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Bamboo as a substitute of plastic for a sustainable future

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Abstract

The exponential growth of human population leads to overexploitation of natural resources, urbanization and industrialization, which are the chief causes of unsustainability. Of three major pillars of sustainable development (Environment, economy and society), environment is tremendously degraded and plastic is one of the significant non-degradable pollutants. Plastic (Polyethylene) once synthesized, it takes hundreds of years to get degraded under natural condition and filling up the landfills and oceans. Even after degradation, if converts into microplastic, a synthetic additive in natural system which can interfere with normal nutrient cycling in ecosystem and ultimately enters the food chain. Although being a hazardous pollutant, plastic is is popularly used because of its tensile and tear strength, weightlessness, elasticity, stability, impermeability and low cost. This plastic pollution needs a solution which can potentially be bamboo in many cases as this woody grass is flexible enough to compete plastic and having tensile strength more than steel. Moreover, bamboo is a renewable natural resource which is regenerated in form of new shoots from the rhizome every year which grow into full culms in a short span of 5-6 months due to fast growth. A single clump can produce new culms every season for more than 100 years if harvested sustainably. It is woody but excluded from the category of tree, so can be procured without any legal permission in India (largest bamboo forest cover). Bamboo is being used multifariously in our traditional system from a mere stitch in a leaf plate (pattal) to domestic tools, agricultural articles, furniture, bridges, house building etc., which have been replaced by plastic and related material now a days. Revival of these hundreds of bamboo products can reduce the load of plastic on Earth. Moreover, modern problems can be beaten by modern solutions by innovatively substituting single use or regularly replaceable plastic items like bamboo-based toothbrush, straws, earbuds, combs, cutlery, décor pieces, panels, boards and modern infrastructure like ones displayed in Barajas International Airport Madrid, Spain, and recently opened Kempegowda International Airport, Bengaluru, India. Besides minimizing the pollution and protecting environment, the exploration of bamboo can provide huge employment and opportunities to entrepreneurs which will lift the economy as well as society and which will ultimately lead to a sustainable system.

Keywords Plastic pollution; Sustainability; Bamboo; Ecosystem; Solution

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1. Introduction

'Plastic' a single term including multiple synthetic or semisynthetic polymers, popularised tremendously since 1950s for its advantages in societal health, energy and safety (Schmaltz et al., 2020). Its lightweight, low cost, easy transportability, impermeability, longevity and resistance made it an ideal material for incalculable products which dominated over any other material on Earth (Bodor et al., 2024). However, the boon once thought became the curse of present world, as most types of plastic once produced does not degrades for centuries and its widespread use has led to an epidemic of botched waste around the globe. Plastic manufacturing of across 7800 MMT (million metric tons) has been done in the form of fibres and resins since 1950, which has exponentially grown in past decades which aggregates to around 400 million tons every year. So far, incineration of vaguely 12% and recycling of around 9% of the produced plastics have been done and the rest has either been tossed of in landfills or emancipated into the atmosphere and ocean making the plastic waste ubiquitous (Schmaltz et al., 2020; UNEP, 2023).

Lacking appropriate action, course of plastic trash into aquatic ecosystems are assumed to be multiplied three times from 11 million tonnes in 2016 to approximately 29 million tonnes in 2040 and by 2050 it will overweigh the fish in ocean (World Economic Forum, 2016), and is estimated that annual production of plastic will reach to 1.2 billion tons if not checked (UNEP, 2023). Along with macro-plastic, micro- or nano-plastic is the other polluting threat which comes from personal care goods or in the form of microfibres from synthetic clothing or as a degradation or weathering product of polyethylene sheets (MacLeod et al., 2021).

The non-degradable plastic is proving hazardous for biodiversity by devastating habitat, expediating passage of invasive species across niches, entrapping marine creatures, accumulating in sediments which impacts animals niched in benthos (Kiessling et al., 2015; Lusher et al., 2018; Brandon et al., 2019). Moreover, plastic imparts physical as well as chemical health hazards to marine as well as terrestrial animals. Upon consumption, plastic gives a feeling of pseudo satiation and blocks digestive track of marine animals with original reports of around 690 species being affected (Gall and Thompson, 2015; Ryan et al., 2016), along with a recent analysis listing 914 affected megafaunal species (MacLeod et al., 2021). Certain chemical constituents or additives of plastic are known to be mutagens, reproductive toxins or even carcinogens which can be accumulated biologically up the food chain during consumption at different trophic levels (Wright and Kelly, 2017; Carbery et al., 2018; Schmaltz et al., 2020). The hazardous impact on human wellbeing could be more pronounced as humans

ingest around 39,000 – 52,000 particles of plastic per annum from edible solids and liquids (Cox et al., 2019).

