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REVIEW ARTICLE **OPEN ACCESS**

Bamboo (*Bambusoideae*): Ecological Functions, Socio-Economic and Ethno medicinal Significance—A Comprehensive Review

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Abstract

Bamboo, a perennial woody grass of the subfamily Bambusoideae (family *Poaceae*), has emerged as a critical bioresource for sustainable development due to its rapid growth, high biomass productivity, and multifunctional applications. Globally, bamboo comprises approximately 1,600 species, with India representing a major center of diversity. This review synthesizes current scientific knowledge on bamboo taxonomy, reproductive biology, propagation techniques, ecological services, and socio-economic contributions. Special emphasis is placed on its role in carbon sequestration, land restoration, and rural livelihood enhancement. Additionally, the review evaluates industrial applications, policy frameworks, and constraints in the bamboo sector. The findings highlight bamboo as a strategic component in climate change mitigation, circular bioeconomy, and sustainable resource management. Future research directions focusing on genetic improvement, value chain optimization, and policy integration are also discussed.

Keywords: *Bamboo, Bambusoideae, carbon sequestration, rural livelihoods, bioeconomy, sustainable development, propagation ecology*.

Introduction

Bamboo is a distinctive group of perennial woody grasses belonging to the subfamily Bambusoideae of the family Poaceae. It is widely distributed across tropical, subtropical, and temperate regions, where it contributes substantially to ecological functioning and human livelihoods. Globally, bamboo comprises nearly 120 genera and around 1,600 species, reflecting remarkable taxonomic diversity and ecological adaptability (Lobovikov *et al.,* 2007; Liese & Köhl, 2015; Dubey *et al.,* 2024). Unlike most timber-producing trees, bamboo matures rapidly and regenerates naturally from its rhizome system after harvesting, allowing repeated biomass production without replanting. This rapid growth, coupled with high productivity, has made bamboo one of the most promising renewable lignocellulosic resources for sustainable development (Scurlock *et al.,* 2000; Liese & Köhl, 2015; Irawan *et al.,* 2025).

India is recognized as one of the world's major centers of bamboo diversity. Approximately 136 bamboo species belonging to 23 genera occur across the country, with the richest diversity found in the North-Eastern region, the Western Ghats, Central India, and the Himalayan foothills (Forest Survey of India, 2021). Although India is the second-largest producer of bamboo after China, the economic potential of this resource has not yet been fully realized. Limited value addition, inadequate processing infrastructure, fragmented supply chains, and insufficient market integration continue to restrict the growth of the bamboo sector (INBAR, 2019; NITI Aayog, 2023). Recent government initiatives, particularly the expansion of the National Bamboo Mission and the removal of bamboo from the definition of "tree" under the Indian Forest Act for non-forest areas, have encouraged cultivation, processing, and private investment, creating new opportunities for sustainable commercialization (Government of India, 2020; Ministry of Agriculture and Farmers Welfare, 2023).

Beyond its economic value, bamboo provides a wide range of ecological benefits. Its extensive rhizome-root network effectively stabilizes soil, minimizes erosion, and improves land productivity, making it particularly valuable for restoring degraded landscapes and rehabilitating fragile ecosystems (Nath *et al.,* 2009). Bamboo forests also play an important role in climate change mitigation because of their rapid biomass accumulation, high rates of carbon sequestration, and capacity to store carbon both above and below ground (Song *et al.,* 2011; Yuen *et al.,* 2017; IPCC, 2022). In addition, bamboo ecosystems provide habitat for numerous plant and animal species, thereby supporting biodiversity conservation and enhancing ecosystem resilience (Liese & Köhl, 2015). The socio-economic importance of bamboo extends across many developing countries, where it serves as a vital source of income, employment, and raw material for rural communities. Often described as the "green gold" or the "poor man's timber," bamboo is extensively used in housing, furniture, handicrafts, paper manufacturing, food products, and agricultural implements (FAO, 2007; INBAR, 2019). In India, millions of people, particularly tribal and forest-dependent households, depend directly or indirectly on bamboo-based activities for their livelihoods. The sector also offers significant opportunities for women-led enterprises and small-scale industries, contributing to rural development and inclusive economic growth (National Bamboo Mission, 2023).

In recent years, interest in bamboo has expanded well beyond its traditional applications. Owing to its favorable mechanical properties, rapid renewability, and relatively low environmental footprint, bamboo has become an attractive raw material for engineered construction materials, bio-composites, biodegradable packaging, textile fibers, biochar, and renewable bioenergy. These emerging applications align closely with the principles of the circular bioeconomy by promoting renewable resource utilization, waste minimization, and carbon-efficient production systems (Van Dam, 2022; INBAR, 2023). Consequently, bamboo is increasingly recognized as an important resource for achieving several Sustainable Development Goals (SDGs), particularly those related to climate action (SDG 13), responsible consumption and production (SDG 12), sustainable cities and communities (SDG 11), and poverty reduction (SDG 1). Despite these advantages, several constraints continue to limit the full utilization of bamboo resources. Irregular flowering cycles, shortages of quality planting material, pest and disease problems, inadequate mechanization, technological gaps in processing, and weak market linkages remain major challenges affecting productivity and commercial expansion (Liese & Köhl, 2015; INBAR, 2023). Overcoming these limitations requires coordinated efforts involving scientific research, technological innovation, supportive policy frameworks, and active participation of local communities. Against this background, the present review critically examines recent developments in bamboo ecology, socio-economic importance, and industrial applications while highlighting emerging research trends and identifying priority areas for sustainable management and future investigation.

