Ethnomedicinal Uses, Phytochemical Constituents, Pharmacological Properties, and Toxicology of the Bambusoideae Species: A Review

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Bamboos are a versatile non-timber subfamily that has been utilized for various purposes. 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. The objective of this review article is to provide in-depth discussion on botany, ethnomedicinal uses, phytochemical constituents, pharmacological properties, and toxicity of bamboo plant extract. Phytochemical studies showed that a total of 21 functional groups were detected from bamboo leaves, stems, and seeds. In addition, volatile compounds that produce aromatic odor also were detected from the bamboo extract. Meanwhile, pharmacological studies revealed that bamboo extract exhibited several pharmacological properties including anti-diarrheal, analgesic effect, antimalarial, anti-ulcer, anti-inflammatory, anti-bacterial, anti-fungal, anti-diabetic, wound healing, anticancer, and hepatotoxicity. The toxicity study found that bamboo extract is safe for consumption and did not show harmful effects. A review of phytochemical constituents and pharmacological properties in plants is important for several purposes such as new drugs discovery and understanding the mechanisms, safety, and efficacy of the bioactive compounds to treat various diseases.

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INTRODUCTION

Bamboos are important versatile non-timber forest species that hold high market value because of their various applications in human life. Bamboo belongs to the subfamily of Bambusoideae, under the grass family known as Poaceae. All the bamboo species are categorized under the subfamily of Bambusoideae. There are over 120 genera and 1641 species from the three tribes: Bambuseae, Arundinarieae, and Olyreae (Table 1) (Soreng *et al*. 2015). The tribe Bambuseae comprises tropical woody bamboos, Arundinarieae comprises temperate woody bamboos, and Olyreae comprises herbaceous bamboos (Wang *et al*. 2020a). Among all the three tribes, the most commonly found bamboo species are from the Bambuseae. The main genera from the Bambuseae are *Bambusa, Dendrocalamus*, and *Gigantochloa* (Liu *et al*. 2020). The other well-known genera are the genus *Phyllostachys* under the tribe Arundinarieae and genus *Olyra* under tribe Olyreae (Ruiz-Sanchez *et al*. 2019; Zhang *et al*. 2020).

Table 1. Taxonomical Classification of Bamboo

Kingdom	:	Plantae
Phylum	:	Magnoliophyta
Class	:	Liliopsida
Subclass	:	Commelinidae
Order	:	Cyperales
Family	:	Poaceae
Subfamily	:	Bambusoideae
Tribe	:	Bambuseae, Arundinarieae, Olyreae

From an early human civilization period until now, bamboo has been used extensively in human daily life. Therefore, bamboo has been called "the plant of multifunctional uses" (Rua *et al*. 2021). Bamboo is widely dispersed around the world, and it comprises 1% of the world forest area (Mustafa *et al*. 2021). It is reported that the bamboo forest area globally are 31.5 million hectares, with Asia region accounting for approximately 25 million hectares (Mustafa *et al*. 2021). The largest bamboo forest area is in India with 9.5 million hectares and China with 6.01 million hectares (Wang *et al*. 2020b). In addition, Asia has the biggest bamboo diversity, including over 90 genera and 900 species, encompassing about 75% of the bamboo species in the world (Bahru and Ding 2021). The highest number of bamboo species can be found in China with over 600 species, followed by India and Japan with 102 and 84 species, respectively (Ahmad *et al*. 2021). The other countries that have diverse and significant bamboo forest are Indonesia, Vietnam, Thailand, Malaysia, Brazil, and the Philippines (Du *et al*. 2018). Every bamboo species is different in terms of physical and biochemical characteristics (Rusch *et al*. 2023). Hence, bamboo has been used in various industries and bamboo byproducts have been utilized for numerous purposes such as construction materials, animal feed, textiles, paper production, sustenance, landscaping, bioenergy, and pharmaceuticals (Rathour *et al*. 2022; Yu *et al*. 2023; de Moraes *et al*. 2024).

Bamboo plants produce a wide range of bioactive compounds that are responsible for various pharmacological activities. Since a long time ago, the bamboo plant has been used for the treatment of various diseases such as fever, influenza, cough, pneumonia, heart disease, and rheumatism (Wang *et al*. 2015; Lu *et al*. 2018). In the phytochemical analysis, a total of 21 functional groups have been detected from the Bambusoideae species' extracts. The functional groups detected are alkaloids, carbohydrates, flavonoids, phenols, proteins, and others (Manohari *et al*. 2016; Dionglay *et al*. 2018; Wani *et al*. 2019; Gauchan *et al*. 2020; Putra 2024). In addition, volatile compounds also have been detected in the bamboo leaves of *Pleioblastus* spp., *Acidosasa* spp., *Pseudosasa* spp., and *Phyllostachys* spp. (Yuan *et al*. 2020; Shen *et al*. 2022; Wang *et al*. 2024). The bioactive compounds that present in the bamboo plant directly contribute to pharmacological activities including anti-diarrheal, analgesic effect, antimalarial, anti-ulcer, anti-inflammatory, anti-microbials, anti-diabetic, wound healing, anticancer, and hepatotoxicity (Wedler *et al*. 2014; Adnan *et al*. 2015; Rashid *et al*. 2016; Upreti *et al*. 2016; Anigboro 2018; Mori *et al*. 2018; Yang *et al*. 2019; Luo *et al*. 2022; Hidayah and Hafsah 2023; Sola *et al*. 2023; Chitiva *et al*. 2024).

Owing to its numerous uses in traditional medicines, various pharmacological studies have been conducted on different parts of several important bamboo species. Hence, this article aimed to comprehensively review the pharmacological properties of bamboo species. Specifically, this article provides an in-depth review of ethnomedicinal uses, phytochemical constituents, pharmacological properties, and toxicology of the

Bambusoideae species. This review article would be useful for future research related to pharmacological potential of bamboo plant that largely can contribute to pharmaceutical and nutraceutical industries.

BOTANICAL DESCRIPTION

Generally, the bamboo plant is divided into two major parts known as upper and underground parts. The upper part is the stem, which is specifically called the culms. It is woody in composition (Chaowana *et al*. 2021). The culm is cylindrical in shape and divided into multiple sections that are separated by diaphragms or nodes (Bala and Gupta 2023). The diameter of bamboo culm is between 0.64 and 30.48 cm. The weight varies depending on the bamboo species. The bamboo plant can grow up to 36 m tall (Bahtiar *et al*. 2019). Unlike a tree, bark is absent in the bamboo plant. In addition, the center of the culm is hollow; in addition, the presence of silica provides the culm with a tough outer shell, which is smooth and flexible (Su *et al*. 2021). The branches of the bamboo plant have commonly emerged from the nodes. The branches can be single or multiple branches per node. The leaves emerge from the nodal segment on the branch. Other leaves are narrow and arranged alternately along the branch. The adaxial surface of the leaves is smooth and abaxial surface of the leaves has trichomes (Li *et al*. 2023).

