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Bamboo Shoots: A sustainable delicacy with environmental benefits: A mini review

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Abstract
The multidimensional function of bamboo as a resilient wonder plant is examined in this review paper, along with its significance in resolving urgent environmental and socioeconomic issues. Introduced is the idea of sustainability and its application to the future, emphasising the necessity of sustainable practises. This paper explores bamboo's significance in soil conservation and erosion avoidance, its ability to store carbon, and its involvement in promoting biodiversity and ecosystem preservation. Sustainable farming methods are explored, along with bamboo's quick development, regenerative qualities, and ethical sourcing. With a focus on bamboo's potential for sustainable development, the economic applications of bamboo are investigated, including those in construction, textiles, agriculture, and renewable energy. Additionally, the benefits of bamboo for reducing poverty, promoting rural development, and creating jobs are examined, with successful case studies of businesses based on bamboo. The overview continues with a discussion of current research and technological developments in bamboo processing, new uses for bioplastics and 3D printing, and the promise of bamboo in green infrastructure and sustainable urban development.

Keywords: Bamboo, bamboo shoots, sustainability, poverty, environmental benefits, future potential

Introduction
The concept of sustainability has become increasingly popular in recent years as our world deals with several social, environmental, and economic issues (Beamer *et al*., 2021) [1]. The ability to meet the requirements of the current generation without sacrificing future generation's ability to meet their own needs is what is meant by sustainability (Verma, 2019) [2]. Sustainability essentially aims to achieve a delicate balance between human activities and the strength and adaptability of natural systems (Mensah, 2019) [3]. One cannot exaggerate how important sustainability is for the future. It is essential that we adhere to practices and systems that assure long-term survival and well-being for both people and the planet as the global population continues to rise along with our consumption habits and resource needs (Gerten *et al*., 2020) [4]. The interrelated problems of environmental deterioration, social inequity, and economic instability are the focus of sustainable development (Mensah, 2019) [3]. The understanding that our planet's resources are limited and vulnerable lies at the core of sustainability (Skene, 2021) [5]. Among the urgent issues we face are climate change, pollution, deforestation, biodiversity loss, and resource depletion (Hayat *et al*., 2023) [6]. These problems endanger not just human well-being and ecosystems, but they also threaten the prospects and well-being of next generations (Sanson and Burke, 2020) [7].
A paradigm shift in our perception and interaction with the planet is required to embrace sustainability. It necessitates reassessing our consumption and production habits, cutting back on waste and pollution, promoting social justice, and preserving and regenerating ecosystems (Rieckmann, 2018) [9]. Sustainability includes economic and social aspects in addition to environmental concerns. It demands structural improvements, innovation, and teamwork across industries and social groups (Rai *et al*., 2021) [10]. Agreement among scientists, policy - makers, and the general public is beginning to develop, underscoring how urgent it is to address sustainability challenges (Shrivastava *et al*., 2020) [11]. The Sustainable Development Goals (SDGs) of the United Nations offer a worldwide framework to direct collective effort towards a more sustainable future (Jonsdottir *et al*., 2021) [12]. These goals cover a wide range of issues, including eradicating poverty and hunger, promoting sustainable energy, guaranteeing access to healthcare and education, and fostering ethical production and consumption (Dossey *et al*., 2019) [13].

By adopting sustainability, we may work to build a future that is socially just, environmentally sustainable, and economically successful (Velenturf and Purnell, 2021) [14]. It presents an opportunity to reconsider how we interact with our surroundings, encourage strong communities, and create a healthy global community (Martinez and short, 2021) [15]. If we want to ensure that the planet is habitable and equitable for generations to come, sustainability is not an option but a necessity (Kiang and behne, 2021) [16].

