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# A COMPREHENSIVE REVIEW OF BAMBOO LEAVES: PHYTOCHEMICALS, BIOACTIVITIES, TOXICITY, RESOURCE POTENTIAL IN VIETNAM

**Quynh Anh Le[1,2,3], Thanh Tai Duong[1], Thu Thuy Thi Nguyen[1], Ngoc Han Cao Nguyen[1], Lan Phi Thi Nguyen[2,3*]**

[1]*Ho Chi Minh City University of Industry and Trade*

[2]*Ho Chi Minh City University of Technology (HCMUT)*

[3]*Vietnam National University in Ho Chi Minh City (VNU HCM)*

*Email: *lanphi@hcmut.edu.vn*

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## ABSTRACT

Bamboo leaves (*Folium Bambusae*) have long been recognized as a traditional medicinal material in Eastern medicine and are extensively utilized in various classical and empirical herbal prescriptions for their heat-clearing, diuretic, and anti-inflammatory properties. In recent years, bamboo leaves have attracted considerable scientific interest, leading to an increasing number of studies. Over the past two decades, research findings related to bamboo species identification, chemical composition, biological activities, and toxicity have been consistently published. This review article synthesizes and summarizes scientific studies on the chemical composition, bioactivities, and toxicity of bamboo leaf extracts. Relevant literature was collected from international scientific databases such as PubMed, ScienceDirect, Google Scholar, Web of Science, Scopus, and ScienceGate, as well as selected reliable online sources. In addition to reviewing bamboo classification systems and global bamboo resources, this article places special emphasis on the current status and development potential of bamboo resources in Vietnam, and explores the relevance of bamboo leaves in the food industry. A total of 86 references were carefully selected based on their relevance and scientific quality and were included for data extraction and synthesis. This article provides comprehensive information on bamboo resources and various research aspects related to bamboo leaves, aiming to guide more in-depth and holistic investigations, as well as broader application trials. These efforts are expected to enhance the value of bamboo, support the sustainable development of bamboo-based ecosystems, and contribute to a green future.

*Keywords:* Bamboo leaves, phytochemical, bioactivities, toxicity, bamboo resources.

## 1. INTRODUCTION

Bamboo belongs to the grass family (Poaceae), subfamily *Bambusoideae*. It is widely distributed across tropical and subtropical regions, particularly in Asia, including China, India, Japan, and Southeast Asian countries [1]. In addition to the well-known economic values derived from bamboo culms and shoots, bamboo leaves have long been recognized as a valuable traditional medicinal material in China, India, and Japan [2]. In Vietnam, bamboo leaves are considered a traditional herbal remedy with therapeutic effects, as documented in ancient Eastern medicine texts such as “Miscellaneous Records of Famous Physicians” and “Collected Works of Tue Tinh”.

In recent years, numerous studies have been conducted to optimize the extraction processes of bamboo leaf extracts, analyze their bioactive components, and assess their toxicity. Several review articles have also been published; however, notable limitations remain. For instance, the review titled "Miraculous medicinal properties of Bamboo: a Review" by Indian authors (2021) describes various medicinal properties of bamboo but lacks reliable citations and does not comprehensively cover scientific evidence on the phytochemical composition and bioactivities of bamboo leaves [3]. Another review by Benjamin, M.A.Z. *et al.* (2023) focused on the *Bambusa* genus and provided detailed information on the compounds and biological activities; however, it did not specifically address bamboo leaves nor include toxicity-related studies [1]. Similarly, a review titled "Bamboo leaf: A review of traditional medicinal property, phytochemistry, pharmacology, and purification technology" published the same year offers a relatively complete overview of the phytochemical and medicinal properties of bamboo leaves but fails to summarize toxicity studies and does not discuss bamboo resource systems [2].

Therefore, this review aims to provide a comprehensive synthesis of published studies on the phytochemical composition, biological activities, and toxicity of bamboo leaves. Additionally, it compiles information on global bamboo resources, with particular emphasis on those in Vietnam, in order to guide future in-depth research and promote efficient and sustainable applications.

## 2. MATERIALS AND METHODS

This review was conducted using a semi-systematic approach, combining keyword-based searches with backward citation tracking from relevant review articles. The literature collection focused on four core areas:

- Phytochemical composition
- Biological activities
- Toxicity assessment
- Bamboo resources and applications

Scientific data were retrieved from major international databases including PubMed, ScienceDirect, Google Scholar, Web of Science, Scopus, SpringerLink, and ScienceGate. Additional information was collected from reputable internet-based sources such as the Food and Agriculture Organization (FAO), International Network for Bamboo and Rattan (INBAR), World Agroforestry Centre (ICRAF), Business Wire, Guadua Bamboo, and Vietnamese platforms including VNScience, Khoa học Phổ thông (a Vietnamese science outreach magazine), and the Department of Science and Technology – Ministry of Natural Resources and Environment.

