products, like second-generation alcohol and prebiotics.

4.2. Rural Development and Poverty Alleviation

Bamboo shoots are a popular food source in many regions of the world, and they can be a valuable source of income for farmers (Satya et al. 2012) (Table 1). Rathour et al. (2022) found that bamboo shoot production can provide a stable source of income for farmers, with the potential to improve food security and reduce poverty in rural areas. The study also found that bamboo shoot production can be integrated into existing farming systems, providing a valuable addition to traditional crops such as rice and maize. A study by Jeffery et al. (2023) found that bamboo cultivation and processing in China can generate income for farmers and processors, and contribute to rural development

Zhang et al. (2019) found that bamboo can be a valuable crop for agroforestry systems in China, as it can be intercropped with other food crops to increase overall productivity and reduce the need for chemical inputs. Another study in Nepal by Atreya et al. (2021) found that bamboo can play a key role in reducing poverty and improving food security by providing a source of income and nutrition for rural communities. Akoto et al. (2020) found that intercropping bamboo in agroforestry systems enhanced the soil fertility, increase crop yields, and provide economic benefits for farmers. This was evidenced by improved soil properties such as soil organic matter, nitrogen, and phosphorus content intercropping with maize and beans compared to monoculture bamboo and found increased crop yield. Bamboo plants can use as soil amendment that increase the soil fertility and it was supported Akoto et al. (2020), when used the *B. vulgaris* and observed dominance in the release of nitrogen and lignin.

4.3. Sustainable Construction and Infrastructure

In addition to ecological benefits of bamboo helping the ecosystem, it is used in the construction of traditional houses and as fuel wood in villages. It also provides protection to houses from wind (Dwivedi et al. 2019). Bamboo provides raw material for structural and non-structural works and can emerge as one of the eco-friendliest as well as most effective in construction these days. Bamboo envelope performs better than a conventional brick and reinforced cement building and owing to the cost-efficient and green construction, bamboo trusses can be easily

used for constructing roof trusses using bamboo rafters and purlins. Split or flattened bamboo or mats are used for flooring. The advantageous properties of heavy load bearing capacity of bamboo make it a very convenient material for high rise construction scaffolding. It is a good alternative to traditional building materials in Nigeria. These studies demonstrated that bamboo is not only cost-effective but also has superior strength and durability compared to other commonly used building materials in Nigeria. Kareem et al. (2018) observed that bamboo has the potential to reduce the cost of construction and improve the quality of housing in Nigeria. Vivas et al. (2019) found that bamboo has a higher compressive strength and modulus of elasticity than the other wood type and can substitute the traditional building material such as timber and steel. The elasticity of bamboo empowers the structure to be earthquake resistant with few chances of it to fall. Furthermore, bamboo can be used in combination with other building materials, such as mud or clay, to create low-cost and sustainable housing (Jeffery et al. 2023).

Table 1. Utilization of bamboo species for ecological and economic benefits.

Benefits	Utilization	Purpose of use	Bamboo species	References
Ecological	Water conservation	Water conservation forest	*Phyllostachys edulis, Dendrocalamus giganteus*	Liu et al., 2018; Maviton and Sankar, 2022
	Ecotourism	Scenic spots	*P. aurea, Bambusa ventricosa, Thyrostachys siamensis*	Hamid et al., 2023
	Carbon sequestration	Reduction in greenhouse gases	*Bambusa sp., P. pubescens, D. strictus*	Jeffery et al., 2023
	Land rehabilitation	Degraded land restoration	*D. asper, D. giganteus, B. vulgaris, B. bambos, Malocanna baccifera, Guadua angustifolia, B. balcooa*	Swarkar et al., 2023; Rani et al., 2023; Lathwal et al., 2023
Economic	Timber	Flooring, pulp and paper, construction material, chopsticks	*P. edulis, D. giganteus, D. strictus; Guadua*	Yadav and Mathur. 2021; Madhushan et al., 2023; Jaramillo et al., 2023
	Shoots	Fresh, dry, canned, flavoured and fermented shoot	*D. giganteus, B. nutans, B. balcooa, D. latiflorus*	Indira et al., 2023; Joshi et al., 2023;

