S.B. Biological and Agricultural Sciences
Vol.1, No.1, January-June 2025: P.35-42
Original Article
Available online at www.bpaspublications.com

Sustainable Development by using Bamboo (*Bambusa vulgaris*)

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How to cite this article: Majumder D., Rani A., Singh N., Singh C., Kanwal A., and Singh R. (2025). Sustainable Development by using Bamboo (*Bambusa vulgaris*). *S.B. Biological and Agricultural Sciences,* 1(1), 35-42.

ABSTRACT
Bamboo belongs to the evergreen or Poaceae family of grasses. It's the world's fastest-growing woody plant. Bamboo is a sturdy, adaptable, environmentally beneficial, and renewable material. The livelihood of millions of people is reliant on this plant. It has been used for eating and cooking for a very long time. Bamboo offers a wide range of new applications outside of its conventional functions, such as replacing costly materials and quickly diminishing wood. In my native state of Tripura, bamboo is a common sight in daily life. Bamboo is used in almost every home for décor, furniture, tables, and even accessories like bottles and cooking. Indeed, as intriguing as this may sound, using bamboo and bamboo products on a daily basis is rather common among the inhabitants of Tripura and the northeast India. We have forgotten our old roots, when we used to use a lot of natural items like bamboo, in this day of chemicals and dangerous pollutants like plastic. Bamboo buildings are inexpensive, lightweight, and resistant to earthquakes. As an excellent substitute for doing water purification, a natural filter constructed of bamboo, pebbles, gravel, and other readily available natural adsorbents found locally is a good alternative for plastic filters. Minerals including potassium, calcium, magnesium, and others are abundant in bamboo charcoal. Bamboo filters, in contrast to contemporary charcoal filters, have the extra advantage of an internal microbial community that breaks down harmful compounds like trihalomethane and chlorine. Toxins are so naturally removed from water. This study is entirely devoted to the advantages and applications of bamboo in day-to-day living. "Go bamboo, go green!"

KEYWORDS: *Bamboo, Renewable, Buildings, Furniture, Inexpensive, Minerals, Charcoal Filters.*

1. INTRODUCTION

Bamboo is a member of the grass family. The bamboo are classified according to their type, species and variety. There are over 1200 types of bamboo worldwide and identification is done according to its flower. In China, bamboo is referred to as "friend of the people," in Vietnam as "brother," and in India as

Received on 25.10.2024/ Revised on 13.01.2025/ Accepted on 05.02.2025
Online First Published on Feb 15, 2025 at https://bpaspublications.com/

the "wood of the poor." Wide stretches of Africa, Asia, the Caribbean, and Latin America are home to the amazing plant known as bamboo.

The experts agree on the following taxonomy of how bamboo is classified. These facts are from the American Bamboo Society's findings.

Kingdom: *Plantae*

Phylum: *Magnoliophyta*

Class: *Liliopsida*

Subclass: *Commelinidae*

Order: *Cyperales*

Family: *Gramineae (Poaceae)*

Subfamily: *Bambusoideae*

Tribe: *Bambuseae*

Subtribe *Bambusinae*

The properties that make bamboo a sustainable product are discussed further (Fig. 1).

Figure 1: The habit of bamboo.

1.1 Sustainability

As a renewable resource, bamboo plants are abundant in practically every part of the world and are important for socioeconomic development (Kumar et al., 2021a). Bamboo's quick growth and capacity to regrow after harvesting are the main reasons it is regarded as a renewable resource. Compared to

traditional timber forestry, bamboo growing uses less resources. In addition, bamboo is a renewable resource for the textile industry due to its antibacterial properties, environmentally benign fibre extraction process, and wide range of textile applications (Kozłowski and Mackiewicz-Talarczyk, 2020).

1.2. Minimal effects on the environment

Compared to crops like cotton that require a lot of water, major species of bamboo require less water to cultivate. Furthermore, bamboo frequently grows well without the use of fertilizers and pesticides, lessening the negative environmental effects of chemical use in agriculture. Bamboo does not harm its surroundings when it is chopped and regrown. It regenerates itself without requiring replanting (Gupta and Kumar, 2008). Studies by Restrepo and Becerra (2016) and Bahari and Krause (2016) show, how using bamboo in manufacturing processes might lessen their negative effects on the environment. According to the research, bamboo can considerably reduce carbon footprint and be used as a sustainable substitute for conventional materials like wood-polymer composites. Furthermore, Agyekum et al. (2017) discovered that bicycle frames made of bamboo had a lower environmental impact in comparison to frames made of steel and aluminium, demonstrating the advantages of using bamboo in a variety of industries to produce cleaner, greener goods.