Methodology

This review was conducted using a systematic literature search to summarize current knowledge on the ecological importance, socio-economic value, and industrial applications of bamboo (Bambusoideae). The review process was designed following widely accepted guidelines for systematic reviews to ensure a transparent and reproducible approach (Tranfield *et al.,* 2003; Moher *et al.,* 2009; Page *et al.,* 2021).

Taxonomy, Morphology and Genetic Diversity

Taxonomy

Bamboo belongs to the subfamily Bambusoideae within the family Poaceae, order Poales. It represents a taxonomically complex and evolutionarily diverse group of grasses, comprising approximately 120 genera and over 1,600 species worldwide (Lobovikov *et al.,* 2007; Liese & Köhl, 2015). Based on phylogenetic and morphological characteristics, bamboos are broadly classified into three major tribes:

- Bambuseae (tropical woody bamboos)
- Arundinarieae (temperate woody bamboos)
- Olyreae (herbaceous bamboos)

Tropical woody bamboos dominate in regions such as South and Southeast Asia, including India, whereas temperate woody bamboos are distributed in East Asia and parts of the Americas (Clark *et al.,* 2015). The classification of bamboo has historically been challenging due to infrequent flowering, which limits the availability of reproductive characters essential for taxonomy. Consequently, modern classification increasingly relies on molecular phylogenetic tools such as chloroplast DNA sequencing and nuclear markers (Triplett & Clark, 2010).

Morphology

➢ ***Culm Structure***

The culm (stem) is typically cylindrical, segmented by nodes and internodes, and may be hollow *(Bambusa vulgaris)* or solid (*Dendrocalamus strictus*). Culm diameter, height, and wall thickness vary significantly among species, influencing their mechanical properties and industrial applications (Liese & Köhl, 2015).

- ***Rhizome System***

The underground rhizome system governs growth pattern and spatial distribution:

- **Pachymorph (sympodial):** Short, thick rhizomes forming dense clumps
- **Leptomorph (monopodial):** Long, slender rhizomes resulting in running growth

This distinction has ecological and silvicultural significance, affecting plantation management and invasiveness (Judziewicz *et al.*, 1999).

- ***Leaves and Branching***

Bamboo leaves are typically lanceolate with parallel venation. Branching patterns vary among genera, often emerging from nodes. The presence of a culm sheath during early growth stages protects the developing culm and contributes to species identification.

- ***Reproductive Morphology***

Bamboo flowering is rare and often gregarious, with long intervals ranging from 30 to 120 years. Inflorescences may be spikelets arranged in panicles, resembling other grasses. Post-flowering mortality is common in many species, a phenomenon known as monocarpic senescence (Janzen, 1976).

Genetic Diversity

Bamboo exhibits considerable genetic diversity across its distribution range, driven by ecological adaptation, polyploidy, and hybridization. However, the study of genetic diversity is constrained by its prolonged flowering cycles and predominantly vegetative reproduction.

- ***Molecular Characterization***

Advances in molecular biology have facilitated the assessment of genetic variation using markers such as:

- Random Amplified Polymorphic DNA (RAPD)
- Amplified Fragment Length Polymorphism (AFLP)
- Simple Sequence Repeats (SSR)

These tools have been successfully applied to evaluate genetic diversity in species such as *Dendrocalamus strictus* and *Bambusa balcooa* (Das *et al.*, 2005).

- ***Clonal Propagation and Genetic Uniformity***

Vegetative propagation methods, including rhizome and culm cuttings, often result in clonal populations with low genetic variability. While advantageous for uniformity in plantations, this may reduce resilience to pests, diseases, and environmental changes (Nayak *et al.*, 2010).

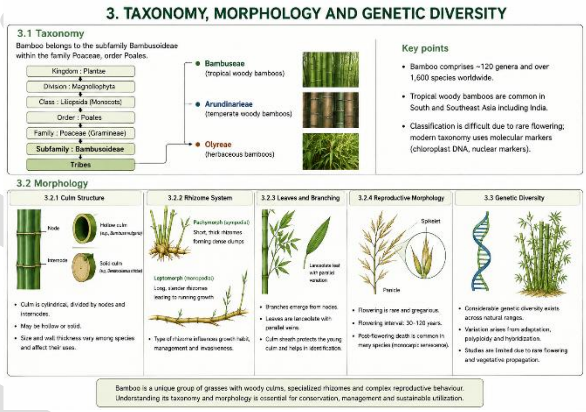
- ***Conservation of Genetic Resources***

Conservation of bamboo genetic resources is critical due to threats such as habitat loss, overexploitation, and climate change. Strategies include:

- **In situ conservation:** Conservation in natural habitats
- **Ex situ conservation:** Germplasm banks and botanical gardens
- **In vitro conservation:** Tissue culture and cryopreservation

- ***Evolutionary Significance***

Phylogenetic studies indicate that woody bamboos evolved through rapid radiation events, leading to complex evolutionary relationships. Hybridization and polyploidy have played significant roles in speciation within the subfamily (Triplett &



Clark, 2010).