The lower part of the bamboo plant, which is known as the underground part, consists of rhizomes and roots. The rhizome is the main vegetative reproductive part of the bamboo plant. The rhizomes are commonly sympodial, serving as the main storage organs for the nutrients which are needed for the plant growth and development (Hu *et al*. 2023). The rhizomes have meristematic buds which develop into shoots and form a cluster of culms (Shou *et al*. 2020). There are two types of bamboo rhizomes, namely clumping and creeping rhizomes (Singnar *et al*. 2021). The clumping rhizomes grow vertically, and new shoots emerges near the main culm. Meanwhile, the creeping rhizomes are grown horizontally, and new shoots are produced at interval which can spread over long distance (Shima *et al*. 2023). The rhizomes are divided by nodes. The roots are produced at the nodal segments. The bamboo roots are fibrous and form a dense network underground to support the plant (Kaushal *et al*. 2020). The roots of the bamboo plant grow fast and rapidly can spread in the soil and colonize the area. The roots play a vital role in absorption of water and nutrients and transport throughout the plant (Hennion *et al*. 2019).

BAMBOO CLASSIFICATION

Belonging to subfamily Bambusoideae in the grass family, bamboo is diverse and widely distributed. Bamboo is classified based on various factors including geographic, morphological characteristics, and chemical composition. Different bamboo species are adapted to specific regions. This directly influences the physical properties, phytochemical constituents, and applications. The classification of bamboo are as described in Table 2.

Table 2. The Classification of Bamboo

Region	Common Bamboo Species	Morphological Characteristics	Physical Properties	Chemical Composition	Applications
Asia	*Bambusa vulgaris, Phyllostachys edulis, Dendrocalamus asper*	Tall, thick culms, hollow internodes	Strong, flexible, lightweight	High cellulose content, silica-rich	Construction, paper production
Africa	*Oxytenanthera abyssinica, Bambusa balcooa*	Medium height, dense foliage	Dense, durable	Moderate lignin, high fiber	Handicrafts, soil conservation, fodder
South America	*Guadua angustifolia, Chusquea* spp.	Large culms, strong fiber structure	High tensile strength, durable fibers	High silica content, resilient structure	Structural applications, bioenergy, furniture
Oceania	*Bambusa arnhemica, Nastus elatus*	Smaller culms, adapted to tropical conditions	Flexible, moisture resistant	High moisture content, adaptable fibers	Traditional tools, thatching, water filtration

ETHNOMEDICINAL USES OF BAMBOO

Since ancient times, bamboo has been widely planted in China and Japan. The bamboo plant, especially the leaves, has played a significant role as traditional medicine to treat various illnesses (Bal *et al*. 2012; Panee 2015). The leaves of the bamboo plant are commonly used for the treatment of cough, improvement of eyesight, and for detoxification (Ren *et al*. 2019). Besides that, bamboo leaves in combination with different herbs have been used in traditional medicine used to treat influenza and fever (Wang *et al*. 2015). In addition, bamboo leaves are used as a treatment option for pneumonia, skin diseases, and ulcer (Li 2017; Lu *et al*. 2018). In India, bamboo leaves from the *Bambusa vulgaris* are prescribed for the treatment of rheumatism, heart diseases, and malaria (Singh *et al*. 2020). It also been reported that the seeds of bamboo also can treat the rheumatism (Ayyanar and Ignacimuthu 2011; Silambarasan and Ayyanar 2015). In Bangladesh, roots and leaves are used to cure fever and skin disease (Hanif *et al*. 2009). Most of the herbal medicine from bamboo was prepared by boiling in hot water and given orally (Sangeetha *et al.* 2015). Based on the ethnomedicinal uses reported, bamboo parts might consist of a wide range of bioactive compounds that possess biological properties.

PHYTOCHEMICAL CONSTITUENTS

Higher plants have been the source of human necessities such as food, shelter, and clothing from the beginning of human civilization (Rex *et al*. 2018). Besides that, plants have been used as a source of medicine either as a traditional or modern medicine (Gakuya *et al*. 2020). The phytochemicals present in the plants are natural bioactive compounds that significantly contribute to various biological activities. Phytochemical synthesis by plants can be divided into primary and secondary metabolites, which are classified based on

chemical structures (Elshafie *et al*. 2023). Primary metabolites such as lipids, carbohydrates, and proteins, are bioactive compounds that are vital for plant physiological and biochemical processes (Salam *et al*. 2023). Meanwhile, secondary metabolites are bioactive compounds that are produced by plants to support the physiological processes and as part of plant defense mechanisms (Kumar *et al*. 2023). Secondary metabolite groups are more diverse than primary metabolites which are the main reason secondary metabolites gain more attention for the development of drugs and medicines (Pang *et al*. 2021). The example of secondary metabolite groups are phenolics, alkaloids, tannins, flavonoids, terpenoids, and others.

Phytochemical Screening in Bamboo

In determining the bioactive compounds in a plant sample, phytochemical screening is an essential step to find the functional groups that are present. Bioactive compounds are grouped based on the chemical structure. The procedure of isolating bioactive compounds from the plant extract is complicated and can be costly. The bioactive compounds are usually quantified by using high-performance liquid chromatography (HPLC), liquid-chromatography mass spectrometry (LCMS), gas-chromatography mass spectrometry (GC-MS), and nuclear magnetic resonance (NMR). Hence, conducting the functional group screening could be beneficial, as it is generally done using a qualitative method, simple procedure, quick and inexpensive (Haida *et al*. 2022).

Based on Table 3, phytochemical screening has been conducted on different bamboo species including *Bambusa vulgaris, Bambusa nutans, Bambusa tulda, Bambusa balcooa, Gigantochloa levis, Dendrocalamus asper, Bambusa blumeana,* and *Bambusa arundinacea.* A total of 21 phytochemical classes such as alkaloids, anthocyanins, betacyanins, carbohydrates, cardiac glycoside, coumarin, diterpenes, flavonoids, glycosides, phenols, phlobatannins, phytosterols, proteins, quinones, reducing sugars, resins, saponins, steroids, terpenoids, triterpenes, and tannins were detected either from the shoots, leaves, stems, and seeds of the bamboo plant (Tripathi *et al*. 2015; Owolabi and Lajide 2015; Tongco *et al*. 2016; Manohari *et al*. 2016; Dionglay *et al*. 2018; Wani *et al*. 2019; Gauchan *et al*. 2020; Putra 2024).