1.3. Reducing global warming and sequestering carbon footprint

Bamboo grows extremely quickly and has a significant ability to absorb carbon dioxide. Unlike other forests, which turn into carbon sources during periods of inactivity, bamboo acts as a carbon sink and helps mitigate climate change year-round. The capacity of different bamboo species to fix carbon has been assessed by numerous international research employing particular criteria. For instance, Tang et al. (2016) discovered that some bamboo species (*Dendrocalamus giganteus*) may have a carbon sequestration rate (CSR) of up to 70.11 tCO_2/ha/yr. According to a different study, a 60-year-managed Moso bamboo forest should sequester 18.69 tCO_2/ha/yr, whereas a younger *Moso bamboo* forest were calculated to have annual carbon accumulation rates between 4.77 and 8.43 tCO_2/ha (Chaowana et al., 2021, Pan et al., 2023).

1.4. Less use of water

Bamboo is a water-conscious plant, especially in areas where water is scarce, due to its reduced water requirements for growth. Bamboo doesn't require as much water as cotton requires to grow. Rarely does it require further watering; 500 litres of water are sufficient to produce 1 kilogram of biomass. (Mishra and Nayak, 2016).

1.5. Sustainable and preservation of biodiversity

Since bamboo fibre is derived from plants, it decomposes naturally in the soil with the aid of microbes and sunshine. Bamboo clothing can be composted and disposed of in an eco-friendly manner. Bamboo forests encourage biodiversity through offering a range of species' habitats. Diverse ecosystems are maintained through the use of sustainable bamboo cultivation techniques (Kumar et al., 2021b). Because of their large root system, connected rhizome bamboos are frequently considered a feasible solution for improving soil qualities in a comparatively short amount of time. But it's important to remember that most of these claims are supported only by anecdotal evidence. Nonetheless, several scholars have attempted to use data analysis to verify these claims. According to Maddalwar et al. (2024), bamboo's deep roots aid in stabilizing the soil by reducing erosion.

2.1 Bamboo fibre's physical and dimensional characteristics

Bamboo fibre is different from other bast fibres like ramie and jute in that it is shorter and finer, having been extracted mechanically. The extraction process determines the dimensional parameter. The length of mechanically extracted bamboo fibre varies from 5 mm to 5 cm, with an average of 22.8 mm and 150 µm for length and diameter, respectively. Less than 12.5 mm in length is not used in the production of yarn.

Usually, these fibres are found in bundles made up of ten to twenty separate fibres. Their short length makes it difficult to spin and weave them into cloth. As such, they are frequently used as technical fibres in the creation of nonwoven fabrics. Fibre from chemically treated regenerated bamboo can have a predetermined diameter and a lengthy length (Akinlab et al., 2017).

Bamboo fibres have a small round lumen in a circular cross-section and a rough surface. 36–41% cellulose, 22–26% lignin, and 16–21% pectin make up the content of bamboo fibres (Malekzadeh et al., 2021). Conversely, bamboo viscose has different characteristics and comes from a chemical extraction method. It belongs to the cellulose II class, which is distinguished by excellent water retention and release ability and low crystallinity. Filaments, or long, continuous strands of material that can be cut to the appropriate staple length, are one way that bamboo viscose is found (Maiti et al. 2022). The packing density of the yarn and, in turn, the mechanical behaviour of fabrics under low temperatures are affected by variations in the cross-sectional form of bamboo viscose fibres.

Bamboo viscose fibre's cross-section has been shown to be asymmetrical and toothed, suggesting that it shares longitudinal and cross-sectional morphology with conventional viscose rayon fibre. Furthermore, a good capacity for water retention is shown by the numerous gaps in the cross-section and the striated cracks running the length of the bamboo viscose fibres (Liu et al., 2012).