			Chongtham et al., 2021 Santosh et al., 2020
Outer sheath	Table, chair, basket and wall of the house	*B. textilis, B. vulgaris, B. chungii*	Hamid et al., 2023
Arts and crafts	Bonsai, root curving, musical instruments	*P. nigra* *Pseudosasa amabilis; G. angustifolia*	Oakes, 1990; Liu et al., 2018; Quintero et al., 2022

4.4. Energy Generation and Biomass Utilization

Biomass energy, derived from plant-based organic matter, can be used for heating, electricity generation, and transportation fuel. In addition to bamboo potential as a food crop, it is also being explored as a source of bioenergy. Bamboo can also be used to produce biofuels, which can help to reduce Nigeria's dependence on fossil fuels. A study by Mosa et al. (2023) and Lathwal et al. (2023a) found that bamboo can be converted into biochar and used as a soil amendment to improve soil fertility and reduce greenhouse gas emissions. According to Jeffery et al. (2023), bamboo can be used as a feedstock for bioethanol production, which can contribute to Nigeria's efforts to diversify its energy sources and reduce dependence on fossil fuels. It is a promising feedstock for biofuel production due to high sugar content. Companies such as Unicane Industries Limited located in Kogi State and Brass Fertilizer and Petrochemical Company Limited (BFPCL) located in Brass Bayelsa state both in Nigeria are specialized in the production of ethanol and methanol from natural resources such as bamboo in the country.

4.5. Pharmaceutical industry

Bamboo has a wide range of medicinal uses in the pharmaceutical industry. Its shoots, leaves, and roots contain various compounds that have anti-inflammatory, antioxidant, and antimicrobial properties (Nirmala et al. 2018; Tundis et al. 2023). Studies have shown that bamboo extract can be used to treat conditions such as diabetes, skin diseases and other cardiovascular diseases. Bamboo also has potential in the production of antibiotics, anti-cancer drug, and anti-viral agents (Kalyan et al. 2023). In addition, bamboo fibres have been used as a source of cellulose (Rasheed et al. 2020), which is used in the production of various pharmaceutical products such as tablets and capsules.

5. Challenges

One major challenge is the lack of knowledge and expertise among builders and architects in the country regarding the proper harvesting, treatment, and construction techniques for bamboo. Other challenge is the lack of genetic diversity among bamboo species (Imarhiagbe et al. 2020). Many bamboo species are clonal, genetically identical and are propagated vegetative rather than sexually. This can make bamboo vulnerable to disease and pests and it also limits the ability to breed new, improved varieties (Banik 1995). The challenge of seedling production and the availability of quality seedlings is another issue that must be addressed (Bahru and Ding 2021). Certain species of bamboo takes several years to reach maturity and the lack of access to quality seedlings can make it difficult for farmers to establish successful bamboo stands (Jeffery et al. 2023).

6. Suggestions

Bamboo forest is an important forest type in many countries, especially in East and Southeast Asian and in African countries. They are versatile not only in industry utilization and in routine life but also in environment protection. There is an old saying, bamboo is the timber of the poor, indicating its status in the life of countryside people and its importance in poverty alleviation. Due to bamboo's economic benefits, the research emphasis has long been put to its biological characteristics and the techniques for its propagation, cultivation, management and utilization. In fact, bamboo possesses a great potential either in soil erosion control, water conservation, or in land rehabilitation and carbon sequestration, which is supposed to give it a promising future. More attention needs to be paid to the research on its ecological functions, with the focus on the hydrological and ecological process of bamboo forest ecosystem, the mechanism and its application of erosion control of bamboo, its capacity of carbon sequestration etc. in the future.

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Conflict of Interest

The authors declare there is no conflict of interest

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