The phytochemicals screening was carried out by using different polarities of the extraction solvents. The higher polarity of solvents such as aqueous, methanol. and acetone were mostly chosen for extraction purposes (Dionglay *et al*. 2018; Putra 2024). This is because polar compounds such as amino acids, sugars, carbohydrates, phenolics, and glycosides are more dominant in the plant and polar solvents are more suitable for the extraction (Nawaz *et al*. 2020). Furthermore, the major phytochemical classes detected in bamboo extracts were alkaloids, carbohydrates, flavonoids, phenols, proteins, saponins, and tannins (Olowabi and Lajide 2015; Tripanthi *et al*. 2015; Gauchan *et al*. 2020; Putra 2024). Meanwhile, among all the phytochemical classes tested, groups of anthraquinones and cyanogenic glycosides were not detected in the bamboo extract (Manohari *et al*. 2016; Tongco *et al*. 2016).

Table 3. Phytochemicals Screening in Bamboo Plant

Functional Group	Test	Result: Solvent Used
Alkaloids	Dragendorff	Present: Chloroform [14], hexane [14], ethyl acetate [14] Absent: Ethanol [8,9,10,11], aqueous [8,9,10,11]
	Mayer	Present: Methanol [1] Absent: Methanol [6,7], ethanol [6,7,8,9,10,11], aqueous [6,7,8,9,10,11]
	Wagner	Present: Methanol [1,15,16], acetone [15], chloroform [16] Absent: Ethanol [2,3,4,5,13], methanol [2,3,4,5], aqueous [12,13], chloroform [15], acetone [16]
Amino acids	Ninhydrin test	Present: Chloroform [15], acetone [15,16], methanol [15,16] Absent: Ethanol [13], aqueous [13], chloroform [16]
Anthocyanins	Sodium hydroxide	Present: Methanol [1]
Anthraquinones	Borntrager's test	Absent: Aqueous [12]
Betacyanins	Sodium hydroxide	Present: Methanol [1]
Carbohydrates	Benedict's test	Present: Ethanol [5] Absent: Ethanol [2,3,4,13], methanol [2,3,4,5], aqueous [13]
	Molisch's test	Present: Ethanol [8], acetone [15,16], methanol [15,16] Absent: Ethanol [9,10,11], aqueous [8,9,10,11], chloroform [15,16]
Cardiac glycoside	Legal	Present: Methanol [1,2,3,4,5], ethanol [8,10], aqueous [8,9,10] Absent: Ethanol [9,11,13], aqueous [11,13]
	Keller-Killani	Present: Aqueous [12]
Coumarin	Sodium hydroxide	Present: Methanol [1]
Cyanogenic glycosides	Picrate paper test	Absent: Ethanol [13], aqueous [13]
Diterpenes	Copper acetate	Present: Ethanol [13], aqueous [13]
Flavonoids	Alkaline reagent test	Present: Methanol [1,3,4,5], ethanol [2,3,4,5,13], aqueous [13] Absent: Methanol [2]
	Shinoda test	Present: Methanol [6,7], ethanol [6,7,10,11], aqueous [6,7,8,9,10], chloroform [14], hexane [14], ethyl acetate [14] Absent: Ethanol [8,9], aqueous [11,12]
	Ammonia test	Present: Chloroform [15,16], acetone [15,16], methanol [15,16]
Glycosides	Borntrager	Present: Methanol [1]

		Absent: Methanol [6,7], ethanol [6,7] aqueous [6,7]
Phenols	Folin-Ciocalteu	Present: Methanol [1]
	Ferric chloride	Present: Ethanol [5,13], methanol [2,4,5], aqueous [12,13], ethyl acetate [14] Absent: Ethanol [2,3,4], methanol [3], chloroform [14], hexane [14]
	Lead acetate	Present: Aqueous [6,7], chloroform [15,16], acetone [15,16] methanol [15,16] Absent: Methanol [6,7], ethanol [6,7]
Phlobatannins	Phlobatannin test	Present: Aqueous [12]
Phytosterols	Liebermann - Burchard	Present: Methanol [4], ethanol [13] Absent: Ethanol [2,3,4,5], methanol [2,3,5], aqueous [13]
	Salkowski test	Present: Methanol [6,7], ethanol [6,7], aqueous [6,7]
Proteins	Ninhydrin	Present: Ethanol [3] Absent: Ethanol [2,4,5], methanol [2,3,4,5]
	Nitric acid	Absent: Ethanol [13], aqueous [13]
	Biuret test	Present: Acetone [15,16], methanol [15,16] Absent: Chloroform [15,16]
Quinones	Sulfuric acid	Present: Methanol [1]
Reducing sugars	Fehling's test	Present: Ethanol [8,9,10,11], aqueous [8,10,11], chloroform [15,16], acetone [15,16], methanol [15,16] Absent: Aqueous [9]
Resins	Acetone-water test	Present: Aqueous [6,7] Absent: Ethanol [2,3,4,5,6,7], methanol [2,3,4,5,6,7]
Saponins	Foam test	Present: Methanol [1,2,3], ethanol [2,3,4] Absent: Ethanol [5], methanol [4,5]
	Froth test	Present: Ethanol [2,4,5,6,7,8,10,11,13] methanol [6,7], aqueous [6,7,8,9,10,11,13] Absent: Ethanol [3,9], methanol [2,3,4,5], aqueous [12], chloroform [14], hexane [14], ethyl acetate [14]
Steroids	Liebermann-Burchard	Present: Ethanol [9,11] Absent: Methanol [1], ethanol [8,10], aqueous [8,9,10,11], chloroform [14], hexane [14], ethyl acetate [14]
Terpenoids	Copper acetate	Present: Methanol [1], ethanol [8,9,10,11], aqueous [8,9,10,11] Absent: Aqueous [12]
	Salkowski	Present: Chloroform [14,15,16], hexane [14], ethyl acetate [14], acetone [15,16], methanol [15,16]
Triterpenes	Salkowski	Present: Ethanol [3,4,5,13], methanol [3,5], aqueous [13] Absent: Ethanol [2], methanol [2,4]
Tannins	Gelatin test	Present: Methanol [1], ethanol[13], aqueous [13]