2.2. Mechanical characteristics of Bamboo

Bamboo fibre's tensile strength, flexural strength, tensile load, elasticity, and moulding capacity are some of the factors that affect how long it lasts. Fabric composed of mechanically extracted bamboo fibre has better resilience to pilling and abrasion in both wet and dry environments than flax and jute (Li et al., 2019). Natural bamboo fibres exhibit reduced when compared to cotton fabrics, natural bamboo fibres exhibit reduced shrinkage, enhanced dye sorption, improved colour clarity, increased wrinkle resistance, and improved lustre without mercerization. The characteristics of viscose rayon, cotton, and modal fibres were contrasted with those of bamboo viscose fibres by Shao et al. (2018). According to their research, the dry tenacity, elongation at break, and moisture absorption characteristics of viscose rayon and bamboo viscose are comparable. On the other hand, bamboo viscose had a marginally higher wet tenacity than viscose rayon. In both dry and wet conditions, bamboo viscose exhibited less tenacity than cotton and modal fibres. Bamboo fibre can be combined with many textile fibres, including cotton, hemp, modal, lyocell, and others, providing a wide range of applications (Mousavi et al., 2022). As a consequence, a variety of fabrics As a result, the qualities of the fabric vary greatly. When compared to cotton and the blends of cotton and bamboo viscose, bamboo viscose fabric exhibits superior tensile extensibility (Jais et al., 2023). However, studies on the intrinsic strength characteristics of bamboo fibres and cotton-bamboo blends have shown that these materials exhibit exceptional tensile strength. This result validates bamboo fibres' ability to improve fabric mixes' overall tensile performance. This indicates decreased hand values and decreased comfort in cotton-containing fabrics, underscoring the significance of taking material interactions into account when blending materials. Additionally, because cotton fabric naturally has a higher degree of stiffness and a bigger diameter of constituent yarn, compared to bamboo viscose and viscose rayon yarns, the overall bending rigidity of cotton fabric was higher because of its inherent stiffness and bigger diameter of constituent yarn. In comparison to cotton fabric, viscose rayon and bamboo viscose fabrics were found to have higher total hand values, which represent the entire feel and texture of the fabric (Kaur et al., 2016).

2.3. Heat and moisture management characteristics of Bamboo

Natural bamboo fibre fabrics include hollow cross sections that let air circulate, making them cool and comfortable to wear. Nonetheless, the uneven length of these fibres makes it challenging to manufacture yarn and fabric. Therefore, the majority of the fibre used to produce the fabrics is chemically removed (Zhao et al., 2024). These textiles can also regulate moisture to a moderate extent. According to Basit et al. (2018), the fibre's superior wicking capacity is attributed to the micro-gaps and micro-holes that it contains. These features efficiently remove moisture from the skin and promote rapid evaporation, which

produces a cooling effect. In addition, the abundance of microcracks and grooves on the fibre surface improves the fabrics' ability to regulate moisture and breathe, outperforming that of cotton and hemp. In addition, these textiles are highly hygroscopic, meaning that the fibres can absorb three times their weight in water, which facilitates dyeing and finishing (Kushwaha et al., 2024). Numerous of the plant's natural characteristics are still present in the fibre that is obtained from bamboo by mechanical extraction.

It should be mentioned, nonetheless, that even under standard washing circumstances, these materials' washing fastness is inadequate. In spite of this disadvantage, bamboo fibre has a lot going for it in terms of comfort, aesthetics, and processing benefits like permeability, softness, pleasant tactile sensation, moisture absorption, and great dye-ability (Malekzadeh et al., 2021). Furthermore, research on the thermal characteristics of bamboo fibre has shown textiles with improved thermal conductivity and possible advantages for heat dissipation. Because of its special qualities, bamboo fibre has consequently become quite popular in the textile industry and is frequently used in the manufacturing of yarn and fabric (Oner, 2019).

2.4. Antimicrobial characteristics of Bamboo

This is because the plant has a built-in defence against microorganisms termed "bamboo-kun," or 2.6-bimethoxy-p-benzoquinone, a bacteriostasis bio-agent. Furthermore, bamboo contains the protein dendrocin, which has a very unique resistance to fungi (Afrin et al., 2012). These advantageous compounds are firmly attached to the cellulose molecule found in bamboo, which enables them to endure mechanical processing. Because of this, bamboo fabric comprised of these bamboo fibres successfully gets rid of mildew and bacteria, in contrast to other cellulosic textiles that encourage their growth, which can cause unpleasant odours and even fibre damage. This characteristic explains bamboo's traditional therapeutic (anti-oxidant) applications in Chinese medicine (Prakash et al., 2021).

2.5. Protection from UV

The natural ability of bamboo fibre to offer protection is well known. Numerous studies have demonstrated that natural bamboo fibre has a remarkable UVPF, which is a significant increase over ramie and viscose (Hatua et al., 2013). Furthermore, research has shown that bamboo fabric is more effective in absorbing UV light than other fabrics like cotton and flax because it has a lower reflectance than those other materials. Bamboo fibre is remarkable because it contains sodium copper chlorophyllin, which has a UV absorption capability twenty times more than that of cotton fibre. Furthermore, a key factor in preventing UV radiation is the density of the bamboo fibres. The densely packed structure of bamboo fibres reduces the entry of harmful UV rays by forming a strong barrier (Teli and Sheikh, 2014).

