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Application of Bamboo-Derived Products as Medicinal Remedy and Related Environmental Studies

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Abstract
Bamboo-derived products exhibit a wide range of applications in biomedicine and environmental research. The distinctive characteristics of bamboo render it suitable for producing char (charcoal/biochar) via pyrolysis, resulting in high yields and offering potential uses across various industries, including its efficacy in detoxifying air, water, and soil. Bamboo charcoal is widely regarded as superior to conventional charcoal, boasting yields ranging from 24.60% to 74.27%, along with an absorption rate four times greater and a surface area ten times larger. Studies in the biomedical field have demonstrated the health-enhancing properties of bamboo species, showcasing their effectiveness as drug-delivery vehicles while protecting against oxidative stress, inflammation, and cardiovascular ailments, underscoring their promising applications in medicine. Moreover, the mechanical attributes of bamboo and its abundance as a resource underscore its potential across diverse industrial sectors such as construction and energy, thereby positively influencing the environment. To summarize, the rapid growth rate, cost-effectiveness, and capacity to bear loads exhibited by bamboo biomass render it a compelling substitute for conventional materials, with potential uses in energy generation as well as eco-friendly adsorbents for detoxification of the environment and medicinal applications.
Keywords: Bamboo; charcoal; biochar; medicinal remedy; environmental

Introduction

Malaysia's revised Nationally Determined Contribution (NDC) aims to reduce greenhouse gas emissions intensity by 45% from 2005 levels by 2030, in line with international climate targets, according to Prime Minister Datuk Seri Anwar Ibrahim at Energy Asia 2023 summit in Kuala Lumpur Convention Centre (KLCC). This pledge is incorporated into the National Energy Policy 2022–2040 and the 12th Malaysia Plan, which emphasize the importance of the energy sector to both socioeconomic growth and the achievement of low-carbon goals. Later this year, Malaysia will launch the Hydrogen Economy and Technology Roadmap and the National Energy Transition Roadmap to meet these objectives. Furthermore, acknowledging the importance of hydrogen for future economic growth, Malaysia has committed to reducing methane emissions by 30% by 2030 compared to 2020 levels and is still committed to using natural gas as a transitional energy source [1].

Utilizing chemical, thermal, or biological processes, biomass energy is a flexible and popular renewable energy source that can be transformed into heat, electricity, or fuel for transportation [2]. Despite the widespread use of biomass energy worldwide, maintaining a sustainable feedstock supply and advancing conversion technology remain significant obstacles. Given their high biomass yield and quick development, grasses and other herbaceous plants are especially well-suited for biomass production [3].

Bamboo - Poaceae family of grasses - recognized for its rapid growth and carbon absorption capabilities, offers diverse applications beyond traditional uses. It is a useful resource for carbon credits because of its effective carbon absorption, as shown in Figure 1. The potential of bamboo, however, is greater; as it reaches maturity, it can be used in a variety of businesses. It can be converted into biofuel, which is advantageous for industries like energy and aviation where sustainability is becoming more

and more important [4]. Research by Littlewood et al. (2013) highlights that local bamboo species in China have high sugar content, which is promising for bioethanol production [5]. Furthermore, bamboo can be used for construction due to its tensile strength, which is higher than steel [6]. However, at the moment, bamboo is mostly used in Malaysia for handicrafts and chopsticks. Bamboo has many practical applications, but its environmental benefits are best shown by its usage in creating oxygen parks in areas with low air quality.