		Absent: Ethanol [2,3,4,5], methanol [2,3,4,5]
	Ferric chloride	Present: Ethanol [8,9,10,11], aqueous [8,9,10,11], chloroform [14,15,16], hexane [14], ethyl acetate [14], methanol [15,16], acetone [15,16] Absent: Methanol [6,7], ethanol [6,7], aqueous [6,7,12]

[1] Putra (2024) – *B. vulgaris*/shoots, [2] Gauchan *et al*. (2020) – *B. nutans*/leaves, [3] Gauchan *et al*. (2020) – *B. nutans*/stems, [4] Gauchan *et al*. (2020) – *B. tulda*/leaves, [5] Gauchan *et al*. (2020) – *B. tulda*/stems, [6] Wani *et al*. (2019) – *B. balcooa*/leaves, [7] Wani *et al*. (2019) – *B. balcooa*/stem, [8] Dionglay *et al*. (2018) – *G. levis*/leaves, [9] Dionglay *et al*. (2018) – *D. asper*/leaves, [10] Dionglay *et al*. (2018) – *B. vulgaris*/leaves, [11] Dionglay *et al*. (2018) – *B. blumeana*/leaves, [12] Manohari *et al*. (2016) – *B. arundinacea*/seeds, [13] Tongco *et al*. (2016) – *G. levis*/leaves, [14] Owolabi and Lajide (2015) – *B. vulgaris*/leaves, [15] Tripathi *et al*. (2015) – *B. nutans*/leaves, [16] Tripathi *et al*. (2015) – *B. vulgaris*/leaves

VOLATILE COMPOUNDS

The bamboo plant has been utilized as a healing agent. In recent years, bamboo forests have been rapidly developed and have gained popularity especially in the Asia region. Bamboo forest provides clean air, strong bactericidal ability, and comfortable thermal environment (Tang *et al*. 2023). Research has forecasted that microclimatic variables within bamboo forests may impact the emission of natural volatiles, thus influencing the efficacy of bamboo forest recreation (Choi *et al*. 2021). The bamboo forest has potential to serve as a therapy place, as it significantly affects physiological regulation such as decreasing negative emotions and increasing positive emotions (Lyu *et al*. 2019).

This evidence showed that bamboo plants biosynthesize a wide range of volatile compounds that produce an aromatic odor. The volatile compounds can be detected by using gas chromatography olfactory (GC-O), GC-MS, and aroma extract dilution analysis (AEDA) (Takahashi *et al*. 2010; Jin *et al*. 2011; Yuan *et al*. 2020; Shen *et al*. 2022; Wang *et al*. 2024).

A recent study conducted by Wang *et al*. (2024) quantified the volatile compounds in the leaves of eight bamboo species, namely *Pleioblastus amarus*, *Pleioblastus maculatus*, *Pleioblastus juxianensis*, *Acidosasa chienouensis*, *Pseudosasa amabilis*, *Phyllostachys rubromarginata*, and *Phyllostachys hirtivagina*. The analysis used GC-MS. A total of 40 compounds were identified (Table 4).

The highest contents of volatile compounds present were alcohols (55.5%), aldehydes (37.8%), terpenoids (4.5%), esters (1.6%), alkanes (0.5%), and ketones (0.2%). Among all the volatile compounds identified, 24 compounds were found to give sensory attributes of bamboo leaves that produce aromatic scents such as grassy, fruity, floral, pine, and cypress scents. The compounds were (*Z*)-3-hexen-1-ol, (*E*)-2-hexen-1-ol, 1-hexanol, 1-octen-3-ol, 3-methyl-3-heptanol, 2-ethyl-1-hexanol, (*Z*)-3-hexenal, hexanal, (*E*)-2-hexenal, benzaldehyde, (*E*,*E*)-2,4-heptadienal, 2-phenylethanal, nonanal, β-cyclocitral, ethyl hexanoic, (*Z*)-3-hexen acetate, acetic acid, α-pinene, β-pinene, 3-carene, limonene, and terpinolene (Wang *et al*. 2024). The study by Shen *et al*. (2022) identified the key odor in active compounds in *Phyllostachys pubescens* including 3-methyl-1butanol (fruity), (*E*)-2-hexenal (leafy, fruity), (*Z*)-4-heptenal (milk, creamy), ethyl hexanoate (fruity, waxy), octanal (orange peel), 6-methyl-5-hepten-2-one (lemongrass) ethyl (*Z*)-hexenoate (fruity), 1-hexanol (oily, benzaldehyde (almond), (*Z*)-2-hexen-1-ol (herbal leaf), (*Z*)-3-hexen-1-ol (fresh), and 1-octen-3-ol (mushroom). The volatile compounds detected from the bamboo plant were commonly in the group of fatty acid, alcohol, aldehydes, terpenoids, esters, and alkanes (Takahashi *et al*. 2010; Jin *et al*. 2011; Yuan *et al*. 2020).

Table 4. Volatile Compounds from the Bamboo Plant

Classification	Characteristics	Species	Part	Compound	References
Alcohol	Alcohols contain one or more hydroxyl (-OH) groups attached to a carbon atom. Alcohols are polar, soluble in water (lower molecular weights) and are widely found in essential oils, plant metabolites, and fermentation products.	*P. amarus , P. maculatus, P. juxianensis, A. chienouensis, P. amabilis, P. rubromarginata, and P. hirtivagina*	Leaves	(Z)-3-Hexen-1-ol, (E)-2-Hexen-2-ol, 1-Hexanol, 2-Furanmethanol, tetrahydro, 1-Octen-3-ol, 3-Methyl-3-Heptanol, 2-Ethyl-1-Hexanol	Wang *et al*. 2024
		P. pubescens Mazel	Leaves and stem powder	1-Butanol, 1-Pentanol, 1-Hexanol, 1-Nonanol, Octanol, 3-Heptanol, (Z)-3-Hexen-1-ol, 4-Hexen-1-ol, (E)-2-Hexen-1-ol, (E)-4-Hexen-1-ol, (R)-2-Octanol, 1-Octen-3-ol, 2-Ethyl-1-hexanol	Shen *et al*. 2022
		Phyllostachys heterocycla cv. Pubescens	Leaves	1-Hexanol, 1-Octanol, 1-Nonanol, 2-Propyl-1-pentanol, (E)-p-Mentha-2,5-dien-7-ol, 2-Methyl-1-phenylprop-2-en-1-ol	Yuan *et al.* 2020
		Phyllostachys heterocycla cv. Pubescens *Phyllostachys kwangsiensis Phyllostachys heterocycla* cv. Gracilis *Phyllostachys heterocycla* cv. Heterocycla	Leaves	3-Methyl-2-butanol, 1-Penten-3-ol, 2-Penten-1-ol, cis-3-Hexenol, Phytol	Jin *et al*. 2011
		Phyllostachys pubescens Mazel	Stems	Hexanol, Heptanol, 1-Octen-3-ol, 2-Ethyl-hexanol, Benzyl alcohol, (E)-3-Octenol, Octanol, Nonanol, 2,6-Dimethyl-cyclohexanol, Indole, (E,Z)-2,6-Farnesol, (Z,Z)-2,6-Farnesol, Phytol , Nonadecanol , Docosanol	Takahashi *et al*. 2010
Aldehydes	Aldehydes have a carbonyl (-CHO) group at the end of a carbon chain. They are highly reactive,	*P. amarus , P. maculatus, P. juxianensis, A. chienouensis, P. amabilis, P.*	Leaves	Hexanal, (E)-2-Hexenal, 2-Hexenal, (E,E)-2,4-Hexadienal, Benzaldehyde, (E,E)-2,4-Heptadienal, 2-Phenylethanal, Nonanal, β-Cyclocitral	Wang *et al*. 2024