In concern of growing deleterious effects of plastic on ecology, some governments at regional, national as well as international level became responsive in last two decades with more than 25 international policies being established to diminish plastic mediated pollution which include UNEA's (United Nations Environment Assembly) various resolutions, G20 Action Plan on Marine Litter (2017) *etc*. (Karasik et al., 2020; Schmaltz et al., 2020). Govt of India banned certain one-time use plastic products causing huge clutter while having meagre utility and plastic bags less than 120-micron thickness from 2022 vide Plastic Waste Management Amendment Rules, 2021, under Environment (Protection) Act, 1986.

Regardless of the policies at different levels, the growth rate of plastic based pollution is not declining which may accredited to fragmented governance, incomprehensive or weak rules, unregulated consumerism *etc*. (Dauvergne, 2018; DeSombre, 2018). The problem furthest complicated due to widespread dispersal and durability of plastics, uncertain scientific data regarding to volume of plastic waste flowing into the oceans, and the complexities in acclamation of responsible sources of that pollution. In the meantime, the flourishing plastics industry has wieled significant influence, distributing plastic through opaque trading structures and remitting waste to authorities with inadequate waste management exercises (Dauvergne, 2018).

Moreover, the technologies and policies alone are insufficient to tackle the crisis of plastic pollution due to its lifecycle, the pervasiveness of microplastics, implementation and costs of technologies etc. These bottlenecks stress the requirement of collaborative actions at multiple levels, one of which highlights the need for substitution of plastic with some renewable and efficient natural resource.

Bamboo 'The Giant Woody Grass' is one such resource which can play the role of real green material efficiently. It is the fastest growing plant with high yielding capacity; culms mature in 5-6 months after emerging from ground and having tensile strength equivalent to steal; is an integral part of traditional households and low maintenance renewable plant with widespread distribution.

2. Bamboo as a substitute of Plastic

2.1. Bamboo Resource availability

Bamboos are abundantly available for usage as these are spread in diverse territories comprehensively from latitude 46° N to 47° S and altitudinal range from sea level to 4300 m above mean sea level (Judziewics et al., 1999; FAO 2007; 2020). Even though bamboos have

the resilience to endure in various soils and climatic situations, certain environments evident to be more preferential for their vigorous growth, where temperatures are warmer (minimum 15-20° C annually) and precipitation suffice to at least 1000-1500 mm annually to avail ample water and high humidity round the year (Scurlock, 2000; Kleinhenz and Midmore, 2001; Nfornkah et al., 2023). This facilitate their abundance in tropical regions most, but being nearly cosmopolitan, their natural stands grow in all the continents together with subtropical and temperate territories around the globe.

Worldwide, an estimated 1250-1600 species under 75-111 genera were recorded as per different reports (Subramaniam, 1998; Ohranberger, 1999; Maria et al., 2016; Kumar et al., 2023). Continentally, bamboos are mainly aggregated in Africa, South America and Asia, where the latter alone have a bamboo stretch of 24.9 million hectares (m ha) encompassing 4.4% of its total forest cover and 71% to the overall bamboo forest domain worldwide. Of which, India is leading with largest bamboo cover *i.e.* 15.69 m ha consisting around 20% of total forest acreage of country, followed by 5.4 m ha bamboo cover in China which is 3% of its total forest land.

In terms of species diversity, Asia is occupying around 1000 species with predominance in China having a number of 534 species (469 endemic, 3 introduced) under 34 genera (5 endemic, 1 introduced); India accommodates around 125 indigenous and 11 exotic species belonging to 23 genera (Scurlock, 2000; FSI, 2011; Maria et al., 2016; Krishnakumar et al., 2017; ISFR, 2017; FAO, 2007, 2020). Other nations with rich bamboo diversity are Japan, Philippines, Thailand, Bangladesh, Indonesia, Papua New Guinea and Malaysia (Gupta and Choudhary, 2009; Krishnakumar et al., 2017).