2.6. Organic bamboo's ecological values

Virgin bamboo, or organic bamboo cloth, has the amazing property of completely decomposing in soil without emitting any dangerous pollutants like methane. This natural fibre, which comes from bamboo, is praised for being a sustainable and eco-friendly textile material for the contemporary day. As such, clothing made entirely of bamboo has negligible environmental effect. Bamboo clothing can be composted biologically, in contrast to synthetic fibres that remain in landfills for a long time (Plakantonaki et al., 2023).

2.7. Eco values of organic bamboo

Since bamboo grows quickly and is a naturally renewable resource, it may provide very good long-term solutions for lowering carbon emissions, particularly in densely populated areas of the world where bamboo is found. Organic bamboo fabric, also known as virgin bamboo, possesses the remarkable quality of being fully biodegradable in soil without releasing harmful pollutants such as methane. This natural fibre, derived from bamboo, is celebrated as a sustainable and environmentally friendly textile material

for the modern era. Consequently, garments crafted from pure bamboo have an insignificant impact on the environment. Unlike synthetic fibres, which persist in landfills for extended periods, bamboo clothing can be composted organically (Plakantonaki et al., 2023).

3. CHALLENGES AND AMBIGUITIES OF BAMBOO AND BAMBOO FIBRES

As a fast-growing natural renewable material, bamboo could offer excellent sustainable solutions to reducing the carbon footprint, especially in highly populated regions in the world where bamboo is available in abundance. In addition to encroaching on native forest regions and reducing biodiversity, *Moso bamboo* forests can alter the characteristics of the nearby soil. It was shown in China that evergreen broadleaf forests were more susceptible to the invasion of Moso bamboo than coniferous and deciduous broadleaf forests. They discovered that Moso bamboo had certain edaphic preferences and flourished in warm, humid, and sunny regions; on slopes between 15° and 30° with aspects to the south, southeast, and east, more than 70% of the biomass and expansion took place. According to maps of remote sensing cover, Moso bamboo also frequently colonizes regions along riversides.

Bamboo's unique life history has garnered attention from all over the world. Although bamboo is a perennial flowering plant, several species of the plant spend decades or even a huge simultaneous flowering and death that occurs after a century, or even longer (Rao et al., 2024). Some bamboo species undergo "gregarious flowering," or mass blossoming, which upsets the plant's life cycle and causes significant ecological effects. Deaths of bamboo plants result in exposed soil and environmental harm as a result of the aftermath. An imbalance in the environment results from the disturbance of communities that depend on bamboo for food and materials. Because of the estrogen in bamboo seeds, the phenomena attract rats, especially Rattus, which accelerates their population increase. This increase causes problems like the rat invasion, the depletion of bamboo resources, and the ensuing famine. As a result, the flowering of bamboo affects those whose livelihoods depend on bamboo resources negatively and may cause famine among farmers who are self-sufficient (Gopan et al., 2024). As an instance, in 2009 in Arunachal Pradesh, India, *Bambusa balcooa* Roxb., *B. tulda* Roxb., *Dendrocalamus hamiltonii* Nees & Arn. ex Munro, and *Stapletonia arunachalensis* (H.B.Naithani) P. Singh, S.S. Dash & P. Kumari all blossomed. Following that, rat epidemics in the flowering region were documented, resulting in significant harm to numerous crops (Kumawat et al., 2014). To give a fair and educated assessment of the total environmental effects of bamboo growth and use, it is crucial to recognize both the advantages and any potential ecological disadvantages.

It's important to keep in mind that purchasing bamboo fabric—especially sustainable bamboo as opposed to bamboo rayon—usually costs more than cotton. Although bamboo is grown and harvested ethically, most bamboo clothing is produced through a chemically intensive process referred to as viscose to produce bamboo rayon. This process uses carbon disulfide as a solvent, which is a dangerous substance that has been linked to dangers to human fertility. Because of air emissions and wastewater discharge, its usage in manufacturing may pose a health risk to industrial workers and pollute the environment. Much study is still needed on the mechanical extraction of bamboo fibre, despite the fact that it is employed in composite and technical textiles (Nayak and Mishra, 2016).

4. CONCLUSION

Because of its distinctive qualities and sustainability, bamboo apparel is becoming more and more popular. Compared to chemically regenerated bamboo fibre, mechanical extraction of bamboo fibre is becoming a more environmentally benign method. Because of these misleading statements, questions about certifications and label integrity are starting to matter when it comes to bamboo fibre. Bamboo fibre is very promising for a variety of textile applications since it has antibacterial qualities and UV protection. Bamboo and its fibres have many positive environmental effects, but it's important to understand the ecological risks that come with its quick and vigorous development.

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