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Sustainable Development by using Bamboo (*Bambusa vulgaris*)

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Abstract
Bamboo is a member of the Poaceae, or evergreen, family of grasses. It is the woody plant that grows the fastest in the world. Bamboo is a durable, versatile, eco-friendly, and renewable material. Millions of people depend on this plant for their livelihood. It has traditionally been used for both cooking and eating. Beyond its traditional uses, bamboo has many new uses, including the replacement of expensive materials and the rapid decomposition of 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!"

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INTRODUCTION

Bamboo belongs to the family of grasses. Bamboo is categorized based on its species, type, and variety. Bamboo comes in more than 1200 varieties worldwide, and they are all identified by their flowers. In Vietnam, bamboo is called "brother," in China, "friend of the people," and in India, "wood of the poor." Bamboo is an incredible plant that grows throughout most of Africa, Asia, the Caribbean, and Latin America.

The following taxonomy for bamboo classification is accepted by the experts. These details come from research conducted by the American Bamboo Society.

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.

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).

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. Additionally, bamboo usually grows effectively without the use of pesticides and fertilizers, reducing the adverse environmental effects of agricultural chemical use. When bamboo is cut and regrown, it doesn't damage the environment. It doesn't need to be replanted because it grows back on its own (Gupta and Kumar, 2008). Research by Bahari and Krause (2016) and Restrepo and Becerra (2016) demonstrates how incorporating bamboo into production processes may mitigate their adverse environmental impacts. According to the study, bamboo can be utilized as a sustainable alternative to traditional materials like wood-polymer composites and significantly lower carbon footprints. 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.

Reducing global warming and sequestering carbon footprint

Bamboo has a considerable capacity to absorb carbon dioxide and grows quite quickly. Bamboo is a year-round carbon sink that helps slow down climate change, in contrast to other forests that become carbon sources while they are dormant. 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).

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).

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. Clothing made of bamboo can be disposed of environmentally by composting. Bamboo forests support biodiversity by providing habitat for a variety of species. Sustainable bamboo production methods help to preserve diverse ecosystems (Kumar et al., 2021b). Connected rhizome bamboos are often thought of as a practical way to improve soil conditions in a relatively short period of time due to their extensive root system. It's crucial to keep in mind, though, that the majority of these assertions are based solely on anecdotal data. 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.

BAMBOO FIBRE'S PHYSICAL AND DIMENSIONAL CHARACTERISTICS

Because bamboo fiber is mechanically harvested, it is shorter and finer than other bast fibers like ramie and jute. The dimensional parameter is determined by the extraction process. Mechanically removed bamboo fiber ranges in length from 5 mm to 5 cm, with an average diameter of 150 µm and length of 22.8 mm. 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). Variations in the cross-sectional form of bamboo viscose fibers impact the yarn's packing density and, consequently, the mechanical behavior of fabrics at low temperatures.

It has been demonstrated that the cross-section of bamboo viscose fiber is toothed and asymmetrical, indicating that it shares longitudinal and cross-sectional morphology with traditional viscose rayon fiber. 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).

Mechanical characteristics of Bamboo

The durability of bamboo fiber depends on a number of characteristics, including its tensile strength, flexural strength, tensile load, elasticity, and molding capability. Compared to flax and jute, fabric made from mechanically extracted bamboo fiber is more resilient to pilling and abrasion in both wet and dry conditions (Li et al., 2019). When compared to cotton fabrics, natural bamboo fibers show higher color clarity, increased wrinkle resistance, improved luster without mercerization, decreased shrinkage, and enhanced dye sorption. Shao et al. (2018) compared the properties of bamboo viscose fibers with those of viscose rayon, cotton, and modal fibers. Their findings indicate that viscose rayon and bamboo viscose have similar dry tenacity, elongation at break, and moisture absorption properties. Conversely, viscose rayon showed a slightly lower wet tenacity than bamboo viscose. Bamboo viscose was less resilient than cotton and modal fibers in both dry and wet circumstances. Numerous textile fibers, such as cotton, hemp, modal, lyocell, and others, can be mixed with bamboo fiber to provide a variety of uses (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. Furthermore, the overall bending rigidity of cotton fabric was higher due to its inherent stiffness and larger diameter of constituent yarn since it has a higher degree of stiffness and a larger diameter of constituent yarn than viscose rayon and bamboo yarns. Total hand values, which reflect the fabric's overall feel and texture, were found to be greater in viscose rayon and bamboo viscose fabrics than in cotton (Kaur et al., 2016).