2.2. Bamboo as a renewable resource

Bamboo is a durable, adaptable and greatly renewable natural resource known since centuries. One time afforestation of bamboo can be used for procurement incessantly as it proliferates through shoots. Bamboo attains complete maturity in 5 to 7 years after its introduction and its culms can be harvested annually; for many purposes harvesting is started from third year onwards (Tripathi, 2008; Nfornkah, 2023). With onset of rainy season, the underground rhizomatous buds (appear on nodes of rhizome) of bamboos lengthen and grow actively into a compact upright shoot which emerge out of ground through its sharp penetrating tip which produces new culms at high yield annually. The underground stem *i.e.* rhizome contains nodes and internodes which grows few to several meters subterranean containing multiple node,

which sprouts off multiple bamboo shoots every season. Thus, unlike trees, which upon harvesting lead to sacrifice of whole individual, bamboo is renewable, as if few culms are harvested from the clump sustainably, it will give rise to new ones in every season. Moreover, rhizomes and adventitious roots of bamboo can extend up to several kms per ha of the bamboo stand, deepens down to 60 cm and survive for a century (Tardio et al., 2018). This subterranean biomass backs bamboo's survival and regeneration capability to exceptional level when several unfavourable factors, such as fire abolish the biomass aboveground. It can, therefore, revegetate and restore productivity to bare land over a short period compared to any other vegetation (Nfornkah et al., 2023).

2.3. Fastest growing plant

Bamboo is considered amongst the fastest growing vegetation around the globe. Certain species showed growth of 0.88 to 1.21 m in a circadian cycle (Zhou et al., 2005; Banik, 2015). In general, a culm takes two to three months to attain its full height, while culm extension in different species varies between 60 to 135 days as per reports on some Indian and Bangladeshi species (Banik, 2000; Nath and Das, 2012). The speedy elongation of culms illustrates woody bamboo by intercalary extension through a solo "grand period of growth'' (Nath and Sileshi, 2020; Nfornkah et al., 2023). Unlike other plants which have meristematic zones at tips or margins only, bamboo have nodes and internodes and comprises growth zone between nodes along with the tips. Thus, bamboo flourishes concurrently from two points; the apical meristematic zone and the growth zone amid the nodes; though the nodes are fixed in terms of numbers during the budding stage of shoot. For example, if a bamboo species having around 60 nodes in a culm and one growth zone grows by 1 cm, it implies that entire culm elongates by 60 cm. Moreover, along with photosynthetically produced nutrients, bamboos share nutrients through underground rhizome network. In fast growing species like moso bamboo, after 2 to 3 months of elongation of the culm after emergence of bamboo shoot from ground, the growth of culm hinders. Then the underground rhizome starts growing and stores the nutrients for upcoming spring when new bamboo shoots emerge from rhizomatous buds. By facilitating the bamboo shoots to avail stored nutrients in the rhizomes, the culms grow rapidly in the successive spring season (Shima et al., 2023).

2.4. The Structural suitability of bamboo

Bamboos offers suitable material for small- and large-scale construction, furniture making, residential fencing, cottage and handicrafts industry products like mats, basketry, decorative *etc*. Bamboo culms are being utilised in construction as it is in structural components (columns,

pillars, posts, stringers or roof trusses) or in split versions as wall cladding, shingles, cover, weight-bearing component for building towers or bridges *etc*. Craftsmen use bamboo as a natural material to craft semi-finished and finished articles such as beds, chairs, tables, handles of shovels, crop planters, rakes etc. (INBAR,1999; Ingram et al., 2010; Lacerda and Kellermann, 2019; Lee et al., 2021; Nfornkah et al., 2023). Moreover, bamboo culms which are desiccated after felling, are strong as well as easy to process, and remain elastic unlike most woods. It makes harvested bamboos a widely useful material for goods that need flexibility, such as fishing rods, bows *etc*. (Lucas, 2013). With excellent mechanical properties, bamboo is forward compared to steel in terms of tensile strength and have better plasticity compared to plastic in numerous applications (Santosh et al., 2021; Nfornkah et al., 2023). Bamboo is competitive to conventional softwood as well as hardwood materials in terms of both performance and price. It is light, stiff, strong, elastic, pest resistant, anti-combustion and high gloss at the same time, also it is stable than other hardwoods as it does not swell or shrink generally (Tripathi et al., 2009).