in this context, Bamboo becomes a potent symbol of sustainability. A "sustainable wonder plant," bamboo is sometimes referred to as having features that make it a significant resource for tackling many sustainability issues. This versatile member of the grass family provides a wealth of cultural, economic, and environmental advantages that support a more resilient and sustainable future (Ramakrishnan *et al*., 2020) [18]. Bamboo has a remarkable growth rate, which is one of its most recognised features. Some bamboo species are known to grow at incredible rates, with some able to grow up to 1 metre (3 feet) in height each day. Bamboo is an exceptionally renewable resource due to its quick growth and capacity to swiftly regrow after harvest. It may be sustainably harvested without harming ecosystem integrity or diminishing natural forests (Chongtham and Bisht, 2020; Auwalu and Dickson, 2019) [19, 20]. Furthermore, bamboo rivals many traditional materials for construction in terms of strength and longevity (Lucus, 2019) [21]. Its flexibility enables it to survive severe weather, such as hurricanes and earthquakes, yet its tensile strength surpasses that of steel (Sikder *et al*., 2016) [22]. A more environmentally responsible option for building is using bamboo because it lessens the need for wood and helps to prevent deforestation (Iroegbu and Ray, 2021) [23]. Additionally, it offers chances for the creation of environmentally friendly architecture, infrastructure, and housing (Omer and Noguchi, 2020) [24]. Bamboo's economic importance cannot be underestimated. Communities all throughout the world use it to generate revenue and a means of livelihood (Melese, 2016) [25]. Several sectors, including construction, textiles, furniture, paper and even energy generation, use bamboo. Its abundance and adaptability make it a desirable choice for sustainable companies and entrepreneurial endeavours, fostering economic development and job possibilities (Prasad and Muthusamy, 2023; Rathour *et al*., 2022) [26, 27].

Bamboo has cultural importance in many countries in addition to its environmental and economic advantages (Montano and Dam, 2021) [28]. It has been an essential part of craftsmanship, traditional practices and artistic endeavour. Bamboo is a symbol of strength, adaptability, and harmony with the environment. Its cultural history preserves the traditional knowledge and skills passed down through the generations, enriching communities and fostering a sense of identity (Bain, 2019) [29].

Bamboo and Environmental Health

Bamboo is a potent tool for management of sustainable land and mitigation of climate change due to its many environmental advantages. Bamboo functions as a powerful carbon sink by having a remarkable capacity to sequester carbon. However, due to its quick growth, certain species can sequester more carbon per hectare than even mature forests. This allows them to capture significant amounts of carbon dioxide from the atmosphere. Whereas, by lowering the greenhouse gas emissions, bamboo can act as a significant partner in the fight against climate change (Goswami *et al*., 2022) [30]. Bamboo is essential for conservation of soil and prevents erosion. Due to its extensive root structure, the soil is more stable, which reduces soil erosion and increases water infiltration. Raindrops are naturally shielded from impact by the dense canopy of bamboo, resulting in less surface runoff and soil erosion. Bamboo maintains ecosystems and avoids sedimentation in rivers and streams by preserving the stability and quality of the soil (Kaushal *et al*., 2020) [31]. Lastly, bamboo promotes habitat preservation and biodiversity. Numerous plant and animal species can find refuge, food, and breeding grounds in its dense woodlands. Ecological corridors are built by bamboo forests, linking disparate habitats and allowing wildlife to migrate more easily. This support for biodiversity improves ecosystem hardiness and aids in the preservation of threatened species (Singh *et al*., 2021) [10].

Sustainable cultivation practices

The key to harnessing bamboo's full potential as a sustainable wonder plant is to use sustainable methods for cultivation. Bamboo is a great sustainable resource due to its quick growth and ability to regenerate. It has astounding growth rates that surpass many traditional timber sources, with some species capable of growing up to 1 metre (3 feet) each day. Due to its quick growth, bamboo may be harvested on a regular basis without destroying natural forests (Chongtham and Bisht, 2020; Ramakrishnan *et al*., 2020) [19, 18]. Bamboo regeneration is further encouraged by sustainable harvesting methods like rotational harvesting and selective cutting, which also protect the integrity of ecosystem. Additionally, the establishment of bamboo plantations presents a tremendous opportunity for supplying rising demand while lessening strain on natural ecosystems. Bamboo may be grown sustainably and under control on well-managed plantations, improving regional economies and reducing the strain on the environment (Soloman *et al*., 2020; Bansal and Zoolagud, 2002) [33, 34]. However, encouraging sustainable bamboo cultivation depends heavily on responsible sourcing and certification programmes. These systems make sure that bamboo is obtained from sustainably harvested natural forests or well-managed plantations while, also meeting economic, social, and ecological standards. Furthermore, it can ensure the sustainable origins of bamboo goods by putting a priority on responsible sourcing and adopting certification programmes, like the Forest Stewardship Council's (FSC) accreditation, which promotes market transparency and customer confidence. By adopting sustainable growing practices, such as rapid growth and regenerative qualities, sustainable harvesting procedures, responsible sourcing and certification procedures, bamboo can be maximized for its beneficial environmental effects and ensured long-term sustainability (Prasad and Muthusamy, 2023; Cantu *et al*., 2021; Huang, 2021) [26, 36].