Propagation

Vegetative Propagation

Due to irregular flowering and poor seed viability, bamboo propagation is predominantly vegetative. This mode ensures rapid establishment, genetic uniformity, and reliable productivity.

- ***Rhizome-Based Propagation***

Rhizome propagation involves the transplantation of underground stem segments containing viable buds. It is one of the most effective methods for clump-forming (sympodial) species.

- High survival rate
- Rapid establishment
- Suitable for large-scale plantation

However, it is labor-intensive and may damage the mother clump if not properly managed (Tewari, 1992).

- ***Culm Cutting Propagation***

Culm cuttings are prepared from mature bamboo stems containing one or more nodes with dormant buds.

- Planted horizontally or at an angle in moist soil

- Requires high humidity and proper irrigation
- Cost-effective and widely practiced

This method is particularly suitable for species such as *Dendrocalamus strictus* and *Bambusa vulgaris* (Banik, 1995).

➢ ***Offset Planting***

Offset planting involves the use of basal culm portions attached to rhizomes.

- Common in traditional farming systems
- High success rate under field conditions
- Requires careful handling due to bulkiness

Micropropagation and Biotechnological Approaches

Recent advancements in plant biotechnology have enabled in vitro propagation (tissue culture) of bamboo, offering significant advantages:

- Rapid mass multiplication
- Production of disease-free planting material
- Conservation of elite genotypes

Micropropagation techniques include:

- Nodal culture
- Somatic embryogenesis
- Organogenesis

Despite its potential, large-scale adoption is constrained by:

- High cost
- Requirement of specialized infrastructure
- Acclimatization challenges during field transfer (Singh *et al.,* 2013)

Constraints in Bamboo Propagation

Propagation of bamboo is hindered by several biological and technical challenges:

- Irregular and unpredictable flowering cycles
- Short seed viability and poor germination rates
- Limited availability of quality planting material
- High labor and transportation costs in vegetative methods
- Lack of standardized propagation protocols for diverse species

Ecological Functions of Bamboo

Bamboo forests are increasingly recognized for the wide range of ecosystem services they provide. Their rapid growth, efficient nutrient utilization, and extensive rhizome-root systems enable bamboo stands to stabilize ecosystems, improve soil quality, and support biodiversity. As a fast-renewable resource, bamboo also contributes to climate change mitigation and ecological restoration, making it an important component of sustainable land management (Liese & Köhl, 2015; INBAR, 2023).

Carbon Sequestration and Climate Change Mitigation

Among fast-growing plant resources, bamboo has attracted considerable attention for its ability to capture and store atmospheric carbon. Many species produce substantial biomass within a short period, allowing them to absorb carbon dioxide efficiently and accumulate carbon in culms, roots, rhizomes, and surrounding soils. Unlike many timber species, harvested bamboo regenerates naturally from existing rhizomes, maintaining carbon uptake without repeated replanting. Long-lasting bamboo products such as engineered panels, flooring, and furniture further extend carbon storage while reducing dependence on energy-intensive construction materials (Song *et al.,* 2011; Yuen *et al.,* 2017; INBAR, 2023; IPCC, 2022).

Recent studies also highlight the potential of bamboo-based restoration programmes to contribute to national carbon neutrality targets, particularly in degraded tropical and subtropical landscapes where biomass accumulation is rapid.

Soil Conservation and Land Restoration

The underground rhizome network and dense fibrous roots of bamboo effectively bind soil particles, reducing erosion caused by rainfall and surface runoff. This characteristic makes bamboo highly suitable for stabilizing riverbanks, hill slopes, mining areas, and other environmentally sensitive sites. Continuous litter deposition improves soil organic matter, enhances microbial activity, and increases nutrient cycling, gradually restoring soil fertility in degraded lands (Nath *et al.,* 2009; FAO, 2018).

Recent restoration projects have shown that bamboo plantations improve soil structure, water infiltration, and microbial diversity, accelerating ecosystem recovery in abandoned agricultural lands and post-mining landscapes (Li *et al.,* 2023; INBAR, 2023).

Biodiversity Conservation

Natural bamboo forests and mixed bamboo ecosystems provide food, shelter, and breeding habitats for numerous organisms, including mammals, birds, insects, reptiles, and soil microorganisms. Bamboo also creates favorable microclimatic conditions by moderating temperature, retaining soil moisture, and protecting the forest floor. In many regions, bamboo functions as a keystone resource for wildlife and enhances landscape connectivity when integrated into agroforestry systems (Liese & Köhl, 2015).

Recent ecological studies indicate that well-managed bamboo landscapes can increase habitat heterogeneity and support pollinators, beneficial insects, and native vegetation, thereby strengthening ecosystem resilience (Zhou *et al.,* 2024).

Water Regulation and Watershed Protection

Bamboo vegetation contributes to watershed health by improving rainfall infiltration and reducing surface runoff. The rhizome-root system enhances groundwater recharge while minimizing sediment transport into rivers and reservoirs. Dense bamboo cover also reduces evaporation from the soil surface and helps maintain moisture during dry periods. These functions are particularly valuable in mountainous watersheds and degraded catchments vulnerable to erosion and seasonal water scarcity (FAO, 2018; INBAR, 2023: Dubey and Dubey, 2021).