The efficient mechanical adaptability of culms of bamboo accredited to balance and harmony between fibres and nodes. A bamboo culm can be regarded a amalgamated material composed of stiff vascular tissue and a soft parenchymatous matrix. Vascular bundles entrenched in the culm engaged as reinforcing fibres against bending forces and provide mechanical support which is analogous to rebar embedded in reinforced concrete (Li and Shen, 2011; Aiping et al., 2012; Dixon et al., 2015; Sato et al., 2017). The rigid fibres, are lined up in the longitudinal course to increase the bowing stiffness of the bamboo culm as a whole to counter crosswinds and bending in response to gravity. The vertical arrangement of fibres tends the culm to tear in the direction of fibre, which makes it easy to work with. On the other hand, splitting of entire culm longitudinally is risked out due to presence of numerous nodes which are irregularly spaced lengthwise and strengthen the bamboo sufficiently to grow as heightened as possible whilst holding its weight down (Shima et al., 2023). Moreover, node in a bamboo culm is characterized by two main attributes; an external ridge and an internal diaphragm extended in hollow cavity. The diaphragm plays as a ring stiffener for the zone proximate to the node as it avoids the crumpling of the culm under exterior pressure thus improving mechanical rigidity of bamboo culm (Liese and Tang, 2015; Shima et al., 2016, 2023).

2.5. Revival of traditional bamboo articles

Bamboo is being used multifariously in our traditional system around the globe with more prominence in Asian countries. There are records dating back more than seven thousand years mentioning bamboo made products like paper, arrows, books and building material (Tripathi et al., 2009). Also, it has been being used conventionally from a mere stitch in a leaf plate (pattal) to domestic tools, agricultural articles, utensils, musical instrument, furniture, bridges, house building, ornamentation, medicine etc. (Sudchaleaw et al., 2023).

The bridges made up using bamboos could be simpler which were made by just putting few culms across a stream, or complex truss bridges and suspension bridges that use bamboo as rope. Some of the ancient boats were bamboo-based rafts. A basket like boat was used in Japan for fishing which was weaved by using split bamboos, while plaited bamboos were used for boats in Vietnam. In old Polynesia, bamboo was used for building large catamarans, mast, rails, shelter, floor and for containers to store fresh water. Bamboos are also used for conventional fencing which were purposed for decoration, privacy, rail guard, livestock raring *etc*. (Tripathi et al., 2009).

Bamboos are also used in construction of floors, walls, and roofs and to create trellises for climber like commercial and ornamental plants (Tamang et al., 2014). Different sized baskets which are still in use are *Chhaku, Chabri, karndu, Dall, Kilta, Khara*, (Fig. 1) are used for diverse purposes like keeping *roti* (Indian bread), carrying vegetables or cow dung or to keep wheat straw for cattle; hand fan '*pakkha',* ladder '*maanj',* protecting fences for young trees '*kirnu',* winnowing tray 'chhajj' (Fig. 2) large drying tray '*changer',* mat '*moste* or *bishal'* hat '*topi'* round basket like carrier to keep sleeping infants '*choura/jhuger'* large boxes '*gadun'* (Upreti and Sundriyal, 2001; Sundriyal and Joshi, 2015) were also a part of common Indian households. Alongside, bamboo is a common wood substitute in scaffolding during house constructions.

Many of these traditional items made of bamboo are being rapidly replaced by plastic and related material now a days. Revival of these hundreds of bamboo products can reduce the load of plastic on Earth.