	contribute to fragrance and flavor in plants. Aldehydes are commonly found in essential oils and metabolic pathways.	*rubromarginata, and P. hirtivagina*			
		P. pubescens Mazel	Leaves and stem powder	Hexanal, (Z)-3-Hexenal, (Z)-2-Hexenal, (E)-2-Hexenal, (Z)-4-Heptenal, Nonanal, (E)-2-Octenal, (E,E)-2,4-Heptadienal, Decanal, (E,Z)-2,6-Nonadienal, 4-Methylbenzaldehyde, 3-Methylbenzaldehyde, Benzeneacetaldehyde, (2,6,6-Trimethyl-1,3-cyclohexadiene-1-carboxaldehyde)	Shen *et al*. 2022
		Phyllostachys heterocycla cv. Pubescens	Leaves	2-Hexenal, (E,E)-2,4-Heptadienal, (E)-2-Octenal, Nonanal, (2E,6Z)-Nona-2,6-dienal, Dodecanal, 2-Undecenal, Pentadecanal, Benzaldehyde, Benzeneacetaldehyde, 2-(2,6,6-Trimethylcyclohexen-1-yl)acetaldehyde, 4-Ethylbenzaldehyde	Yuan *et al.* 2020
		Phyllostachys heterocycla cv. Pubescens *Phyllostachys kwangsiensis Phyllostachys heterocycla* cv. Gracilis *Phyllostachys heterocycla* cv. Heterocycla	Leaves	(E)-2-Hexenal, Nonaldehyde (Nonanal), Vamilic aldehyde , (2,6,6-Trimethylcyclohexa-1,3-dienecarbaldehyde), α-Ionone, β-Ionone	Jin *et al*. 2011
		Phyllostachys pubescens Mazel	Stems	Hexanal, Heptanal, (E)-2-Heptenal, Benzaldehyde, Octanal, Phenylacetaldehyde, (E)-2-Octenal, Nonanal, (E,Z)-2,6-Nonenal, Decanal, (E,E)-2,4-Nonadienal, (E)-2-Decenal, (E,E)-2,4-Decadienal, Pentadecanal, Hexadecanal	Takahashi *et al*. 2010
Esters	Esters contain a carbonyl (-COO-) functional group and are typically formed from the reaction of carboxylic acids with alcohols. Esters are	*P. amarus , P. maculatus, P. juxianensis, A. chienouensis, P. amabilis, P. rubromarginata, and P. hirtivagina*	Leaves	Ethyl hexanoic, (Z)-3-Hexen acetate, 2-Octyl acetate	Wang *et al*. 2024

	responsible for fruity aromas and flavors that are mostly found in fruits, flowers and essential oils.	*P. pubescens* Mazel	Leaves and stem powder	Hexyl 2-methyl-butanoate, Hexyl n-valerate, (Z)-3-Hexenyl pentanoate, (Z)-3-Hexenyl (E)-hexenoate	Shen *et al*. 2022
		Phyllostachys heterocycla cv. Pubescens *Phyllostachys kwangsiensis Phyllostachys heterocycla* cv. Gracilis *Phyllostachys heterocycla* cv. Heterocycla	Leaves	2-Ethylhexyl acetate, 1,2-Benzenedicarboxylic acid-bis-(2-methylpropyl)ester	Jin *et al*. 2011
		Phyllostachys pubescens Mazel	Stems	Benzyl salicylate, Methyl salicylate	Takahashi *et al*. 2010
Carboxylic acids	Carboxylic acids have a carboxyl (-COOH-) group and are classified as weak acids. Carboxylic acids play an important role in plant metabolism, synthesis of fatty acid.	*P. amarus , P. maculatus, P. juxianensis, A. chienouensis, P. amabilis, P. rubromarginata, and P. hirtivagina*	Leaves	Acetic acid	Wang *et al*. 2024
		P. pubescens Mazel	Leaves and stem powder	(E)-3-Hexenoic acid, Butanoic acid	Shen *et al*. 2022
		Phyllostachys pubescens Mazel	Stems	Nonanoic acid, Propanoic acid, Decanoic acid, Dodecanoic acid (Lauric acid), Tetradecanoic acid (Myristic acid), Pentadecanoic acid, Palmitic acid (Hexadecanoic acid), Linoleic acid	Takahashi *et al*. 2010
Terpenes and terpenoids	Terpenes are hydrocarbon compounds derived from isoprene units (C_5H_8), while terpenoids contain oxygenated	*P. amarus , P. maculatus, P. juxianensis, A. chienouensis, P. amabilis, P. rubromarginata, and P. hirtivagina*	Leaves	α-Pinene, β-Pinene, 3-Carene, Limonene, Terpinolene, Caryophyllene, β-Copaene, γ-Muurolene, Germacrene D, Bicyclosequiphellandrene, β-Cyclogermacrane α-Muurolene, β-Cadinene, trans-Calamenene	Wang *et al*. 2024