Role in Sustainable Landscapes

Bamboo is increasingly incorporated into agroforestry systems, urban greening programmes, and ecological restoration initiatives because it delivers both environmental and socio-economic benefits. It can rehabilitate degraded land, improve ecosystem productivity, and simultaneously provide renewable raw materials for local communities. Owing to these multiple functions, bamboo is regarded as an important nature-based solution that supports climate adaptation, biodiversity conservation, sustainable land management, and several Sustainable Development Goals (SDGs) (IPCC, 2022; INBAR, 2023; UNEP, 2024).

Overall, the available evidence demonstrates that bamboo is much more than a commercial resource. Its ecological functions contribute to carbon storage, soil protection, biodiversity conservation, water regulation, and landscape restoration, highlighting its importance in addressing contemporary environmental challenges.

Socio-Economic Importance

Bamboo has long been an integral part of rural livelihoods and local economies, particularly in Asia, Africa, and Latin America. Because of its fast growth, versatility, and ability to regenerate after harvesting, it provides a renewable source of raw material for households, artisans, and industries. In recent years, bamboo has also gained recognition as an important resource for the green economy and the development of sustainable bio-based industries (INBAR, 2019; FAO, 2007; INBAR, 2023; Alamerew *et al.,* 2025).

Livelihood Support and Rural Economy

For many rural and forest-dependent communities, bamboo is more than a construction material—it is an important source of employment and household income. Income is generated through bamboo cultivation, harvesting, processing, transportation, and the sale of finished products. Globally, more than 2.5 billion people use bamboo in their daily lives, while millions of people in India depend on bamboo-related activities for either full-time or seasonal employment (FAO, 2007; INBAR, 2019). In many tribal regions, bamboo-based occupations such as basket making, mat weaving, handicraft production, and small-scale furniture manufacturing require relatively low investment and rely on locally available skills. These activities also create employment opportunities for women and self-help groups, contributing to income diversification and reducing rural poverty (Lobovikov *et al.,* 2007; Kumar *et al.,* 2026).

Cottage and Small-Scale Industries

Traditional bamboo industries continue to play an important role in the rural economy. Bamboo is widely used for producing baskets, mats, household articles, furniture, fencing materials, handicrafts, and agricultural tools. These enterprises are generally small in scale and depend on indigenous knowledge that has been passed down through generations. Although the sector supports thousands of artisans, its growth is often limited by outdated processing methods, inconsistent product quality, poor market access, and inadequate value addition. Improving design, mechanization, branding, and marketing could substantially increase the economic returns from bamboo-based products (FAO, 2007; INBAR, 2023).

Industrial Applications and Value Addition

The industrial use of bamboo has expanded considerably during the last decade. Advances in processing technologies have enabled bamboo to be used in paper and pulp manufacturing, engineered construction materials, laminated boards, flooring, furniture, textile fibres, activated carbon, and biodegradable packaging. Its high cellulose content makes bamboo suitable for paper production, while its strength-to-weight ratio has encouraged its use in engineered building materials. Growing demand for environmentally friendly alternatives to timber and plastics has further increased the commercial importance of bamboo. Nevertheless, India's contribution to the global bamboo market remains relatively modest because of limited processing facilities, fragmented supply chains, and insufficient investment in value-added products (INBAR, 2019; Van Dam, 2022).

Food Security and Nutritional Value

Young bamboo shoots are widely consumed as a traditional food in several Asian countries, particularly in Northeast India, China, Japan, Thailand, and Nepal. They are valued for their high dietary fibre content and provide vitamins, minerals, essential amino acids, and several bioactive compounds with antioxidant properties (Nirmala *et al.,* 2011). Fresh, fermented, canned, and pickled bamboo shoots have become commercially important products in many regions. Their increasing popularity has created new opportunities for small-scale food processing industries and rural entrepreneurship.

Bamboo in the Green Economy

The growing emphasis on sustainable development has renewed interest in bamboo as a renewable biological resource. Because it grows rapidly, regenerates naturally after harvesting, and is biodegradable, bamboo offers an environmentally preferable alternative to many conventional raw materials. It can partially replace timber, plastics, steel, and other carbon-intensive materials in selected applications, thereby supporting resource-efficient production systems. Bamboo-based industries also fit well within the concept of the circular bioeconomy by promoting renewable resource use, recycling of biomass residues, and waste minimization. These characteristics make bamboo relevant to several Sustainable Development Goals, including poverty reduction (SDG 1), decent work and economic growth (SDG 8), responsible consumption and production (SDG 12), climate action (SDG 13), and life on land (SDG 15) (INBAR, 2023; UNEP, 2024).

Government Initiatives and Institutional Support

Over the past few years, policy reforms have strengthened the bamboo sector in India. The amendment that removed bamboo grown outside forests from the definition of a tree simplified harvesting and transportation procedures, encouraging private cultivation and investment. In addition, the National Bamboo Mission has promoted nursery development, plantation establishment, processing infrastructure, skill development, and market linkages through financial and technical assistance (Government of India, 2020; Ministry of Agriculture & Farmers Welfare, 2023). Organizations such as the International Bamboo and Rattan Organization (INBAR), the Indian Council of Forestry Research and Education (ICFRE), and state forest departments continue to support bamboo research, technology transfer, entrepreneurship development, and capacity building across the country.