The search strategy applied chronological filters from the most recent to older publications. The inclusion criteria focused on ensuring scientific relevance and quality. Specifically, documents were selected based on: (1) direct relevance to the review topic; (2) publication in reputable, peer-reviewed journals; (3) high citation frequency; and (4) availability of full-text access. Only documents meeting these criteria were included. In total, the review incorporated:

- 50 articles on phytochemical composition (published between 2009 and 2025);
- 33 articles on biological activities (published between 2013 and 2025);
- 15 articles on toxicity (published between 2006 and 2025);

- 31 sources on bamboo resources and applications include 22 scientific articles (published between 2003 and 2023) and 9 online references (updated between 2019 and 2023).

The structured process for literature identification and selection is illustrated in Figure 1.

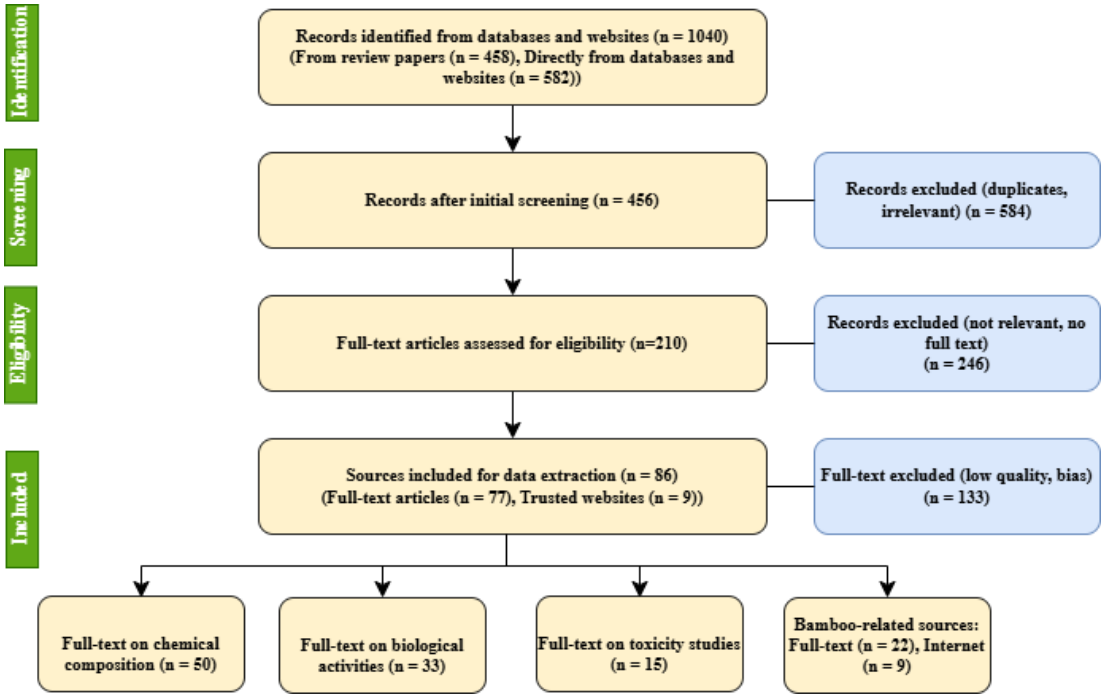


*Figure 1.* Literature screening and selection process

## 3. RESULTS AND DISCUSSION

### 3.1. Phytochemical

#### *3.1.1. Phenolic*

Phenolics are naturally occurring compounds that contain one or more hydroxyl (-OH) groups directly attached to a benzene ring. These include phenolic acids, flavonoids, stilbenes, tannins, and lignans, all of which play important roles in plant growth and defense. Polyphenols are widely found in plants and are known for their beneficial biological activities in human health [4]. As a result, this group has received the most attention in bamboo leaf studies. Total phenolic content (TPC) and total flavonoid content (TFC) have been analyzed by various researchers across different bamboo species and countries, using diverse extraction conditions and methods [5–15].

The main phenolic compounds reported include:

- **Phenolic acids**: protocatechuic acid, chlorogenic acid, caffeic acid, coumaric acid, ferulic acid, 4-Hydroxybenzoic acid, and p-Coumaric acid are commonly found in most bamboo leaf species [16–29]. These acids exhibit antioxidant, anti-inflammatory, and hepatoprotective properties, and inhibit reactive oxygen species (ROS) production. Chlorogenic acid and p-Coumaric acid are considered key contributors to antioxidant activity. 3-O-caffeoyl-1-methylquinic acid, isolated from

*Phyllostachys edulis* (China), has demonstrated antioxidant effects, activation of cellular defense systems, and skin cancer prevention potential [25].

- **Flavonoids**: These are the most abundant and significant group of phenolics in bamboo leaves. Identified flavonoids include Isoorientin, Orientin, Homoorientin, Vitexin, Homovitexin, Isovitexin, and Luteolin. Other components include Rutin, Tricin, Apigenin, Kaempferol, Quercetin, Catechin, and Naringin (Naringenin 7-Rhamnoglucoside) [16–35]. Syringaresinol-β-D-glucoside has been identified as a marker compound for *Phyllostachys bambusoides* and *Pseudosasa japonica* (Korea) [36]. 7-O-Methyltricin was reported in *Phyllostachys edulis* [25]. Multiple studies consistently affirm that flavonoids are the most bioactive and promising compounds in bamboo leaves. Isoorientin, in particular, is recognized for its anti-inflammatory and wound-healing effects.