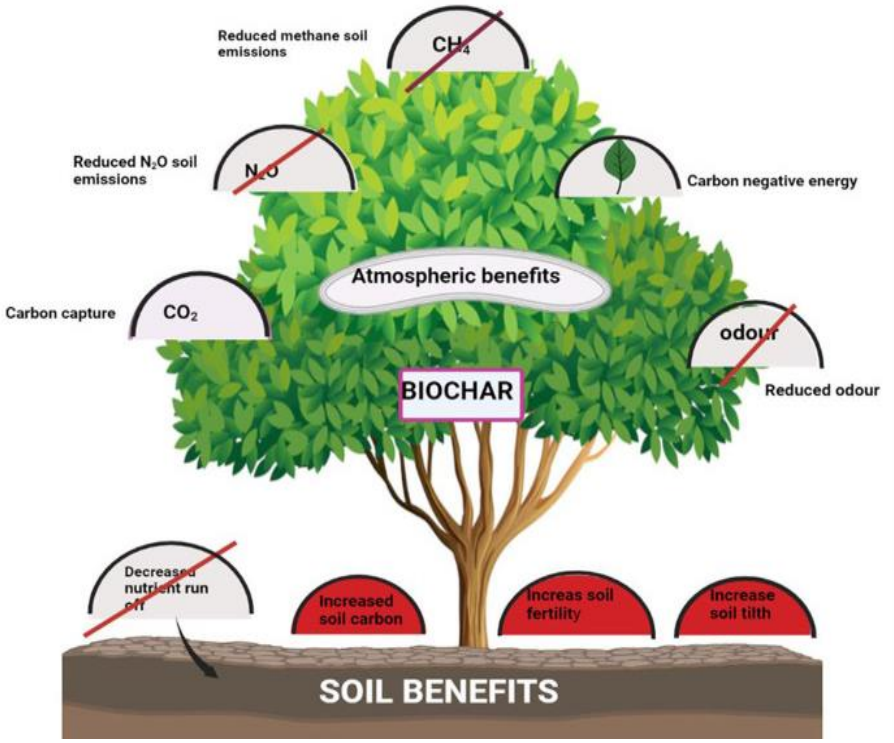

Figure 1 Environmental benefit of bamboo [4]

Traditional and modern medicinal approach

Bamboo is gaining more recognition for its medical and environmental benefits despite its fast growth and diverse uses. Bamboo has long been utilized in Asian civilizations due to its health benefits [7]. Because of its historical medical uses, scientists are researching to confirm and broaden the plant's therapeutic potential [8]. Using its traditional uses as a starting point, this research aims to discover novel applications of bamboo in medicine. The environmental advantages of bamboo are also becoming more well-known, as its quick growth and renewability make it a viable option for environmentally friendly activities and the preservation of the environment.

Many ailments, such as diabetes, obesity, cancer, hypertension, and edema, have historically been treated with bamboo [9,10,11]. The therapeutic potential of bamboo leaves, abundant in bioactive substances like flavonoids, polysaccharides, and phenolic acids, has been brought to light by recent research [8,9,11]. These constituents have exhibited noteworthy pharmacological properties, encompassing anti-inflammatory, anti-viral, anti-cancer, anti-microbial, and antioxidant actions [10,11,12]. According to studies, extracts from bamboo leaves can shield the liver, control blood cholesterol levels, and enhance blood circulation, as shown in Figure 2. Because of their antioxidant qualities and ability to prolong shelf life, bamboo leaf flavonoids are food processing additives. In contrast, bamboo leaf extracts have been shown to improve fat excretion and decrease inflammation. However, difficulties in their separation and purification limit the practical application of bamboo leaf flavonoids, highlighting the necessity for efficient techniques to separate these advantageous chemicals. Table 1 shows the summary of the different aspects of the traditional vs. modern approach.

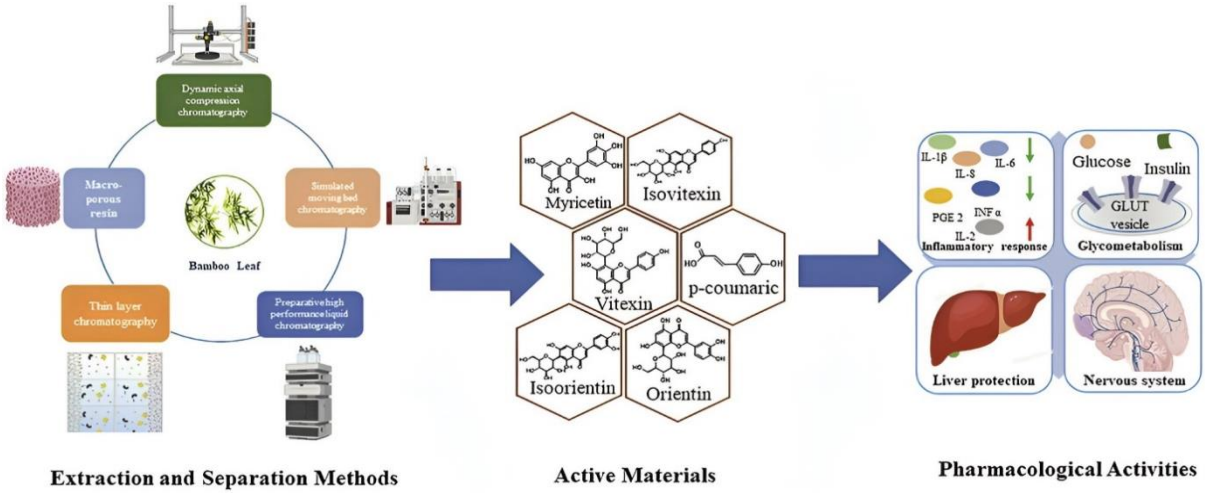

Figure 2 Overview of bamboo from raw to product [8].