	functional groups. Terpenes and terpenoids are major components of essential oils, secondary metabolites and plant resins.	*P. pubescens* Mazel	Leaves and stem powder	p-Cymene, α-Guaiene, Caryophyllene, (4,11,11-Trimethyl-8-methylene-bicyclo[7.2.0]undec-4-ene)	Shen *et al*. 2022
		Phyllostachys heterocycla cv. Pubescens *Phyllostachys kwangsiensis Phyllostachys heterocycla* cv. Gracilis *Phyllostachys heterocycla* cv. Heterocycla	Leaves	Cedrol	Jin *et al*. 2011
		Phyllostachys pubescens Mazel	Stems	(E)-Geranyl acetone, α-Guaiene, β-Guaiene, β-Bisabolene, (E)-Nerolidol, Caryophyllene oxide, β-Ionone, α-Cadinol, β-Bisabolol, α-Bisabolol	Takahashi *et al*. 2010
Ketones	Ketones contain a carbonyl (C=O) group bonded to two carbon atoms. Ketones are volatile and contribute to aroma and flavor in plants.	*P. amarus , P. maculatus, P. juxianensis, A. chienouensis, P. amabilis, P. rubromarginata, and P. hirtivagina*	Leaves	3-Octanone, 2-methyl	Wang *et al*. 2024
		P. pubescens Mazel	Leaves and stem powder	2-Pentanone, 2,3-Butanedione, 1-Penten-3-one, 6-Methyl-2-heptanone, 6-Methyl-5-hepten-2-one, 2-Undecanone, 3-Methyl-3-penten-2-one	Shen *et al*. 2022
		Phyllostachys heterocycla cv. Pubescens *Phyllostachys heterocycla* cv. Heterocycla	Leaves	3,5-Octadien-2-one, Geranylacetone, (6,10,14-trimethyl-2-pentadecanone), Farnesyl acetone, 3-Ethyl-2-hydroxy-2-cyclopenten-1-one, 4-(2,6,6-Trimethylcyclohexa-1,3-dien-1-yl)butan-2-one, Damascenone, 1-(4-tert-butylphenyl)propan-2-one, 1-Acetyladamantane	Yuan *et al*. 2020
		Phyllostachys heterocycla cv. Pubescens *Phyllostachys kwangsiensis*	Leaves	4-Hydroxy-2-butanone, Phenylcyclohexanone	Jin *et al*. 2011

		Phyllostachys heterocycla cv. Gracilis *Phyllostachys heterocycla* cv. Heterocycla			
		Phyllostachys pubescens Mazel	Stems	6-Methyl-5-hepten-2-one, 2-Nonanone, (6,10,14-Trimethyl-2-pentadecanone), Farnesyl acetone	Takahashi *et al*. 2010
Furans & derivatives	Furans are oxygen-containing heterocyclic compounds often formed during thermal degradation of organic matter.	*P. pubescens* Mazel	Leaves and stem powder	2-Pentylfuran, (E)-2-(1-Pentenyl)furan, 2-Ethylfuran	Shen *et al*. 2022
		Phyllostachys heterocycla cv. Pubescens *Phyllostachys kwangsiensis* *Phyllostachys heterocycla* cv. Gracilis *Phyllostachys heterocycla* cv. Heterocycla	Leaves	Furfural, 5-Ethyl-2(5H)-furanone	Jin *et al*. 2011
Ionones & related	Ionones are aromatic compounds derived from carotenoids with floral, fruity and woody scents.	*Phyllostachys heterocycla* cv. Pubescens	Leaves	β-Ionone, Dihydroactinidiolide, β-Cyclocitral, Theaspirane	Yuan *et al.* 2020
Phenolic & Methoxy compounds	These compounds contain a hydroxyl (-OH) or methoxy (-OCH_3) group attached to an aromatic ring.	*Phyllostachys heterocycla* cv. Pubescens	Leaves	4-Hydroxy-2-methylacetophenone, 4-Ethyl-2-methoxyphenol	Yuan *et al.* 2020
		Phyllostachys pubescens Mazel	Stems	4-Ethylphenol, 4-Ethyl-2-methoxyphenol, 2-Methoxy-p-cresol, 4-Vinyl-2-methoxyphenol, Eugenol	Takahashi *et al*. 2010
Polycyclic & aromatic hydrocarbon	These are hydrocarbons containing multiple	*P. pubescens* Mazel	Leaves and stems powder	o-Xylene, p-Xylene, Tetradecane, Naphthalene	Shen *et al*. 2022

	benzene rings. Mostly found in combustion byproducts, plant resins, and fossil fuels.	*Phyllostachys heterocycla* cv. Pubescens	Leaves	(1,1,6-Trimethyl-naphthalene), (4-Propan-2-ylcyclohexa-1,4-dien-1-yl)methanol	Yuan *et al.* 2020
		Phyllostachys heterocycla cv. Pubescens *Phyllostachys kwangsiensis Phyllostachys heterocycla* cv. Gracilis *Phyllostachys heterocycla* cv. Heterocycla	Leaves	Toluene, 1H-Indole, 1,6-Dimethyl-naphthalene, 2-(1-Methylethyl)-naphthalene, 4-Methyl-1,1'-biphenyl, 1-Ethyl-naphthalene, (1,4,6-Trimethyl-naphthalene), (1,4,5-Trimethyl-naphthalene), 1,1'-Methylenebis-4-methylbenzene, 4,4'-Dimethylbiphenyl, 1-Methyl-3-(phenylmethyl)benzene, (E)-1,2,3-Trimethyl-4-(prop-1-en-1-yl)naphthalene, (6,10,14-Trimethyl-2-pentadecane)	Jin *et al*. 2011
		Phyllostachys pubescens Mazel	Stems	Naphthalene, 2-Methyl-naphthalene, 1-Methyl-naphthalene, 2-Ethyl-naphthalene, 2,6-Dimethyl-naphthalene, 1,2-Dimethyl-naphthalene, 1,3-Dimethyl-naphthalene, Acenaphthene, Phenanthrene, Dibenzofuran, Fluorene, Fluoranthene, Pyrene	Takahashi *et al*. 2010
Alkanes & hydrocarbons	Alkanes are saturated hydrocarbon (C-C single bonds) and hydrocarbons include unsaturated forms such as alkenes and alkynes. The compounds are nonpolar and are found in plant waxes.	*Phyllostachys pubescens* Mazel	Stems	Tetradecane, Pentadecane, Hexadecane, Heptadecane, Pentacosane, Hexacosane, Heptacosane, Nonacosane, 1-Tricosene	Takahashi *et al*. 2010

PHARMACOLOGICAL PROPERTIES

Pharmacological properties from plant extracts include therapeutic effects and biological activities of bioactive compounds derived from plants that can be utilized in medicine (Tran *et al*. 2020). Pharmacological properties are mostly attributed to secondary metabolites which possess various health benefits. The pharmacological potential of plants differs due to different compositions of bioactive compounds. As for the bamboo plant extract, the pharmacological properties that have been studied are described in the following subsections.