Challenges and Future Prospects

Despite its considerable potential, several constraints continue to limit the growth of the bamboo sector. Many producers face difficulties due to fragmented markets, inadequate processing technologies, inconsistent quality standards, poor storage facilities, and dependence on intermediaries. Limited access to institutional finance, technical training, and modern machinery further reduces the competitiveness of small-scale enterprises. Future progress will depend on strengthening value chains, improving processing technologies, encouraging product diversification, expanding market access, and supporting community-based enterprises. Greater investment in research, innovation, and policy implementation can help transform bamboo into a more competitive and sustainable bioresource that contributes simultaneously to rural livelihoods, industrial development, and environmental conservation.

Industrial and Ethno-Medicinal Applications of Bamboo

Engineered Bamboo and Construction Materials

One of the most significant advancements in bamboo utilization is the development of engineered bamboo products such as laminated bamboo lumber (LBL), bamboo scrimber, and composite panels. These materials exhibit superior mechanical properties, including high compressive and tensile strength, making them suitable substitutes for conventional timber, steel, and concrete in construction (Sharma *et al.,* 2015).

Engineered bamboo products are increasingly used in:

- Structural frameworks and prefabricated housing
- Flooring and paneling systems
- Bridges and scaffolding

Bamboo scrimber, in particular, demonstrates enhanced dimensional stability and durability due to resin impregnation and densification processes (Yu *et al.,* 2017). Such materials contribute to reduced carbon footprints in the construction sector by replacing energy-intensive materials.

Bamboo-Based Textiles and Fiber Technology

Bamboo has gained prominence in the textile industry due to its soft texture, moisture-wicking capacity, and antimicrobial properties. Bamboo fibers are processed primarily through viscose (regenerated cellulose) methods, although mechanical processing methods are also being explored for sustainability (Van der Lugt & Vogtländer, 2015).

Applications include:

- Apparel (sportswear, innerwear, socks)
- Medical textiles (bandages, masks)
- Technical textiles

The presence of bioactive compounds (often referred to as “bamboo kun”) is associated with antibacterial properties, although its persistence in processed fibers remains debated (Sun *et al.,* 2016). Nonetheless, bamboo textiles are increasingly marketed as eco-friendly alternatives to cotton and synthetic fibers.

Bioenergy and Biofuel Production

Bamboo’s high lignocellulosic biomass content makes it an efficient feedstock for bioenergy production. It is utilized in:

- Bioethanol production through enzymatic hydrolysis and fermentation
- Charcoal and activated carbon production
- Gasification and pyrolysis systems

Studies indicate that bamboo biomass has favorable calorific value and low ash content, enhancing its suitability for renewable energy systems (Scurlock *et al.,* 2000). Furthermore, bamboo charcoal is widely used for water purification and air filtration due to its high adsorption capacity.

Bamboo in Sustainable Packaging and Bioplastics

With increasing global concerns over plastic pollution, bamboo has emerged as a viable raw material for biodegradable packaging solutions. Bamboo pulp is utilized in:

- Paper and cardboard production
- Food-grade packaging materials
- Disposable cutlery and containers

Recent advancements have enabled the development of bamboo-based bio-composites and bioplastics, which offer improved mechanical strength and environmental compatibility compared to petroleum-based plastics (Zhang *et al.,* 2020). These materials are increasingly adopted in packaging industries aiming to reduce ecological footprints.

Bamboo Composites and Advanced Materials

Bamboo fibers are increasingly incorporated into polymer matrices to produce high-performance composites. These bamboo fiber-reinforced composites (BFRCs) are used in:

- Automotive components
- Aerospace materials (experimental stage)
- Furniture and interior design

Such composites exhibit high strength-to-weight ratios and improved biodegradability compared to synthetic fiber composites (Faruk *et al.,* 2012). Additionally, nanocellulose extracted from bamboo is being explored for advanced applications in electronics, biomedical devices, and nanotechnology.

Bamboo in Biochar and Environmental Remediation

Bamboo-derived biochar has gained attention for its role in soil amendment and environmental remediation. Due to its porous structure and high surface area, bamboo biochar is effective in:

- Carbon sequestration
- Heavy metal adsorption
- Soil fertility enhancement

Its application in phytoremediation systems further strengthens bamboo’s role in sustainable environmental management (Beesley *et al.,* 2011; Rawat *et al.,* 2023).

Emerging Role in Green Architecture and Carbon-Neutral Design

Bamboo is increasingly integrated into green building technologies and carbon-neutral architectural designs. Its rapid renewability, coupled with low embodied energy, makes it a preferred material in sustainable construction frameworks such as LEED-certified buildings. Engineered bamboo structures are now being designed to meet international building standards, enhancing their global acceptance (Van der Lugt *et al.,* 2006).

7.8 Medicinal properties: Deeply rooted in traditional medicine, bamboo is a highly versatile plant. Its shoots, leaves, sap, and roots contain high levels of antioxidants, flavonoids, and essential amino acids. The plant is most commonly utilized to alleviate inflammation, decrease blood sugar levels, enhance skin health, and aid respiratory functions. Virtually every part of the plant—including the leaves, shoots, and sap—contains rich phytochemicals such as flavonoids, silica, and amino acids that provide antioxidant, anti-inflammatory, and metabolic health benefits (Singhal *et. al.,* 2013; Sangeetha *et. al.,* 2015; Wang *et. al.,* 2020; Akhtar & Patowary, 2022; Lee *et. al.,* 2023; Uprarawanna *et. al.,* 2025; Pizzol *et. al.,* 2025). Generally, bamboo leaves are used as traditional medicine to treat diseases such as cough, rheumatism, influenza, fever, skin disease, heart disease, and malaria. The bamboo extracts contain a wide range of functional groups that are responsible for pharmacological activities. Major active components and medicinal property, plant parts used and Therapeutic Mechanism are depicted in Table 2.