*3.1.2. Volatile organic compounds (VOCs)*

The characteristic aroma of bamboo leaves mainly derives from aldehydes, alcohols, volatile fatty acids, and furans. Representative VOCs in bamboo leaf extracts include esters, aldehydes, alcohols, β-amyrene, α-amyrin acetate, friedelin, (e)-2-hexenal, cis-3-hexen-1-ol, benzaldehyde, and octanal [7, 28, 37–39]. These compounds provide a natural pleasant fragrance and also possess antioxidant, antibacterial, antifungal, and anti-inflammatory properties. Notably, cis-3-hexen-1-ol (27–35%) was found in *Phyllostachys heterocycla* [38] and limonene was reported in *Phyllostachys bambusoides* and *Phyllostachys pubescens*, comprising up to 32% of steam-distilled essential oil [40]. Coumaric lactone was also reported in *Phyllostachys nigra* var. *henonis* and *Phyllostachys* Sieb. et Zucc. [24, 26].

*3.1.3. Alkaloids*

Alkaloids have been detected in bamboo leaf extracts [11, 13, 19, 41]. The ethanol extract of *Bambusa vulgaris* contained the highest alkaloid content at 4.1% among identified compounds [5]. Alkaloids were associated with antifungal activity in studies on *Bambusa blumeana* [11].

*3.1.4. Saponins*

Saponins were identified in several studies. They were present in aqueous extracts of *Bambusa vulgaris* leaves and contributed to antibacterial activity [41], as well as to beneficial biochemical changes in the liver and kidneys [5].

*3.1.5. Steroids and phytoestrogens*

Steroids, particularly in the unsaturated form, were identified in *Bambusa vulgaris* [41]. β-Sitosterol and friedelin (phytosterols or triterpenoids) were reported in *Sasa palmata* [7]. Phytoestrogens were also found in extracts of *Bambusa bambos* (L.) Voss, primarily β-sitosterol and stigmasterol. The hydroalcoholic extract of *Bambusa bambos* has been suggested as a safe alternative to hormone replacement therapy for managing menopausal symptoms [42].

*3.1.6. Other bioactive compounds*

Minor compounds identified in a few studies include anthraquinones (0.06% in *Bambusa vulgaris* extract), which contribute to general bioactivity [5], and cyclitol detected via LCMS in *Bambusa stenostachya*, a naturally bioactive molecule [27].

The phytochemical profile of bamboo leaf extracts is influenced by multiple factors. Various extraction methods have been employed across studies, ranging from conventional techniques such as Soxhlet extraction and maceration [7, 15], to modern approaches including pressurized liquid extraction, microwave-assisted extraction, and ultrasound-assisted extraction [8, 10, 23, 32, 43]. A common limitation in these investigations is the insufficient assessment of influencing parameters, as most studies are conducted under a single condition or involve limited optimization, thereby restricting the broader applicability of the results. The age of the bamboo plant and the timing of leaf collection have been shown to significantly impact both the phytochemical content and the bioactivity of the extracts [14, 23]. However, very few studies have addressed the effects of external factors such as environmental conditions, soil type, or leaf maturity, which are likely to contribute meaningfully to phytochemical variability. Advanced analytical techniques such as HPLC, RP-HPLC, UHPLC, LC-MS/MS, and UPLC–QTOF–MS/MS have been widely used to identify specific phytochemicals in bamboo leaf extracts [13, 16, 17, 22, 23, 30, 31, 42, 44]. The current literature largely focuses on well-established compound classes, including phenolic acids, flavonoids, and volatile compounds. A broader exploration of less-characterized phytochemical groups is needed to achieve a more comprehensive understanding of the phytochemical complexity of bamboo leaves.

## 3.2. Biological activities

### *3.2.1. Antioxidant activity*

Antioxidant activity is one of the most characteristic properties of phytochemicals, particularly phenolic compounds such as flavonoids [4]. The antioxidant potential of bamboo leaf extracts has been demonstrated in numerous studies and across various bamboo species [6, 9, 10, 13-17, 19-23, 26, 28, 34, 38, 40, 43, 45-49]. Dried leaves from *Bambusa* spp., *Dendrocalamus* spp., and *Thyrsostachys siamensis* have shown strong antioxidant effects - comparable to green tea and superior to many other herbs such as hibiscus or lemongrass [12] (Table 1).

### *3.2.2. Antibacterial and antifungal activities*

Different bamboo species have demonstrated broad-spectrum antibacterial and antifungal effects, particularly *Phyllostachys pubescens*, *Bambusa blumeana*, and *Bambusa vulgaris*. Extracts from *Bambusa* spp., *Phyllostachys* spp., *Dendrocalamus strictus*, and *Chimonocalamus delicatus* have been shown to inhibit several bacterial strains, including *Bacillus subtilis*, *Pseudomonas aeruginosa*, *Enterococcus faecalis*, *Staphylococcus aureus*, *Escherichia coli*, *Staphylococcus epidermidis*, and *Klebsiella pneumoniae* [15, 19, 22, 38, 46, 48]. Phenolic-rich extracts from *Bambusa vulgaris* leaves exhibited strong antibacterial effects [50]. At the 12th World Bamboo Congress (2024), it was affirmed that flavonoid-rich bamboo leaf extracts are effective against a wide range of bacteria [51].