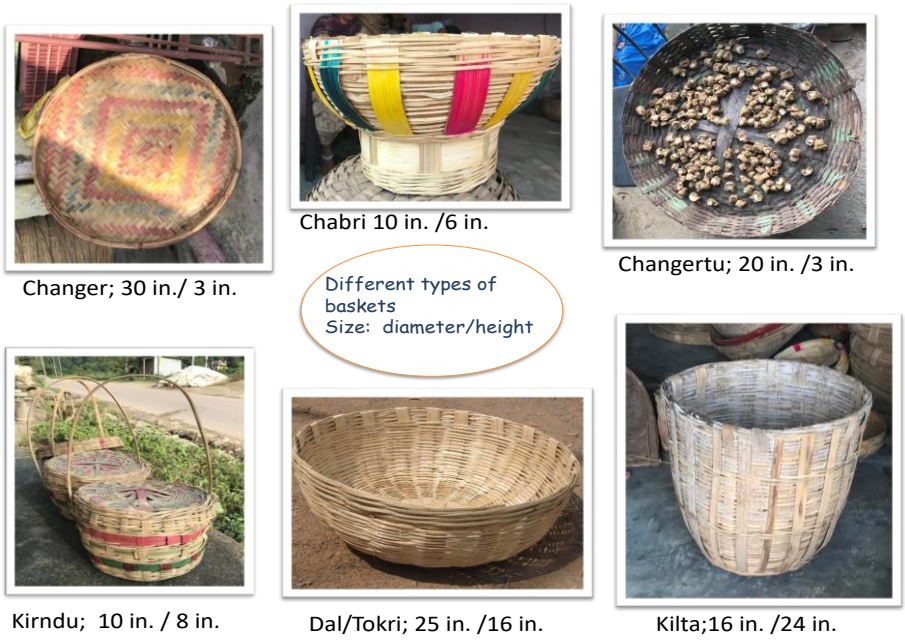

Fig. 1. Different types of baskets used traditionally in Indian system

Fig. 2. Traditional bamboo products A) Individual Plant protecting fence '*kirnu*' B) & C) agricultural supports C) vegetable carrier D) bamboo hut E) roof support F) hand fan and flute G) winnowing tray H) Ladder

2.6. Bamboo as a preferential substitute in modern world

Alongside being the backbone of rural life since ages, potential of bamboo is recognized all around globe in current ages too. Expansion of green markets proposes novel opportunities for bamboo products industry while generating rural employment and suppressing plastic supremacy at the same time. Bamboo have made dominant place in some contemporary industries over or along with plastic such as tooth picks, chopsticks, incense sticks, ice-cream sticks, rulers, kites, firecrackers *etc*. from bamboo splints.

Nevertheless, the potential of commercializing and establishing bamboo as a green substitute is immeasurable and can be explored to a wider extent. Bamboo blinds can be introduced in place of venetian blinds which are made up of synthetic constituents, with expanding markets and offices in urban areas it makes a market of 300 million yearly. Bamboo is also considered as a preferable material for bedspreads particularly in summers as they are cooler. The usual wooden pencils are being replaced by complete or partial plastic body pencils with lead refill due to short availability of wood, if the pencil industry takes up bamboo as a wood substitute it can raise a market of approximately Rs. 50 million (Anon, 2003; Tripathi, 2008).

Bamboo has been a time tested, affordable, abundant and considered valuable for constructing houses which continued to be cherished in the modern era too for its sound structural ability and aesthetics. In modern form, bamboo can replace steel, cement and plastic for construction requirements while applying sophisticated design expertise and availing improved composite techniques which involves: Support structures like roof trusses, columns, purloins, scaffolding, rafts etc. for shelters; bamboo mat corrugated sheets for roofing and mat boards for doors and window shutters; bamboo grid with cement mortar plaster for walls; bamboo composite laminates as window and door frames, flooring tiles etc. (Tripathi, 2008; Moran et al., 2019; Madhushan et al., 2023). Composites of glass fiber reinforced plastics (FRP) is among the most trending materials now a days, using natural resources like bamboo fiber for developing such material will be eco-friendly as well as high quality as bamboo fiber can be easily altered to be better abrasion resistant, microbe resistant, size stable, heat conductive, water proof and fire proof using different physicochemical methods (Tripathi et al., 2009).

Moreover, the versatility of bamboo is making it a desirable material over synthetic polymers for creating executive designs to lend ethnic touch to furniture and interiors of houses, workplaces to even international structures like ones displayed in Barajas International Airport Madrid, Spain, and recently opened Kempegowda International Airport, Bengaluru, India. This

woody as well as flexible grass, fits perfectly in with the sparseness of modern unfussiness and even with opulent interiors. Furniture manufactured with weaved bamboo with renewed interests is gaining much demand over the plastic ones accredited to its natural grace and portability, and specially used to liven up balconies, verandas and terraces in modern houses (Tripathi et al., 2009).