Role of Bamboo in disease and health management has been described below:

- In Skin Health & Anti-Aging: Bamboo is an exceptional source of natural silica, which stimulates collagen synthesis to maintain skin elasticity and reduce wrinkles. Bamboo fresh leaf green tea acts as antiaging. This process enhances skin elasticity and combats lines and wrinkles. Furthermore, it serves to calm dermatological flare-ups and accelerate the recovery of wounds.: Its natural antimicrobial and anti-inflammatory mechanisms help speed up the recovery of skin eruptions, ulcers, and minor wounds. It is helpful in Acne Management. Its topical or internal application helps balance sebum production and fight underlying bacterial acne.
- In Control of Blood Sugar & Cholesterol: Contemporary scientific studies reveal that bamboo extracts rich in flavonoids can lower blood glucose levels. Bamboo shoot extracts and fortified foods help lower and regulate blood glucose levels. They also assist in balancing lipid metrics by minimizing the body's absorption of fats. The high concentration of dietary fiber in the shoots helps block fat absorption, significantly lowering "bad" LDL cholesterol. It is helpful in weight Control. It's low in calories and rich in cellulose properties stimulates healthy digestion while increasing satiety to support weight loss.
- Respiratory Relief: Historically, bamboo has been applied as an expectorant to eliminate mucus, clear airways, and remedy coughs or asthma symptoms. Bamboo extract helps to eliminate excess mucus and eases breathing in conditions like asthma. In Ayurvedic medicine, bamboo manna is a primary ingredient in formulations used to treat colds, sore throats, and sinus congestion. Traditional Chinese formulas use bamboo shavings to clear heat from the lungs and resolve thick phlegm.
- Gut & Liver Protection: Serving as an organic antioxidant and anti-inflammatory agent, bamboo reinforces liver function. It safeguards cells from oxidative damage. Polysaccharides derived from bamboo act as prebiotics, to nourish healthy gut bacteria. Traditional decoctions of the leaves are used to expel intestinal parasites, such as threadworms. It helps effectively in constipation Relief: The abundant structural fiber adds bulk to stool, supporting smooth bowel movements.
- Source of Vitamins: Existing research on vitamins predominantly highlights vitamin C (ascorbic acid) and vitamin E (tocopherol). Both vitamins are crucial for generating antioxidants within the body, while vitamin E operates alongside vitamin C to fortify immune defense. Similar to most standard vegetables, raw bamboo shoots boast a significantly higher concentration of vitamin C compared to vitamin E. Furthermore, depending on the geographical area, freshly harvested bamboo shoots provide a solid supply of β-carotene and B-complex vitamins (Nirmala *et. al.,* 2018; Akhtar & Patowary,2022).
- Bamboo is highly valued in traditional medical systems like Ayurveda and Traditional Chinese Medicine (TCM). Vanshalochana (Tabashir), in Ayurveda and Traditional Chinese Medicine (TCM), this sweet, whitish unique, silica-rich mineral resin that naturally secretes and hardens inside the hollow nodes of specific bamboo stems which is used to relieve excessive thirst, treat diarrhea, and soothe fevers. It acts as a restorative tonic in Ayurveda to combat general debility and strengthen bone tissue (Fajage *et. al.,* 2024).
- Source of Minerals: Based on existing data, bamboo shoots serve as an excellent source of macro and microelements. The primary macro-elements present are potassium (K), phosphorus (P), sodium (Na), calcium (Ca), and magnesium (Mg). Conversely, the essential microelements include cobalt (Co), copper (Cu), nickel (Ni), manganese (Mn), selenium (Se), iron (Fe), and zinc (Zn). A majority of research highlights potassium as the most plentiful macro-element in bamboo shoots, with phosphorus and magnesium ranking next in abundance (Singhal *et. al.,* 2013; Wang *et. al.,* 2020; Akhtar & Patowary,2022; Lee *et. al.,* 2023; Uprarawanna *et. al.,* 2025; Pizzol *et. al.,* 2025).

The medical efficacy of bamboo is not limited to a single species because the entire Bambusoideae subfamily shares a core genetic blueprint rich in specific secondary metabolites. Almost all structural bamboo varieties possess high organic silica which is vital for tissue synthesis, joint flexibility, and bone remineralization. All species such as Phyllostachys, *Dendrocalamus*, and other Bambusa variants—are heavily utilized in traditional, clinical, and folk medicine systems globally. It contains Flavonoids & Phenols which provide broad-spectrum anti-diabetic, anti-inflammatory, and anti-aging properties regardless of the exact species (Haida and Sanusi, 2025). The table 3 below outlines other major medicinal bamboo species, their geographic roots, and their specific therapeutic properties:

Precautions for using Bamboo as medicine and food:

- Raw bamboo shoots contain natural cyanogenic glycosides, which are toxic. They must always be thoroughly boiled or fermented before consumption to neutralize these toxins. Additionally, pregnant individuals should avoid concentrated bamboo shoot supplements, as traditional data suggests they can stimulate uterine contractions.
- Pregnancy Risk: Pregnant women, particularly in the first trimester, are advised to avoid consuming bamboo shoots as they may cause pregnancy-related complications.
- Thyroid Function: Frequent consumption of bamboo shoots can have goitrogenic (thyroid-shrinking) effects, so moderation is recommended for individuals with thyroid issues.
- Scientific Evidence: While bamboo has centuries of traditional backing, more in-depth human trials are needed to fully standardize its clinical efficacy and dosages.