Fungal strains inhibited by bamboo extracts include *Phytophthora capsici*, *Fusarium graminearum*, *Valsa mali*, *Botryosphaeria dothidea*, *Venturia nashicola*, *Botrytis cinerea*, *Colletotrichum musae*, *Alternaria alternata*, *Aspergillus niger*, and *Penicillium chrysogenum* [11, 14, 19, 52] (Table 1).

### *3.2.3. Anticancer activity*

In vitro studies on breast and prostate cancer cells showed that extracts from *Bambusa arundinacea*, *Phyllostachys* spp., *Guadua incana* possess anticancer properties [40, 48, 53] (Table 1).

*3.2.4. Anti-inflammatory and vasoprotective effects*

Extracts of *Phyllostachys edulis* reduced the expression of pro-inflammatory cytokines, likely due to phenolic and flavonoid compounds such as isoorientin, orientin, and isovitexin [16]. Both orientin and isoorientin inhibited cytokine activity and exhibited vasoprotective effects by suppressing lipopolysaccharide (LPS)-induced inflammation [54] (Table 1).

*3.2.5. Anti-hyperglycemic activity*

Hydroalcoholic extracts from *Bambusa bambos* leaves significantly reduced blood glucose levels in streptozotocin (STZ)-induced diabetic mice. At a dose of 400 mg/kg, the effect was comparable to the standard drug metformin [55] (Table 1).

*3.2.6. Neuroprotective activity*

In Alzheimer's disease model mice, bamboo leaf extracts were shown to regulate neurotransmitter pathways, inhibit neurotransmitter-degrading enzymes, and improve learning and memory function, demonstrating neuroprotective effects [56] (Table 1).

*3.2.7. Anti-allergic effects*

Extracts from *Phyllostachys pubescens* leaves significantly inhibited IgE production in peripheral blood lymphocytes, reducing levels by up to 42.8% compared to the control, indicating strong anti-allergic potential [22] (Table 1).

*Table 1*. Biological activities of bamboo leaves

| No. | Biological Activity | Species | Countries | References |
|---|---|---|---|---|
| 1 | Antioxidant | *Bambusa* spp., *Dendrocalamopsis* spp., *Dinochloa* spp., *Gigantochloa* spp., *Lophatherum* spp., *Pleioblastus* spp., *Phyllostachys* spp., *Chimonocalamus delicatus*, *Shibataea* spp., *Thyrsostachys* spp., *Schizostachyum* spp. | India, Malaysia, Myanmar, Nepal, Japan, China, Korea | [4, 6, 9, 10, 13-17, 19-23, 26, 28, 34, 38, 40, 43, 45-49] |
| 2 | Antibacterial | *Bambusa* spp., *Phyllostachys* spp., *Chimonocalamus delicatus* | Myanmar, Nepal, Japan, China, India | [15, 19, 22, 38, 46, 48, 50, 51] |
| 3 | Antifungal | *Bambusa* spp., *Phyllostachys* spp. | Philippines, China | [11, 14, 19, 52] |
| 4 | Anticancer | *Bambusa* spp., *Phyllostachys* spp. | India, Korea | [40, 48, 53] |
| 5 | Anti-inflammatory, Vasoprotective | *Phyllostachys edulis* J. Houz | China | [16, 54] |

| | | | | |
|---|---|---|---|---|
| 6 | Anti-hyperglycemic | *Bambusa bambos* | India | [55] |
| 7 | Neuroprotective | Bamboo leaf extract | China | [56] |
| 8 | Anti-allergic | *Phyllostachys pubescens* | Japan | [22] |

With a diverse range of phytochemicals, bamboo leaf extracts have demonstrated a wide spectrum of biological activities across various studies. However, most findings are limited to in vitro experiments conducted at a few selected concentrations, often without appropriate control groups for comprehensive efficacy evaluation. Future research should delve deeper into the underlying biological and chemical mechanisms and expand toward in vivo investigations to validate and broaden current findings.

### 3.3. Toxicity evaluation

To ensure the safe application of bamboo leaves in food and health products, toxicity testing is essential. *In vitro* studies using extracts of *Phyllostachys* spp. on mouse cells have shown no cytotoxic effects [27, 33, 57]. Similarly*, in vivo* studies on various organisms such as Artemia salina larvae, mice, and rabbits have demonstrated the safety of bamboo leaf extracts from *Bambusa* spp*., Phyllostachys* spp*., Dinochloa sublaevigata, Gigantochloa levis, and Schizostachyum brachycladum* [5, 13, 24, 25, 35, 55, 58]. Dietary supplementation with bamboo leaf powder or extract in broiler chickens did not adversely affect physiological parameters and even improved growth performance and oxidative stress resistance [59,60] (Table 2).