In addition to its medicinal applications, bamboo is increasingly recognized for its environmental benefits. Its rapid growth and high biomass yield make it a valuable resource for bioremediation and soil improvement [13]. Studies have demonstrated bamboo's effectiveness in removing heavy metals from contaminated soils and its potential for enhancing soil fertility [14,15,16]. The study by Lo et al. (2024) found that Moso and Ma bamboo-activated carbons had optimal pH ranges of 5.81–7.86 and 7.10–9.82, respectively, for heavy metal ion adsorption, with the removal efficiency decreasing in the order: $Pb^{2+} > Cu^{2+} > Cr^{3+} > Cd^{2+}$ [16]. These environmental benefits complement bamboo's traditional uses, highlighting its versatility and sustainability. This study aims to explore the dual potential of bamboo-derived products in both medicinal and environmental contexts, drawing from historical applications and contemporary scientific findings to assess their efficacy and sustainability.

Table 1: Summary of traditional vs modern approach in different aspects [8,9,10,11,12].

Aspect	Traditional Approach	Modern Approach
Primary Uses	Medicine, construction, crafts	Medicine, biofuel, environmental remediation, food additives
Medicinal Applications	Treats diseases such as edema, hypertension, diabetes	Contains bioactive compounds like flavonoids and polysaccharides with antioxidant, anti-inflammatory, and anti-viral properties
Key Bamboo Products	Bamboo shoots, bamboo fibres, bamboo charcoal	Bamboo leaf extracts, bamboo-based biofuels, bamboo-derived food additives
Scientific Research	Limited to traditional knowledge and anecdotal evidence	Extensive studies on bioactive compounds in bamboo leaves, pharmacological activities, and industrial applications
Pharmacological Benefits	Historical use for health benefits	Modern validation of anti-oxidant, anti-inflammatory, anti-viral, and liver-protective effects
Environmental Impact	Utilized for construction and crafts, with less focus on sustainability	Significant focus on sustainability; used for biofuel, environmental remediation, and reducing carbon footprint
Food Industry Applications	Minimal use in food	Bamboo leaf flavonoids (BLF) used as antioxidants and flavour enhancers in food processing
Technological Challenges	Traditional methods with limited innovation	Advanced extraction and purification methods needed for bioactive compounds; ongoing research to improve practical applications

Bamboo-derived products

Bamboo has been integral to traditional medicine for its diverse health benefits, such as diuretic, digestive, anti-inflammatory, and antioxidant properties, derived from its shoots, leaves, and stems. Modern research has advanced these traditional applications by employing cutting-edge extraction methods—such as supercritical fluid extraction, which efficiently isolates high-purity compounds; ultrasound-assisted extraction, which enhances efficiency and speed; and enzyme-assisted extraction, which increases yield by breaking down complex plant matrices. These innovations have enabled the development of novel formulations in cosmeceuticals, nutraceuticals, and pharmaceuticals. As a result, bamboo's bioactive constituents, including flavonoids, phenolic acids, and lignans, have been more effectively harnessed, creating new health and wellness products that capitalize on bamboo's enhanced medicinal potential [16,17]. This progression merges traditional knowledge with contemporary science, broadening bamboo's applications in modern therapeutic and wellness contexts.

Table 2: Summary of bamboo products and its applications [4,7,13].

Product	Applications	Active Compounds	Preparation Method
Bamboo Extract	Antioxidant, anti-inflammatory, antimicrobial	Flavonoids, phenolic acids	Solvent extraction (ethanol, water)
Bamboo Charcoal	Detoxification, gastrointestinal issues	Activated carbon	Pyrolysis of bamboo at high temperatures
Bamboo Shoot Extract	Digestive health, anti-cancer properties	Lignans, phenolic compounds	Extraction using water or ethanol
Bamboo Silica	Bone health, joint pain relief	Silica, minerals	Preparation through extraction from bamboo stems
Bamboo Leaf Tea	Immune system support, stress relief	Flavonoids, polyphenols	Infusion of dried bamboo leaves