Challenges and Constraints

Despite its ecological and economic importance, the bamboo sector faces several structural and biological constraints that limit its optimal utilization. One of the primary biological challenges is the irregular and long flowering cycle (30–120 years), often followed by mass mortality, which disrupts resource availability and ecosystem stability (Liese & Köhl, 2015). Additionally, limited seed viability and dependence on vegetative propagation restrict large-scale, genetically diverse plantation development (Scurlock *et al.,* 2000). From a technological perspective, the sector suffers from inadequate processing infrastructure and lack of advanced treatment technologies, leading to poor product quality and reduced durability (INBAR, 2019). The absence of standardized grading and preservation techniques further constrains industrial applications.

Economically, weak market linkages, price instability, and exploitation by intermediaries hinder the profitability of bamboo-based enterprises, particularly affecting rural and tribal communities (FAO, 2007). Moreover, limited access to credit, insufficient skill development, and lack of awareness impede entrepreneurship and value addition. Policy-related challenges include fragmented institutional frameworks and inconsistent implementation of government schemes, despite initiatives such as the National Bamboo Mission (Government of India, 2020). Furthermore, pest and disease incidences, such as fungal infections and insect infestations, pose risks to productivity and sustainability (Nath *et al.,* 2009). Addressing these constraints requires integrated interventions encompassing technological innovation, policy strengthening, and capacity building to fully harness bamboo's potential in sustainable development.

Future Prospects and Research Directions

Bamboo holds significant promise as a strategic resource within the framework of sustainable development and the emerging bioeconomy. Future research should prioritize genetic improvement and molecular breeding to develop high-yielding, stress-tolerant, and disease-resistant bamboo species. Advances in biotechnological interventions, including tissue culture and genomic tools, can facilitate large-scale propagation and conservation of genetic resources (Liese & Köhl, 2015). There is a critical need to enhance carbon sequestration assessments through long-term ecological studies and standardized methodologies to integrate bamboo into global climate mitigation frameworks (Song *et al.,* 2011). Additionally, research on soil–plant interactions and ecosystem services will strengthen its role in land restoration and climate-resilient landscapes (Nath *et al.,* 2009).

From an industrial perspective, the development of engineered bamboo products, bio-based composites, and advanced processing technologies can significantly improve value addition and global competitiveness (Scurlock *et al.,* 2000). Strengthening supply chains, market linkages, and policy support mechanisms is essential to promote bamboo-based enterprises, particularly in rural and tribal economies (INBAR, 2019). Furthermore, interdisciplinary approaches integrating ethnobotanical knowledge, socio-economic studies, and sustainability science are necessary to ensure inclusive and community-based resource management. Overall, bamboo research should align with circular economy principles to maximize its ecological and economic potential.

Future research and development must transition bamboo (Bambusoideae) from a traditional, localized resource into a highly standardized, industrialized green asset.

Conclusion

Bamboo (Bambusoideae) represents a highly versatile and sustainable bio-resource with significant ecological, economic, and industrial relevance. Its rapid growth, high carbon sequestration capacity, and ability to restore degraded ecosystems position it as an effective tool for climate change mitigation and environmental management (Scurlock *et al.,* 2000; Nath *et al.,* 2009). Simultaneously, bamboo plays a crucial role in supporting rural livelihoods and fostering economic development through its diverse applications in construction, handicrafts, textiles, and emerging bio-based industries (FAO, 2007; INBAR, 2019).

Despite its vast potential, the sector remains constrained by technological, institutional, and market-related challenges. Addressing these limitations through scientific innovation, policy support, and value chain development is essential for enhancing its utilization efficiency. Integrating bamboo into the circular bio-economy and sustainable development frameworks can significantly contribute to achieving environmental sustainability and socio-economic resilience.

Almost whole *Bambusoideae* family functions as a vital, sustainable resource providing significant ecological, socio-economic, and ethno-medicinal benefits. Future efforts must prioritize maximizing this potential by combining traditional knowledge with advanced industrial processing, standardized pharmacological research, and sustainable management practices.