Recently, six compounds (p-Coumaric acid, ferulic acid, caffeic acid, protocatechuic acid, gallic acid, and vanillic acid) were evaluated through in silico methods by Malaysian researchers and were found to be non-toxic and suitable for potential development into antimicrobial drugs [50] (Table 2).

However, some studies have indicated that extracts from *Phyllostachys edulis* may cause cytotoxicity in human liver cells (HepG2) at high concentrations, although they are safe at lower levels [16, 18] (Table 2).

In summary, bamboo leaves appear safe in preclinical assessments, but current toxicity studies remain limited to a few species and are primarily conducted in vitro or in animal models. Therefore, further toxicity testing, including clinical trials, is needed to provide a more comprehensive safety profile and to support the wider application of bamboo leaves.

*Table 2*. Toxicological studies on bamboo leaves

| No. | Test Type | Bamboo Species | Results | Reference |
|---|---|---|---|---|
| 1 | In vitro on HaCaT and 3T3 fibroblasts | *Phyllostachys edulis* | Non-toxic at 10–250 µg/mL and 5–100 µM | [33] |
| 2 | In vitro on HepG2 | *Phyllostachys edulis* | Cytotoxic at 0.1 and 0.2 mg/mL | [16] |
| 3 | In vitro on HepG2 | *Phyllostachys pubescens* | Safe at ≤120 µg/mL; toxic at >240 µg/mL | [18] |
| 4 | In vitro on mouse microglia (BV2 cells) | *Phyllostachys* spp. (Isoorientin) | Safe at 20 µM; neuroprotective | [57] |

| No. | Test Type | Bamboo Species | Results | Reference |
|---|---|---|---|---|
| 5 | In vitro on NIH/3T3 cells | *Bambusa stenostachya* | Non-toxic per ISO standard | [27] |
| 6 | In vivo on Artemia salina larvae | *Bambusa* spp., *Dinochloa sublaevigata*, *Gigantochloa levis*, *Schizostachyum brachycladum* | All samples non-toxic ($LC_{50}$ > 1000 µg/mL) | [13] |
| 7 | In vivo on ICR and Sprague Dawley mice | *Phyllostachys nigra* var. *henonis* | Safe at ≤4.3 g/kg/day; no toxicity | [27] |
| 8 | In vivo on Swiss albino mice | *Bambusa bambos* | No acute toxicity at 2000 mg/kg | [55] |
| 9 | In vivo on Sprague Dawley mice | *Phyllostachys nigra* var. *henonis* Strapf | No toxicity at <5000 mg/kg | [58] |
| 10 | In vivo on Sprague–Dawley & Kunming mice | Phyllostachys nigra var. *henonis* | Safe up to 4.3 g/kg/day | [24, 35] |
| 11 | In vivo on pregnant Dutch rabbits | *Bambusa vulgaris* | No histological damage, but affected liver, kidney, and hormones | [5] |
| 12 | In vivo on broiler chickens | *Bambusa vulgaris* | Reduced heat stress, improved growth at 1–2% | [59] |
| 13 | In vivo on broiler chickens | *Bambusa vulgaris* | Improved feed conversion, growth, reduced oxidative stress | [60] |
| 14 | In silico prediction | *Bambusa vulgaris* | No predicted toxicity | [50] |

Toxicological studies on bamboo leaf extracts remain limited in terms of species coverage and published data. Current findings are largely confined to in vivo experiments in animals, conducted at specific dosage levels. Future research should focus on clinical trials in both animals and humans to advance the application potential of bamboo leaf extracts, particularly in the food industry.

### 3.4. Global and Vietnamese bamboo resources

According to data from the Royal Botanic Gardens, Kew (updated as of July 2023), bamboo belongs to the grass family (Poaceae), subfamily *Bambusoideae*, and is categorized into three main tribes:

*Bambuseae* (tropical woody bamboos, the most common),

*Arundinarieae* (temperate bamboos), and

*Olyreae* (herbaceous bamboos that typically grow under forest canopies).

Each tribe contains numerous genera and species, totaling 139 genera and approximately 1,821 identified species worldwide [61]. The most commonly cultivated species is *Bambusa vulgaris* [62] (Figure 2).