Bamboo is an environmentally benign and highly functional resource that may be used to make a wide range of useful goods in everyday life and numerous sectors. Bamboo vinegar, salt, shoots, extracts, and biochar are some of the most well-known items made from bamboo. These goods all use bamboo's special qualities, including its high fiber content, diverse mineral makeup, and beneficial substances [18]. Research by Prakash (2020) reported that bamboo fiber offers several advantages over cotton, including superior moisture absorption, excellent air permeability, high elasticity, a softer feel, and enhanced dyeability, and become a promising alternative to cotton in textile applications [19]. While bamboo salt and extracts provide both conventional and contemporary health benefits, bamboo vinegar and charcoal support agricultural production and environmental sustainability [20,21]. A tasty and nutrient-dense food source, bamboo shoots emphasize the plant's function in enhancing nutritional health. All of these goods made from bamboo highlight the plant's remarkable usefulness and ability to promote environmental preservation and human well-being. Figure 3 shows an overview of bamboo-derived products and the benefits of bamboo products in different industries.

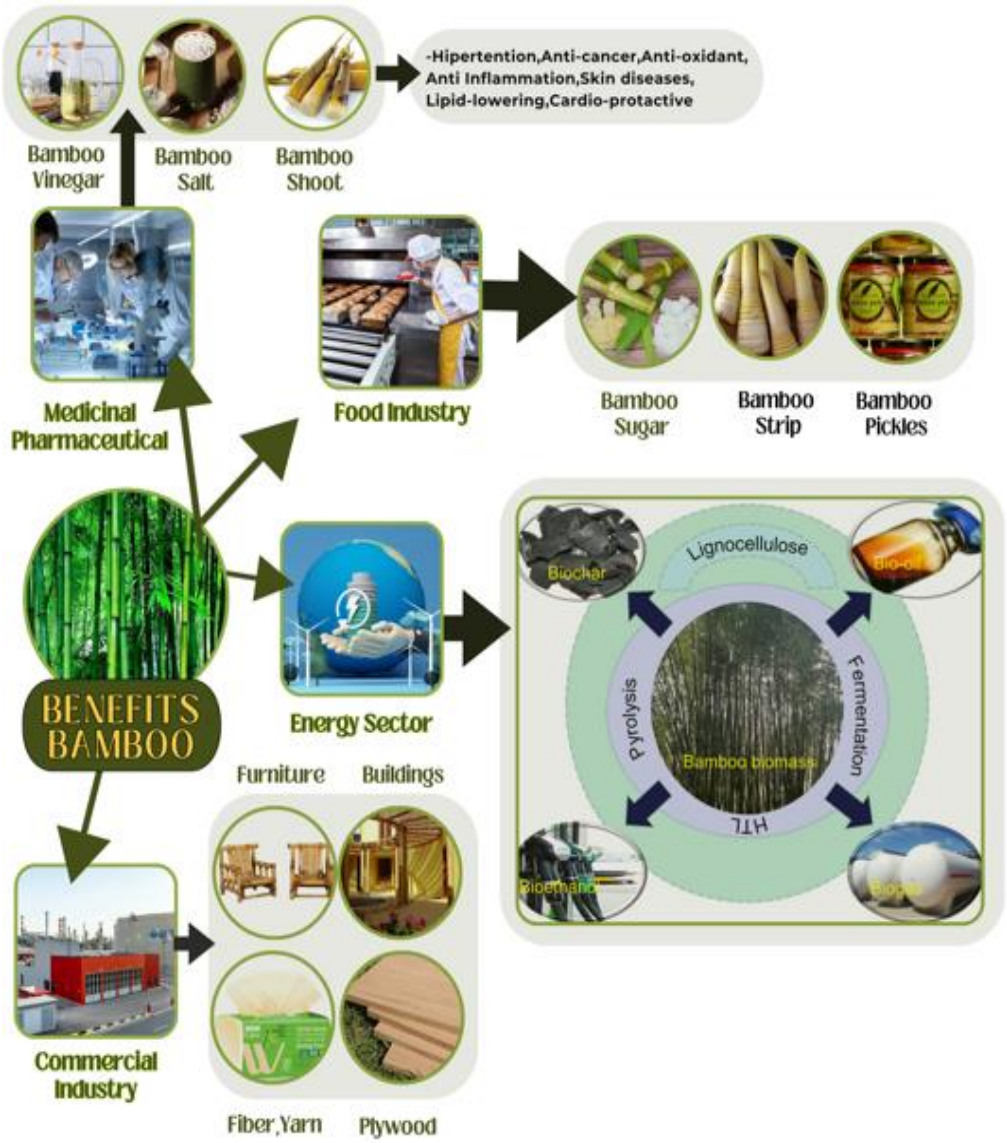

Figure 3 Overview of bamboo derived products and benefit of bamboo products in different industries