Anti-diarrheal Effect

Diarrhea is one of the most common diseases that caused by contaminated or wrong diets. It can lead to infection in the absorptive and secretory functions (Oghenesuvwe *et al*. 2018). The anti-diarrheal activity of bamboo was assessed by using the castor oil induced method (Rashid *et al*. 2016) (Table 5a). The mice were administered with the methanolic extract of *Bambusa bambos* leaves at the concentration of 200 and 400 mg/kg body weight. The results showed that administration of 400 mg/kg of methanolic extract of *B. bambos* leaves significantly reduced the number of diarrheal feces and lowered the percentage of inhibition of diarrhea compared to the 200 mg/kg of methanolic extract of *B. bambos* leaves and 50 mg/kg of loperamide. This study suggested that bamboo extract has anti-diarrheal properties. However, further investigation is needed to explore the underlying mechanism of action of this activity.

Analgesic Effect

Pain is an unpleasant sensation that is often caused by tissue damage. The sensation of pain is due to sensory nerve fibers stimulation (Khan *et al*. 2020). Modern medicines are effective in treating pain; however, several side effects may be observed, such as ulcer (Roy *et al*. 2023). Hence, the potential of bamboo extract to exhibit analgesic effect has been studied. The analgesic effect of bamboo plant extracts was determined using the acetic acid induced writhing in Swiss albino mice (Table 5b). Based on the previous studies, the aerial parts of *Bambusa spinosa*, *Bambusa vulgaris*, and *Dendrocalamus giganteus* were extracted with methanol at the concentrations of 50, 100, 200, and 400 mg/kg body weight (Haque *et al*. 2014; Haque *et al*. 2015; Adnan *et al*. 2015). Based on the results obtained, treatment of the mice with 400 mg/kg *B. spinosa* extract significantly reduced the number of abdominal constrictions and increased the percentage of inhibition with 2.4% and 60% inhibition, respectively (Adnan *et al*. 2015). The finding by Haque *et al*. (2015) showed that administration of 400 mg/kg methanolic extract of *B. vulgaris* resulted in a lower number of abdominal constrictions (3.0) and high percentage of inhibition (44.4%). In another study by Haque *et al*. (2014) also found that increment in the concentration of *D. giganteus* methanolic extract significantly reduced the number of abdominal constrictions and increased the percentage of inhibition. The presence of bioactive compounds from the group of alkaloids, saponins, flavonoids, and tannins might exhibit the analgesic effect (Haque *et al*. 2014). These findings suggest that bamboo extract may have analgesic properties.

Table 5. Pharmacological Properties of Bamboo Extracts

(a) Biological Activity: Anti-diarrheal					
Experiment Model; Test Subject	Plant Part; Species	Solvent	Extract Concentration	Result	Reference
Castor oil induced method; Swiss albino mice	Leaves; *Bambusa bambos*	Methanol	200, 400 mg/kg; 50 mg/kg loperamide	Administration of 400 mg/kg of extract resulted with 55.56% inhibition of diarrheal.	Rashid *et al*. 2016
(b) Biological Activity: Analgesic					
Experiment Model; Test Subject	Plant Part; Species	Solvent	Extract Dose; Positive Control	Result	Reference
Acetic acid induced writhing; Swiss albino mice	Aerial parts; *Bambusa spinosa*	Methanol	50, 100, 200, 400 mg/kg; 200, 400 mg/kg aspirin	Administration of 400 mg/kg of bamboo extract led to 60% reductions in the number of writhing.	Adnan *et al*. 2015
Acetic acid induced writhing; Swiss albino mice	Aerial parts; *Bambusa vulgaris*	Methanol	50, 100, 200, 400 mg/kg; 200, 400 mg/kg aspirin	Administration of 400 mg/kg of bamboo extract resulted with 44.4% of writhing reduction.	Haque *et al*. 2015
Acetic acid induced writhing; Swiss albino mice	Aerial parts; *Dendrocalamus giganteus*	Methanol	50, 100, 200, 400 mg/kg; 200, 400 mg/kg aspirin	The highest writhing inhibition was recorded from the administration of 400 mg/kg of bamboo extract with 51.9%.	Haque *et al*. 2014
(c) Biological Activity: Antimalarial					
Experiment Model; Test Subject	Plant Part; Species	Solvent	Extract Dose; Positive Control	Result	Reference
In vivo; Wistar albino mice	Leaves; *Bambusa vulgaris*	Aqueous	100, 200, 300 mg/kg; 100 mg/kg lonart	Malarial parasites load was significantly decreased as the administration of bamboo extract increased.	Anigboro 2018
(d) Biological Activity: Anti-Ulcer					
Experiment model; Test subject	Plant part	Solvent	Extract dose; Positive control	Result	Reference
In vivo; Albino mice	Leaves; *Bambusa balcooa*	Ethanol, methanol	Not mentioned; Ranitidine	Methanol extract exhibited anti-ulcer activity with 14.66% of protection ratio.	Upreti *et al*. 2016
(e) Biological Activity: Anti-Inflammatory					
Experiment Model; Test Subject	Plant Part; Species	Solvent	Extract Dose; Positive Control	Result	Reference
In vitro; Bovine serum albumin	Leaves; *Gigantochloa apus*	Ethanol	28, 42, 56, 70, 84 ppm; Diclofenac sodium	Increment of bamboo extract concentrations resulted in increment of bovine serum albumin inhibition.	Hidayah and Hafsah 2023