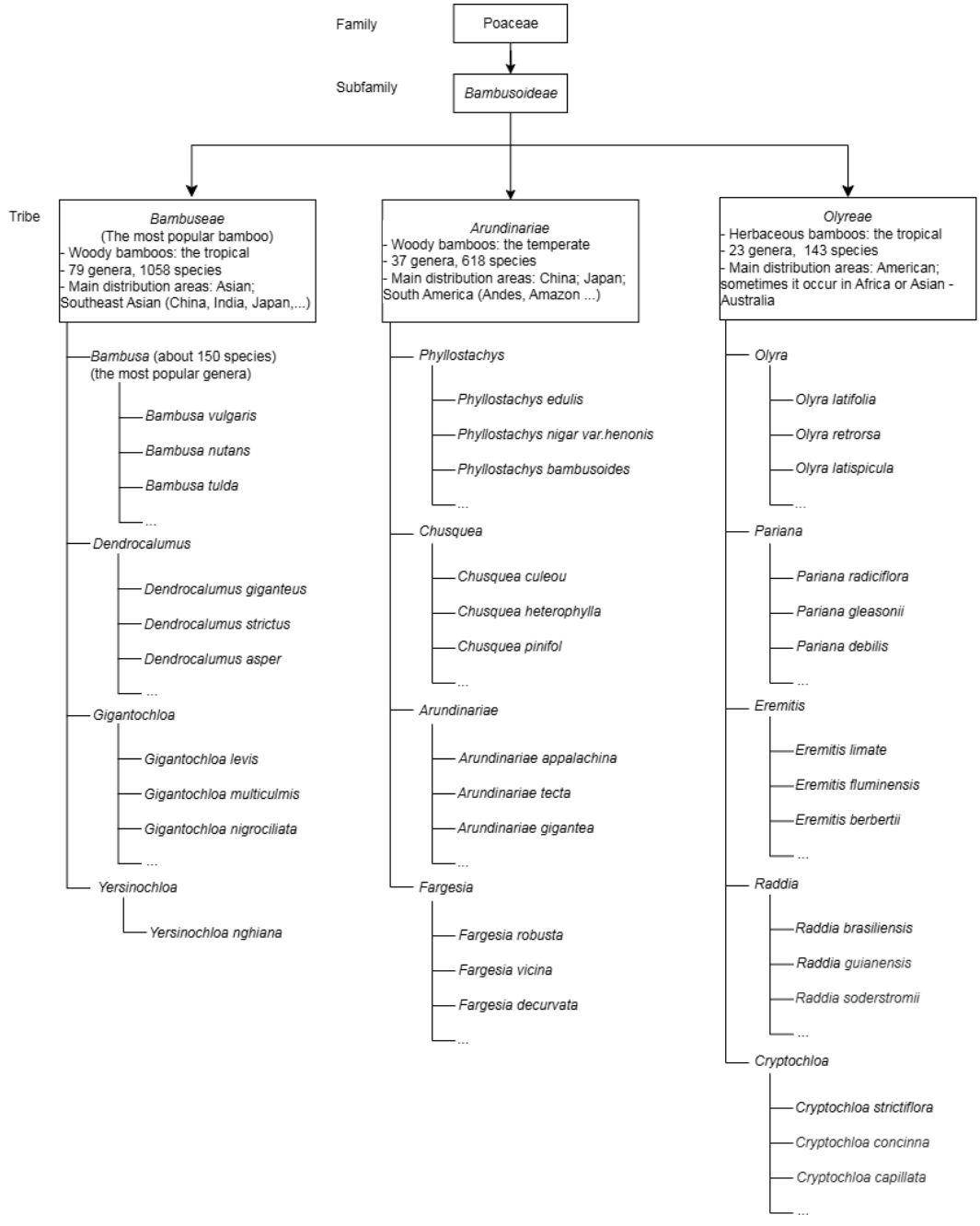


*Figure 2.* Taxonomic classification of bamboo (*Bambusoideae*)

The global bamboo coverage is estimated at approximately 35 million hectares, representing around 1% of the world's forest area [63, 64]. Although taxonomically a grass, bamboo offers ecological and economic benefits comparable to, and in some cases exceeding, those of industrial tree species such as *Acacia* and *Eucalyptus*. Its principal advantages include a rapid growth rate, high planting density, and significant biomass yield. Additionally, its short harvesting cycle enhances its economic viability [63-66]. The global bamboo market is projected to grow at a compound annual growth rate (CAGR) of 5.7% from 2021 to 2028, reaching an estimated value of USD 82.9 billion by 2028 [67].

Bamboo is primarily distributed in Asia, Africa, and the Americas, with Asia accounting for approximately 55% of the global bamboo area. Major bamboo-producing countries include China, India, Vietnam, and Japan [1-3, 64, 68–70] (Figure 3).

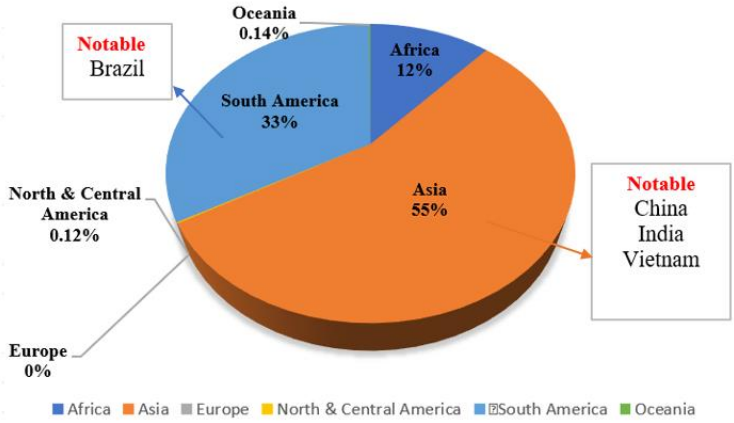


*Figure 3.* Bamboo distribution by region

## Bamboo Resources in Vietnam

Vietnam's tropical monsoon climate is highly favorable for bamboo growth. The country has around 1.6 million hectares of bamboo, found across all ecological regions-from mountains and plains to coastal and island areas. Among Vietnam's 63 provinces, 37 have more than 10,000 hectares of bamboo [71, 72]. Bamboo accounts for about 15% of Vietnam's natural forest area, and notably, 95% of bamboo coverage in the country is in natural forests, primarily located in the Northern Midlands and Mountains, North Central, and Central Highlands regions [71, 73] (Figure 4).