Benefits of bamboo in medicine

Bamboo offers a range of health benefits due to its rich content of bioactive compounds, including flavonoids, phenolic acids, and other phytochemicals. These compounds contribute to several key therapeutic effects:

1. **Anti-Inflammatory Properties:** Compounds found in bamboo have strong anti-inflammatory properties that can help reduce the symptoms of long-term inflammatory diseases like arthritis. By lowering the synthesis of inflammatory mediators and altering inflammatory pathways, these substances help control the pain and swelling brought on by inflammatory illnesses [22].

2. **Antioxidants Effect:** The high concentrations of flavonoids and phenolic acids in bamboo extracts are thought to be responsible for their antioxidant qualities [23]. Free radicals are unstable chemicals that can harm cells and exacerbate oxidative stress. These antioxidants aid in their neutralization. Bamboo can potentially reduce the risk of chronic diseases like cancer, neurological disorders, and cardiovascular disease by reducing oxidative damage.

3. **Cardioprotective Effects**: Research indicates that bamboo may influence lipid metabolism to provide cardioprotective benefits [24]. Bamboo extracts have the potential to increase good HDL cholesterol and decrease bad LDL and triglyceride levels. Due to its ability to lower the risk of atherosclerosis and other cardiovascular diseases, this lipid-modulating impact promotes heart health.

4. **Digestive Health**: The high fiber content of bamboo shoots is particularly noteworthy as it aids in regular bowel movements and prevents constipation, thereby promoting digestive health [25]. Because it promotes satiety and lowers total calorie consumption, bamboo's fiber also aids in weight management. Furthermore, bamboo fiber's prebiotic properties can improve the balance of gut flora, promoting general health and digestive wellness.

In conclusion, bamboo's diverse range of bioactive compounds provides several health benefits, from reducing inflammation and oxidative stress to supporting cardiovascular health and enhancing digestive function. These properties underscore the potential of bamboo as a valuable natural resource in promoting overall health and wellness.

Bamboo in environmental remediation

Bamboo's unique properties make it a promising material for environmental remediation, particularly through bamboo biochar and activated charcoal as shown in Figure 4. It has been demonstrated that bamboo biochar, created by pyrolyzing bamboo at high temperatures in an oxygen-restricted atmosphere, improves soil quality by increasing the soil's structure, ability to store water, and availability of nutrients [14]. Studied by Mahanim et al. (2011) study that bamboo charcoal is superior to conventional charcoal, offering yields between 24.60% and 74.27%, with an absorption rate four times higher and a surface area ten times larger [26]. Soil fertility and agricultural productivity both rise as a result. Furthermore, biochar can trap carbon, which lowers greenhouse gas emissions and helps slow down climate change. Because of its porous structure, it can also hold onto organic and heavy metal pollutants, preventing them from penetrating groundwater and lowering soil pollution [27].