Economic applications

A variety of economic applications can be found for bamboo, including those in the food, construction, textile, and renewable energy industries. Bamboo shows tremendous potential as an adaptable building material in the construction sector. However, because of its durability, adaptability, and light weight, it is ideal for structural components including beams, columns, and flooring (Borowski *et al*., 2022) [337]. Although, the use of bamboo in building also includes reinforcing applications, where bamboo composites can

increase the longevity and strength of concrete buildings. Furthermore, bamboo is a desirable solution for eco-friendly and economical construction projects due to its quick growth and wide availability (Yadav and Mathur, 2021) [38]. It has a potential for use in bioenergy production and renewable energy sources aside from construction and textiles (Rathour *et al*., 2022) [27]. While, bamboo is an excellent option for bioenergy production using procedures like pyrolysis and gasification due to its quick growth and high biomass yield. It is possible to lessen dependency on fossil fuels and reduce greenhouse gas emissions by turning bamboo into biofuels like bioethanol and biodiesel. However, the use of bamboo in the production of bioenergy offers rural communities the chance to diversify their sources of income and encourage the use of sustainable energy sources (Borowski, 2022) [37].

On the other hand, bamboo has culinary uses in the food industry as well. the bamboo plant edible young shoot, or bamboo shoots, are used in a variety of cuisines around the world. Their delicate flavour, crisp texture, and nutritious content have earned them widespread acclaim (Joshi *et al*., 2023) [39]. Due to their high content of dietary fibre, vitamins, and minerals, bamboo shoots are a nutritious complement to a variety of foods, including stir-fries, soups, and salads. Bamboo shoots provide eight types of amino acids that are essential for humans, as they cannot be synthesized in the body (Wang *et al*., 2020) [40]. Bamboo is a rich source of several essential minerals, including potassium, calcium, magnesium, and manganese. It also contains smaller amounts of iron, zinc, and copper, as well as trace amounts of other minerals (Chongtham *et al*., 2021) [41]. In terms of vitamins, bamboo is particularly high in vitamin B6 and also contains vitamin C, thiamin, riboflavin, and folate. Bamboo contains several phytochemicals, including phenolic acids, flavonoids, and lignans (Gao *et al*., 2022) [43]. These compounds have been shown to have antioxidant and anti-inflammatory properties, as well as potential health benefits in areas such as cardiovascular disease and cancer prevention (Noremylia *et al*., 2023) [44]. bamboo also contains some anti-nutrients, such as cyanogenic glycosides and lectins, which can be toxic in high amounts. However, these compounds can be reduced through proper preparation techniques, such as boiling or soaking. The digestibility of bamboo can vary depending on the specific type of bamboo and how it is prepared (Silva *et al*., 2020) [45]. Some research has shown that the digestibility of bamboo shoots can be improved through various processing methods, such as soaking, boiling, or fermenting (Chongtham *et al*., 2021) [41]. In addition to the nutrients and phytochemicals discussed above, there is some evidence to suggest that bamboo may have additional health benefits. For example, bamboo shoots have been shown to have prebiotic effects, promoting the growth of beneficial gut bacteria (Chen *et al*., 2019) [47]. Bamboo extract has also been studied for its potential anti-inflammatory and anti-cancer properties (Noremylia *et al*., 2023) [44].

Additionally, foods can be wrapped in bamboo leaves to add a subtle and earthy flavour (Santosh *et al*., 2023) [48]. In some tribal groups of Southern India, Bambusa arundinacea seed rice (BSR) consumption is widespread. After being dehusked, bamboo tree seeds are dark in colour and closely resemble rice grains (*Oryza sativa*) in terms of their physical and chemical characteristics. Rice seeds from other grass species, including the Bambusa, may have antihyperglycemic properties, however this has not been researched or fully investigated so far (Haldipur and Srividya, 2021) [49]. The numerous commercial uses of bamboo for construction, textiles, food, and renewable energy sources demonstrate its adaptability and promise for sustainable economic growth (Sawarkar *et al*., 2022) [51]. However, it is crucial to embrace ethical and sustainable practices that guarantee the long-term survival of bamboo resources and utilisation in the diverse sectors. Although, the advance circular economies, lessen the impact on the environment, and lead to a wealthy and sustainable future by utilising economic potential of bamboo (Jain *et al*., 2022; Seddon *et al*., 2021) [52].