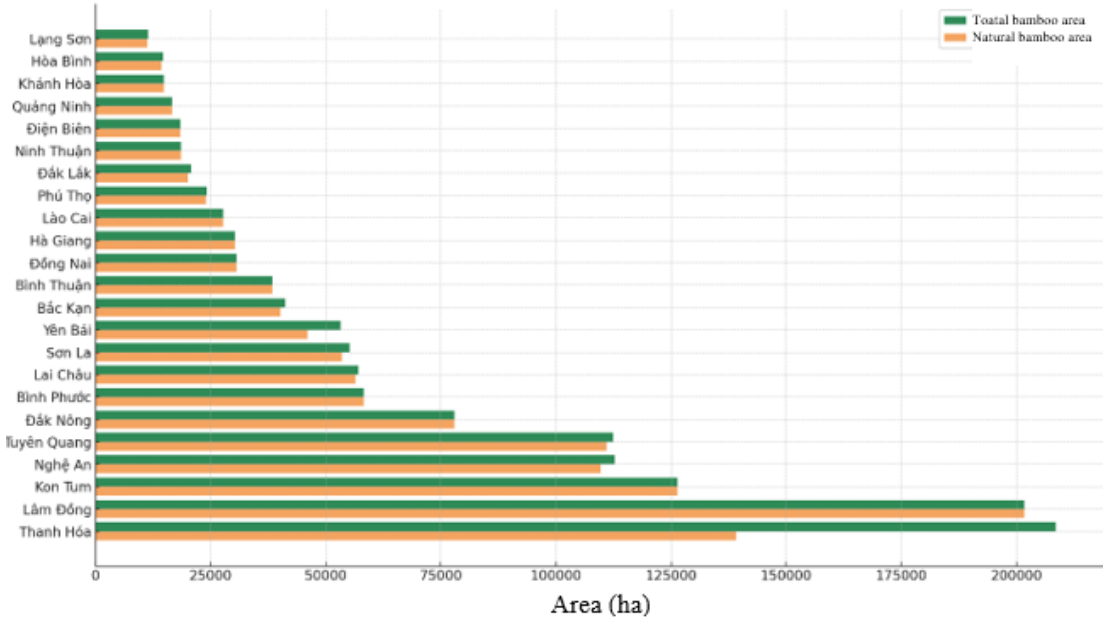


*Figure 4.* Bamboo Area by Province (Natural vs. Total)

Vietnam is home to approximately 26 genera and 216 species of bamboo, with the most diverse genera being *Bambusa* (60–70 species), *Dendrocalamus* (20–25 species), *Gigantochloa* (10–16 species), *Schizostachyum* (14 species), and *Indosasa* (11 species) [74, 75].

Common and widely distributed species in Vietnam include: *Bambusa blumeana* (thorny bamboo), *Bambusa vulgaris, Schizostachyum* spp*., Gigantochloa* spp. [70, 76].

Most of these species are native, while 16.7% are introduced [62]. Endemic or recently identified species include *Chimonocalamus bidoupensis, Yersinochloa nghiana, Yersinochloa dalatensis, Cochinchinochloa braiana, Annamocalamus kontumensis*, and *Nianhochloa bidoupensis* [77–81].

These findings underscore bamboo's crucial role in conserving Vietnam's biodiversity and contributing to global ecological sustainability. An article published by the Khoa học Phổ thông magazine (under the HCMC People's Committee) emphasized bamboo's potential for forest restoration and climate change mitigation. Vietnamese bamboo is recognized as a "champion species" for its environmental benefits. It grows rapidly, generates large biomass in a short time, and sequesters significantly more carbon 7-30% more than fast-growing trees such as fir and eucalyptus. Additionally, bamboo roots help reduce soil erosion by up to 75%. In Vietnam, bamboo is considered a "lifesaver" in flood-prone areas. Therefore, bamboo plays a vital role in both improving livelihoods and addressing global climate challenges [82, 83].

However, Vietnam's bamboo industry remains underdeveloped. Although the country has approximately 25% of China's bamboo area, its bamboo exports are only valued at USD 300–400 million per year, while China earns up to USD 500 billion annually [84]. While the global bamboo area increased by 50% between 1990 and 2020, largely due to rapid expansion in China and India, Vietnam's bamboo area has not significantly increased and may even have declined [83]. Thus, conservation and sustainable development of Vietnam's bamboo resources is an urgent priority.

In summary, bamboo leaves are a rich source of bioactive compounds, yet they remain underutilized and largely overlooked in practical applications. In many regions, they are still mainly used as animal feed [59, 60, 85] or for wrapping food products such as cakes and traditional dishes, or for decorative purposes. As such, they are often regarded as by-products or waste materials of the bamboo industry.