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Table 1. Socio-economic importance of bamboo

Aspect	Key Features	Examples/Applications	Socio-economic Benefits	Key References
Livelihood support	Employment through cultivation, harvesting, processing and marketing	Nursery raising, bamboo plantations, handicrafts, local trade	Income generation for rural and tribal communities; women empowerment; poverty reduction	FAO (2007); INBAR (2019, 2023)
Cottage and small-scale industries	Low investment, labour-intensive, skill-based enterprises	Baskets, mats, handicrafts, furniture, household items	Self-employment, preservation of traditional knowledge, rural entrepreneurship	Lobovikov et al. (2007); FAO (2007)
Construction and housing	Strong, lightweight and renewable material	Housing, scaffolding, roofing, flooring, bridges	Cost-effective and environmentally friendly construction material	Liese & Köhl (2015); Van Dam (2022)
Paper and pulp industry	High cellulose and relatively low lignin content	Writing paper, packaging paper, pulp products	Alternative raw material to wood, reduced pressure on forests	INBAR (2019); FAO (2007)

Aspect	Key Features	Examples/Applications	Socio-economic Benefits	Key References
Furniture and engineered products	High mechanical strength and durability	Laminated boards, bamboo plywood, flooring, furniture	Value addition, export potential, sustainable wood substitute	Van Dam (2022); INBAR (2023)
Textile industry	Cellulose extracted for fibre production	Bamboo viscose, blended fabrics, technical textiles	Expanding eco-textile market and industrial diversification	INBAR (2023)
Food and nutrition	Edible young shoots rich in fibre, vitamins and minerals	Fresh shoots, fermented shoots, pickles, canned products	Nutritional security and income from food processing	Nirmala et al. (2011)
Bioenergy and bio-based products	High biomass production	Charcoal, pellets, briquettes, bioethanol, biochar	Renewable energy source and waste utilization	INBAR (2023); IPCC (2022)
Green economy and circular bioeconomy	Renewable, biodegradable and recyclable resource	Bioplastics, biodegradable packaging, green building materials	Lower carbon footprint, resource efficiency and sustainable production	UNEP (2024); INBAR (2023)
Government support	Policy reforms and institutional programmes	National Bamboo Mission, skill development, processing units	Improved market access, entrepreneurship and value chain development	Government of India (2020); Ministry of Agriculture & Farmers Welfare (2023)
Major challenges	Weak value chains, limited mechanization, poor processing infrastructure, market fluctuations	Small-scale production, limited exports	Need for policy support, technological innovation and capacity building	INBAR (2019, 2023); FAO (2007)

Table 2: Active component and medicinal property, plant parts used and Therapeutic Mechanism are depicted

Medicinal Property	**Active Bioactive Constituents**	**Plant Part Used**	**Primary Therapeutic Mechanism**
Antioxidant & Free-Radical Scavenging	Phenolic compounds, flavonoids (*orientin, vitexin*), and ascorbic acid equivalents.	Leaves & Seeds.	Demonstrates high DPPH, H_2O_2, and ferric reducing antioxidant power (FRP) to minimize localized oxidative cellular stress.
Anti-Inflammatory & Analgesic	Ferulic acid, structural bio-silica, and flavone fractions.	Leaves & Culm (Stalk).	Suppresses pro-inflammatory markers (in vitro assays show up to 40% target pathway inhibition), dramatically reducing joint swelling and Vata-related musculoskeletal pain.
Antimicrobial & Antibacterial	Secondary metabolic tannins, essential oils, and phenolic acids.	Leaves.	Displays protective broad-spectrum inhibition against bacterial strains and acts as a localized natural antiseptic agent to assist in clean tissue preparation.
Antiviral / Respiratory Defense	Soluble organic plant polysaccharides and leaf extracts.	Leaves.	Suppresses viral pathogen attachment (in vitro laboratory assays showed up to 60% baseline inhibition against common respiratory viral strains like Influenza A).
Anti-Hyperglycemic (Antidiabetic)	Extracted core polysaccharides and complex structural dietary fiber.	Young Shoots & Leaves.	Inhibits rapid carbohydrate breakdown enzymes, preventing post-meal glycemic surges and supporting pancreatic metabolic health.
Tissue Regeneration & Bone Support	Silicic acid, organic calcium, magnesium, and trace manganese.	Culm Sap & Leaves.	Promotes collagen type-1 synthesis directly in bone tissue matrixes, which aids structural skeletal remineralization and counters osteoarthritis.

Table 3: Major medicinal bamboo species, their geographic roots, and their specific therapeutic properties

Bamboo Species	**Primary Medical System**	**Key Medicinal Uses**
Phyllostachys edulis / Phyllostachys nigra (Moso & Black Bamboo)	Traditional Chinese Medicine (TCM)	The leaves (*Dan Zhu Ye*) are a clinical staple used to clear stomach and heart heat, reduce high fevers, relieve restlessness, and act as a natural diuretic to treat painful urinary conditions.
Bambusa vulgaris (Common Bamboo)	African & Asian Folk Medicine	Widely researched for its high antioxidant concentration. Extracts are used to treat malaria, typhoid fever, and high blood pressure, and exhibit strong liver-protective properties.
Dendrocalamus strictus (Solid Bamboo / Male Bamboo)	Indian Ethnomedicine	Its leaves contain dense phenolic and flavonoid compounds that exhibit highly potent free-radical scavenging (antioxidant) and anti-inflammatory properties.
Pleioblastus amarus (Bitter Bamboo)	Traditional Chinese Medicine (TCM)	Specifically cultivated for its *Ku Zhu Ye* (Bitter Bamboo Leaves), which are targeted at detoxification, curing chronic mouth ulcers, and soothing lung inflammation.
Bambusa tulda (Bengal Bamboo)	Tribal & Regional Folk Medicine	Traditionally deployed in specialized emergency folk applications, such as a localized antidote or supportive treatment for tetanus infections.

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