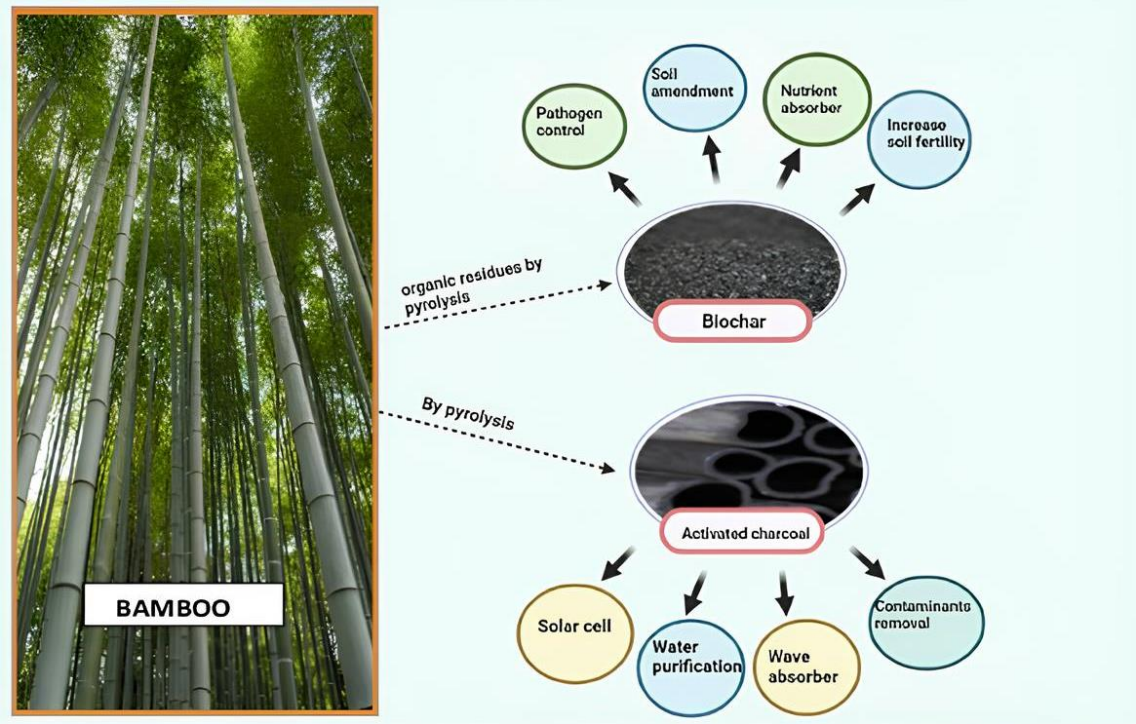

Figure 4 Production of bamboo as biochar and activated carbon [4].

Water and air can be effectively purified with activated bamboo charcoal, which is made by further processing bamboo biochar to improve its surface area and adsorption capability. Its large surface area and high porosity allow it to absorb various contaminants, such as heavy metals, poisons, and viruses [4]. This makes it an effective instrument for treating water, as it may eliminate impurities and raise the standard of the water. Furthermore, in various contexts, such as wastewater treatment plants and industrial operations, activated charcoal can be utilized to stop the spread of infections and smells [28,29]. When taken as a whole, these uses demonstrate bamboo's enormous potential to help sustainable practices and solve environmental issues. Table 3 shows the summary of the environmental applications of bamboo.

Table 3: Environmental applications of bamboo.

Application	Bamboo-Derived Product	Environmental Benefits
Biofuel Production	Bamboo biomass	Renewable energy source
Packaging	Bamboo fiber, biocomposites	Biodegradable, sustainable
Soil Remediation	Bamboo biochar	Soil improvement, carbon sequestration
Water Purification	Activated bamboo charcoal	Advanced filtration, pathogen control
Air Purification	Bamboo-based filters	Improved air quality

Application and challenges

Bamboo-derived products have shown promise in several medicinal applications. Extracts from bamboo have demonstrated antioxidant properties, which can help neutralize free radicals and reduce oxidative stress. They also exhibit anti-inflammatory effects, potentially aiding in treating inflammatory conditions. Additionally, bamboo extracts have shown antimicrobial activity against various pathogens, indicating their potential as natural antimicrobial agents. In traditional medicine, bamboo is used for various ailments, including fever, coughs, and digestive issues.

From an environmental perspective, bamboo offers several benefits. It is a highly sustainable resource, growing rapidly and requiring less water than conventional crops. Bamboo is also crucial in soil erosion control due to its extensive root system [30]. Furthermore, bamboo forests can support diverse ecosystems, contributing to biodiversity.

Despite its potential, the application of bamboo-derived products faces several challenges. Standardizing bamboo extracts is difficult due to variability in species, growth conditions, and processing methods. Regulatory hurdles also present challenges, as there are limited standardized regulations for bamboo-derived medicinal products. Economic factors include the high costs associated with research, quality control, and large-scale production. Environmental concerns involve assessing the impact of large-scale bamboo farming on local ecosystems and water resources. Additionally, public awareness and acceptance of bamboo-derived products remain limited in some regions, hindering widespread adoption.

Conclusion

Bamboo-derived products represent a promising area of research, combining traditional knowledge with modern scientific approaches to offer potential medicinal and environmental benefits. Their applications in healthcare are supported by emerging scientific evidence, while their environmental advantages highlight bamboo's role as a sustainable resource. Addressing standardization, regulation, and economic challenges will be crucial in realizing the full potential of bamboo. With ongoing research and development, along with increased public awareness and supportive policies, bamboo-derived products could significantly contribute to health and environmental sustainability.

Acknowledgement
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