Bamboo and sustainable development

Fast-growing and adaptable bamboo has become recognised as a potent resource for sustainable development. It offers enormous promise for reducing poverty and fostering rural development, acting as a means for establishing sustainable livelihoods, generating revenue, and generating employment. Numerous advantages of this renewable resource support community prosperity and economic growth all over the world (Prasad and Muthusamy, 2023; Lee *et al*., 2021) [26, 53]. Bamboo has a number of benefits, one of which is its capacity for quick growth. Some species can reach maturity in as little as three to five years. With such a short growth cycle, swift harvesting and ongoing regrowth are made possible, giving rural communities a reliable source of income (Huang, 2021) [36]. Bamboo is a potential option for regions with limited agricultural prospects since it can be grown on marginal grounds that are unsuitable for other crops. Communities can diversify their economic sources and become less reliant on one source of income by utilising the possibilities of bamboo (Patel *et al*., 2021) [55]. Businesses using bamboo have shown success in a number of locations, demonstrating its potential for sustainable development. For instance, the introduction of plantations of bamboo and the growth of enterprises associated to bamboo have greatly boosted the local economy in Anji County, China. Today, the region is acknowledged as a top supplier of high-quality bamboo items, including flooring, furniture, and handicrafts. This transition has increased revenue and opened up employment opportunities for locals, reducing poverty and promoting rural development (Yun *et al*., 2022) [56]. Similar to this, programmes based on bamboo have been successful in the Philippines (Salzer *et al*., 2016) [57]. On the island of Bohol, the Bambusetum Project has made sustainable bamboo growing and product development its main priorities. In addition to improving livelihoods of farmers, the project also included community training and capacity-building initiatives. The introduction of high-value bamboo goods, such as furniture and construction supplies, has boosted economic development while the focus on sustainable practises has helped preserve biodiversity and the environment (Salzer *et al*., 2016; Tolentino, 2009) [57, 58]. The environmental sustainability of bamboo goes beyond its economic advantages. Bamboo is a renewable resource that is extremely important in halting deforestation and fostering reforestation efforts (Minale and Abebe, 2020) [59]. Its large root system makes it a useful instrument for soil restoration and reducing climate change since it prevents soil erosion. Additionally, bamboo forests serve as carbon sinks, trapping large volumes of carbon dioxide to help lower greenhouse gas emissions (Rathour *et al*., 2022) [27]. Governments, NGOs, and the private sector can work together to support bamboo-based businesses financially and technically, promoting the expansion of sustainable industries (Arjumand, 2023) [60].

Innovations and Future Directions

Research and development in bamboo hold great promise for maximizing its sustainability potential and expanding its applications. In order to improve bamboo's mechanical characteristics, strength, and aesthetic appeal, research is currently being done on improving bamboo processing methods and product development (Iroegbu and Ray, 2021) [23]. New uses for bamboo are being investigated as a result of technological developments, such as the creation of bioplastics made from bamboo fibres and the use of bamboo in 3-D printing. The transition to more eco-friendly and sustainable materials is facilitated by these innovations (Li *et al*., 2020) [61]. Furthermore, Bamboo's special qualities make it a great choice for environmentally conscious infrastructure and sustainable urban development. Bamboo can be used in construction, green roofs, and urban-landscaping due to its quick growth, strength, and adaptability. Bamboo can be used in sustainable urban planning to reduce the effect of urban heat islands, enhance air quality, and build durable and visually beautiful urban environments. Embracing these innovations and exploring bamboo's potential in emerging fields will unlock new opportunities for sustainable development and make the future greener (Stefanakis, 2019) [62].

Conclusion

A wonderful and adaptable resource, bamboo makes a significant contribution to sustainability and sustainable development. Because of its distinctive environmental advantages, including as carbon sequestration, soil protection, and biodiversity enhancement, it can be an effective strategy for reducing climate change and protecting ecosystems. The long-term survival of bamboo resources is guaranteed through sustainable farming methods, responsible sourcing, and certification procedures. There are potential for sustainable living, income production, and job creation thanks to the economic applications of bamboo, which span the industries of construction, textiles, renewable energy, and agriculture. The business successes that use bamboo are examples of its ability to promote socioeconomic growth and environmental care. Additionally, bamboo is consistently being researched and advanced technologically, and is being used in a variety of industries such as bioplastics and 3D printing. The use of bamboo in green infrastructure and sustainable urban development offers chances to design robust, environmentally beneficial, and aesthetically beautiful urban landscapes. Together, bamboo's durability, economic potential, and adaptability make it a tremendous tool for constructing a future that is both sustainable and wealthy.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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