The application of bamboo has spread to another level such as computer Bamboo laptop designed for Asus Ecobook or BoxWave's case for the iPhone to follow the current market trends to satisfy ‘hyper consumers’, the term used for extremely selective consumers. Another remarkable invention by French Company Roof is the manufacturing of motorcycle helmets with bamboo fiber hull, passing successfully the safety necessities by the Standard E22-05, certification requisite for marketing in Europe (Chele et al., 2012).

Another greener impact that bamboo making is in textile industry. As the fashion world is growing at the fastest rate and looking for newer and sustainable fabric options, bamboo fiber is among the top favorites. The fabric opted from bamboo fibers said to be soft like cashmere and fluid like rayon or silk which prompts designers to taking up it as a substitute of silk. It has a light and soft texture, is cool and with special manufacturing procedures a wonderfully absorbent and breathable fabric is obtained from bamboo fiber entirely. A vast range of products has been launched and retailed in markets including, t-shirts, tops, underclothing, stockings, towels, sweaters, beddings, blankets, mats, foot mats *etc*. (Tripathi et al., 2009; Chele et. al., 2012; Jais et al., 2023). Bamboo fabric and fiber is also used to make diapers for babies and sanitary pads for menstruating women, which reduces a lot of plastic and other nonbiodegradable waste as bamboo fabric is biodegradable.

Moreover, main impact can be drawn using bamboo when replacing certain day to day use plastic products such as personal care amenities *e.g*., plastic toothbrush, which is one of the largest sources of plastic pollution around the world. A toothbrush has a life of 3-4 months; thus, a person uses 3-4 brushes annually which are eventually discarded. With around 8 billion world population, if we consider even half the population uses conventional plastic toothbrushes, millions of tons of plastic trash are generated every year which is remaining as it is on some part of earth for centuries. A very efficient substitute of this is ‘bamboo toothbrush’ which comprised of a bamboo handle and bamboo fibre mixed bristles, 90% of which is biodegradable and get decomposed within 6 months like any other wood. Likewise other products such as bamboo tongue cleaner, bamboo combs, hair brushes, shaving brushes,

water bottles *etc*. (Figure 3) are making place in markets along with substituting single use plastic items which has been banned by certain governments including Govt. of India since 2022, like straws, cotton buds, single use cutlery, bamboo-based substitutes are available for these.