Since the mid-20th century, bamboo leaves have garnered increasing scientific interest, particularly in the analysis of their chemical composition. A review of scientific publications from 2003 to the present reveals that more than 18 genera and 67 species from countries such as India, Taiwan, South Korea, Malaysia, Myanmar, Nepal, Nigeria, Japan, the Philippines, China, and Italy have been investigated for their phytochemical contents and biological activities. Applications of bamboo leaves in the food and pharmaceutical industries have also been studied and are expanding, with emerging products such as bamboo beer, bamboo leaf tea, and tea bags.

However, no scientific studies on bamboo leaves have yet been reported from Vietnam, highlighting a significant untapped potential for research and development. Promoting the use of bamboo leaves not only enhances the economic value of bamboo as a crop but also supports the conservation and sustainable development of bamboo ecosystems. Utsaphong Uprarawanna *et al.* published a comprehensive review of the nutritional and functional value of bamboo, emphasizing that bamboo leaves, not just bamboo shoots, have potential applications in food and medicine. The authors advocate for the development of value-added products from the entire bamboo plant as a viable solution to address global food security challenges [86].

## 4. CONCLUSION

Bamboo leaves contain a diverse array of phytochemical compounds and exhibit various biological activities, including antioxidant, antibacterial, and anti-inflammatory effects. Despite their significant potential, bamboo leaves remain largely underutilized - particularly in Vietnam, where no scientific studies have yet been published. This review highlights the potential of bamboo leaves for development in the food and pharmaceutical industries and opens new directions for research, especially in toxicity assessment and broader food-related applications. Utilizing this untapped natural resource could enhance the economic value of bamboo and promote the sustainable development of bamboo-based ecosystems.

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## TÓM TẮT

### TỔNG QUAN TOÀN DIỆN VỀ LÁ TRE: THÀNH PHẦN HÓA HỌC, HOẠT TÍNH SINH HỌC, ĐỘC TÍNH VÀ TIỀM NĂNG TÀI NGUYÊN TRE TẠI VIỆT NAM

Lê Quỳnh Anh[1,2,3], Dương Thanh Tài[1], Nguyễn Thị Thu Thủy[1],
Nguyễn Cao Ngọc Hân[1], Nguyễn Thị Lan Phi[2,3*]
*[1]Trường Đại học Công Thương Thành phố Hồ Chí Minh (HUIT)*
*[2]Trường Đại học Bách Khoa (HCMUT)*
*[3]Thường Đại học Quốc gia Thành phố Hồ Chí Minh (VNU HCM)*
[*]Email*: lanphi@hcmut.edu.vn*

Lá tre (*Folium bambusae*) từ lâu đã được biết đến là một dược liệu truyền thống trong y học cổ truyền phương Đông, và được sử dụng phổ biến trong nhiều bài thuốc dân gian nhờ các đặc tính thanh nhiệt, lợi tiểu và chống viêm. Những năm gần đây, lá tre được nhiều nhà khoa học quan tâm, từ đó nhiều công trình nghiên cứu đã được công bố. Trong vòng hai thập kỷ qua, các nghiên cứu liên quan đến định danh loài, thành phần hóa học, hoạt tính sinh học và độc tính của lá tre đã được nghiên cứu và đăng bài liên tục. Bài báo tổng quan này nhằm hệ thống hóa và tóm lược các nghiên cứu khoa học hiện có về thành phần hóa học, hoạt tính sinh học và độc tính của chiết xuất lá tre. Nguồn dữ liệu được thu thập từ các cơ sở dữ liệu khoa học quốc tế uy tín như PubMed, ScienceDirect, Google Scholar, Web of Science, Scopus và ScienceGate, cùng với một số nguồn trực tuyến đáng tin cậy khác. Ngoài việc khảo sát hệ thống phân loại tre và hiện trạng tài nguyên tre trên phạm vi toàn cầu, bài báo đặc biệt nhấn mạnh đến thực trạng và tiềm năng phát triển tài nguyên tre tại Việt Nam, đồng thời xem xét vai trò tiềm năng của lá tre trong ngành công nghiệp thực phẩm. Tổng cộng 86 tài liệu tham khảo đã được tuyển chọn kỹ lưỡng dựa trên tiêu chí mức độ liên quan và độ tin cậy khoa học, được sử dụng để trích xuất và tổng hợp dữ liệu. Bài viết cung cấp một cái nhìn toàn diện về nguồn tài nguyên tre và các khía cạnh nghiên cứu liên quan đến lá tre về Phytochemical, hoạt tính sinh học và thử nghiệm độc tính; qua đó định hướng cho các nghiên cứu chuyên sâu hơn cũng như các thử nghiệm ứng dụng rộng rãi trong tương lai. Những đóng góp này kỳ vọng sẽ nâng cao giá trị của cây tre, thúc đẩy sự phát triển bền vững hệ sinh thái tre, và góp phần vào mục tiêu phát triển xanh.

*Từ khóa:* Lá tre, hóa thực vật, hoạt tính sinh học, độc tính, tài nguyên tre.