Heat and moisture management characteristics of Bamboo

Fabrics made of natural bamboo fiber include hollow cross sections that allow air to flow, which keeps them cool and comfortable to wear. However, it is difficult to form yarn and fabric from these fibers due to their unequal length. 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. Bamboo fiber has many advantages over other materials, including permeability, softness, a pleasant tactile sense, moisture absorption, and excellent dye-ability, notwithstanding this drawback (Malekzadeh et al., 2021). Additionally, studies on bamboo fiber's thermal properties have produced textiles with enhanced thermal conductivity and potential benefits for heat dissipation. Bamboo fiber has gained a lot of popularity in the textile sector due to its unique properties, and it is widely used to make yarn and fabric (Oner, 2019).

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. Additionally, dendrocin, a protein found in bamboo, has a particularly special resistance to fungus (Afrin et al., 2012). Because these beneficial substances are tightly bonded to bamboo's cellulose molecule, they can withstand 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).

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 fiber is unique because it contains sodium copper chlorophyllin, which is 20 times more effective at absorbing UV rays than cotton fiber. Furthermore, the density of the bamboo fibers plays a crucial role in blocking UV rays. Bamboo fibers' closely packed structure creates a powerful barrier that blocks the entry of damaging UV rays (Teli and Sheikh, 2014).

Organic bamboo's ecological values

Virgin bamboo, also known as organic bamboo cloth, has the remarkable ability to decompose entirely in soil without releasing any harmful pollutants, such as methane. Bamboo is the source of this natural fiber, which is hailed as an eco-friendly and sustainable textile resource for the modern era. Therefore, the environmental impact of clothing made entirely of bamboo is minimal. Unlike synthetic fibers that end up in landfills for a long time, bamboo clothing can be composted biologically (Plakantonaki et al., 2023).

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. Virgin bamboo, sometimes referred to as organic bamboo cloth, has the exceptional property of completely biodegrading in soil without emitting toxic pollutants like methane. This organic fiber, which comes from bamboo, is hailed as a sustainable and eco-friendly textile material for the contemporary age. The environmental impact of clothing made from pure bamboo is therefore negligible. Bamboo clothing may be decomposed naturally, in contrast to synthetic fibers that remain in landfills for a long time (Plakantonaki et al., 2023).

BAMBOO AND BAMBOO FIBRES: DIFFICULTIES AND AMBIGUITIES

Bamboo is a rapidly growing natural renewable material that may provide great sustainable solutions for lowering carbon emissions, particularly in densely populated areas of the world where bamboo is widely available. In addition to encroaching on native forest regions and reducing biodiversity, *Moso bamboo* forests can alter the characteristics of the nearby soil. In China, it was demonstrated that coniferous and deciduous broadleaf forests were less vulnerable to Moso bamboo invasion than evergreen broadleaf forests. More than 70% of the biomass and expansion occurred on slopes between 15° and 30° with aspects to the south, southeast, and east. They found that Moso bamboo had specific edaphic preferences and thrived in warm, humid, and sunny areas. 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. Rats, particularly Rattus, are drawn to bamboo seeds because of the estrogen they contain, which speeds up the growth of their population. Issues like the rat invasion, the depletion of bamboo supplies, and the resulting hunger are brought on by this growth. Therefore, the flowering of bamboo has a detrimental impact on individuals whose livelihoods rely on bamboo resources and can lead to famine among self-sufficient farmers (Gopan et al., 2024). For example, *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 flourished in 2009 in Arunachal Pradesh, India. Rat outbreaks in the flowering area were then reported, causing serious damage to many 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. The majority of bamboo apparel is made using a chemically demanding technique called viscose to create bamboo rayon, despite the fact that bamboo is ethically cultivated and harvested. 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. Although bamboo fiber is used in technical and composite textiles, much research is still required on its mechanical extraction (Nayak and Mishra, 2016).

CONCLUSION

Because of its distinctive qualities and sustainability, bamboo apparel is becoming more and more popular. Mechanical extraction of bamboo fiber is increasingly a more environmentally friendly process than chemically regenerated bamboo fiber. 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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