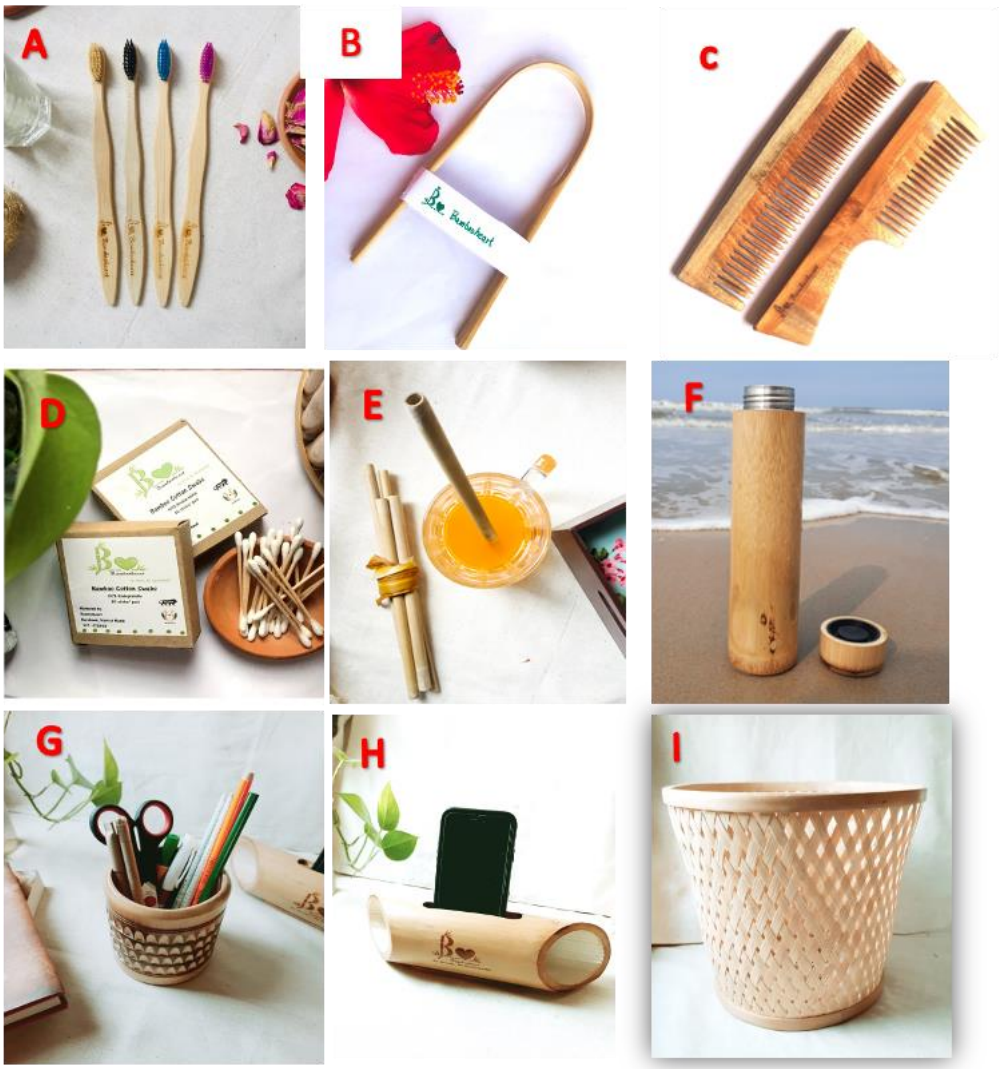

Fig. 3. Various new world daily usage bamboo products A) Toothbrush B) Tongue cleaner C) Combs D) Cotton earbuds E) Straws F) Water bottle G) Stationary stand E) Sound amplifier F) Planter

Even with available options of sustainable substitutes of plastic, it is very challenging to replace the mainstream plastic items, as people are habitual of them and think them as fashionable especially in rural and sub-urban areas. Alongside, lack of awareness about harmful impacts of plastic and benefits of traditional sustainable products is another reason of hinderance in replacing them. Lack of availability of eco-friendly products in common markets, and if

available, their cost comparison with plastic ones (as the latter is cheap) makes customer unwilling to opt them. In case of bamboo, the communities and artisans that used to work on bamboo products were involved in manufacturing and distribution of bamboo articles door to door which made them easily accessible in rural households, but with changing time, as the plastic revolutionised the markets, the demand of these products declined, which lead to discouragement for traditional manufacturers. Which further lead to not passing the crafting knowledge to their future generation as it was not enough to fulfil their financial needs and the culture of white-collar jobs was more appealing rather than to be a typical craftsman.

Nonetheless, many schemes and Missions at state, national and international level are being implied to revive the bamboo culture like National Bamboo Mission by Govt. of India, which promotes bamboo plantation and provides training of bamboo crafting in different parts of country to revive the bamboo culture and uplift communities' socio-economically. Moreover, many small- and large-scale enterprises are emerging since the last decade which are working on bamboo based sustainable products along with spreading awareness regarding sustainability. Along with physical methods, use of social media and digital marketing, which are the most impactful modus to reach people in this era of digitalisation can be exploited by knowledgeable and aware population/ social entrepreneurs/ Govt. and Non Govt. organisation to educate and convince people to switch to greener consumerism and sustainable lifestyle.

Conclusion

The revival of traditional ways and implying innovation offers great versatility to the application of bamboo, which can add to its contribution in the area of social design, posit it at an alternative efficient substitution for plastic along with other superior qualities that place it in an advantageous position. Awareness and education regarding harms of plastic and benefits of bamboo through conventional and modern modes can lead to more acceptability of green products by consumers. Besides reducing the pollution and protecting environment, the investigation and exploration of bamboo has a potential to generate immense employment and openings to rural population as well as entrepreneurs which will support the socioeconomic structure that ultimately led to a sustainable system.

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Conflict of Interest

The authors declare there is no conflict of interest

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