In vitro; Lipopolysaccharide-induced nitric oxide production	Leaves, shoots; *Phyllostachys edulis*	Ethanol	0.1, 0.2 mg/mL; Not mention	Bamboo leaves and shoots extracts were able to reduce Interlukin-6 and Monocyte Chemoattractant Protein-1 production.	Tundis *et al*. 2023
In vitro; Lipopolysaccharide-induced nitric oxide production	Leaves; *Sasa albomarginata*	Aqueous	1, 3, 10 mg/mL; Not mention	The bamboo leaves extract was significantly inhibited LPS-induced inflammatory responses.	Kojima *et al*. 2022
In vivo; Swiss mice	Rhizomes; *Guadua paniculata*	Aqueous	1, 5, 10, 30 mg/kg; 0.5 mg/kg Dexamenthasone	Inflammation was suppressed through downregulation of neutrophil recruitment and decreased of hyperalgesia	Sousa *et al*. 2021
In vitro; Lipopolysaccharide-induced nitric oxide production	Shoot, shoot shells; *Pleioblastus amarus*	Ethanol	20, 50, 100 µg/mL; 5µM BAY11-7082	Application of bamboo extracts were able to suppress LPS-induced nitric oxide production.	Ren *et al*. 2019
In vitro; Lipopolysaccharide-induced nitric oxide production	Leaves; *Sasa coreana*	Methanol	20, 100 µg/mL	Application of bamboo extract was significantly inhibited the production of nitric oxide.	Yang *et al*. 2017
In vitro; TNF-α induced inflammatory	Leaves; *Phyllostachys edulis*	Aqueous	25 – 250 µg/mL; 10 – 100 µg/mL Isoorientin	Bamboo leaves extract inhibited the tumor necrosis factor alpha-induced release of interlukin 8 and vascular endothelial growth.	Wedler *et al*. 2014
(f) Biological Activity: Anti-Bacterial					
Experimental Model: Bacteria Strain	Plant Part; Species	Solvent	Extract Dose; Positive Control	Result	Reference
Microdilution method; *Staphylococcus aureus, Streptococcus pneumoniae, Klebsiella pneumoniae*	Leaves, culms; *Guadua* aff. *lynnclarkiae*	Ethanol	1.55 mg/mL; 30 µg/mL Chloramphenicol	Minimum inhibitory concentration: *S. aureus*: 1.55 mg/mL (leaves and culms) *S. pneumoniae*: 12.5 mg/mL (leaves), 6.25 mg/mL (culms) *K. pneumoniae*: 6.25 mg/mL (leaves and culms)	Sola *et al*. 2023
Microdilution method; *Bacillus subtilis, Escherichia coli, Pseudomonas aeruginosa*	Leaves; *Olyra glaberrima, Aulonemia aristulata, Filgueirasia arenicola, Filgueirasia cannavieira, Merostachys neesii,*	Hexane, Ethanol	0.31 – 20 mg/mL; 3.9 – 1000 µg/mL Gentamicin	Hexane extract was more active as anti-bacterial effect compared to ethanol extract.	Anselmo-Moreira *et al*. 2021

	Merostachys pluriflora				
Agar punch diffusion assay; *Staphylococcus aureus, Bacillus subtilis, Escherichia coli*	Leaves; *Phyllostachys heterocycla*	Essential oil	0.56 – 18 mg/mL; Not available	Minimum inhibitory concentration: *B. subtilis*: 1.12 mg/mL *S. aureus*: 2.25 mg/mL *E. coli*: 0.56 mg/mL	Tao *et al*. 2019
Turbidity method; *Pseudomonas syringae, Erwinia chrysanthemi*	Leaves, branches, culms; *Phyllostachys heterocycla*	Ethanol, super-heated steam	1.5 µL; Not available	Super-heated steam culms extract inhibited the growth of *P. syringae* and *E. chrysanthemi.*	Mori *et al*. 2018
Double-plate punching method; *Bacillus subtilis, Escherichia coli, Pseudomonas fluorescens, Flavobacterium*	Leaves; *Phyllostachys heterocycla*	Essential oil	2.5, 5, 10, 20 mg/mL; Not available	Essential oil extracted showed antibacterial effect on all the tested bacterial strains.	Tao *et al*. 2018
Agar diffusion method; *Bacillus cereus, Staphylococcus aureus, Escherichia coli, Klebsiella pneumoniae*	Leaves; *Bambusa vulgaris*	Chloroform, hexane, ethyl acetate	10, 50, 100 mg/mL; 10 mg/disk Gentamicin	Minimum inhibitory concentration (mg/mL): *B. cereus* = 1.25 (hexane), 2.5 (chloroform), 5.0 (ethyl acetate) *S. aureus* = 2.5 (hexane), 5.0 (chloroform), 1.25 (ethyl acetate) *E. coli* = 2.5 (hexane), 3.5 (chloroform), 1.25 (ethyl acetate) *K. pneumoniae* = 3.5 (hexane), 2.5 (chloroform), 1.25 (ethyl acetate)	Owolabi and Lajide 2015
In vitro; *Staphylococcus aureus*	Leaves, branch, culm, knot, rhizome, root; *Phyllostachys pubescens*	Ethanol, hot aqueous	600, 1200 µg/mL	Hot water extract of all parts of *P. pubescens* were able to inhibit the growth of *S. aureus.*	Tanaka *et al*. 2014
Broth dilution method; *Escherichia coli, Staphylococcus aureus, Pseudomonas aeruginosa*	Seeds; *Bambusa bambos*	Essential oil	0.08 – 8%; Ciprofloxacin	Minimum inhibitory concentration: *E. coli*: 0.90% *S. aureus*: 1.80% *P. aeruginosa*: 2.05%	Soumya *et al*. 2014
Agar diffusion method; *Staphylococcus aureus, Escherichia coli*	Leaves; *Phyllostachys heterocycla*	Essential oil	50.42, 72.03, 102.9, 147, 210, 300 µL/mL	The essential oil extracted from *P. heterocycle* showed the anti-bacterial effect on the *E. coli* and *S. aureus.*	Jin *et al*. 2011
(g) Biological Activity: Anti-Fungal					

Experimental Model; Fungal Strain	Plant Part	Solvent	Extract Dose; Positive Control	Result	Reference
Disk diffusion method; *B. cinerea, G. cingulata, T. harzianum, H. peltate, H. lactea*	Leaves, branches, culms; *Phyllostachys heterocycla*	Ethanol, super-heated steam	20 µL; Not available	Super-heated steam culms extract inhibited the growth of *B. cinerea, G. cingulate, T. harzianum.*	Mori *et al*. 2018
Agar diffusion method; *A. niger, V. albo-atrum*	Leaves; *Bambusa vulgaris*	Chloroform, hexane, ethyl acetate	10, 50, 100 mg/mL; 10 mg/disk Ampicillin	Minimum inhibitory concentration (mg/mL): A. *niger* = 1.25 (hexane), 2.5 (chloroform), 2.5 (ethyl acetate) *V. albo-atrum* = 5.0 (hexane), 2.5 (chloroform), 1.25 (ethyl acetate)	Owolabi and Lajide 2015
Broth dilution method; *C. albicans, C. tropicalis, C. krusei*	Seeds; *Bambusa bambos*	Essential oil	0.08 – 8%; Clotrimazole	Minimum inhibitory concentration: *C. albicans*: 1.65% *C. tropicalis*: 2.88% *C. krusei*: 2.00%	Soumya *et al*. 2014
(h) Biological Activity: Anti-Diabetic					
Experimental Model; Method/Test Subject	Plant Part; Species	Solvent	Extract Dose; Positive Control	Result	Reference
In vivo; Mice	Leaves; *Dendrocalamus latiflorus*	Ethanol	200 mg/kg; 20 mg/kg pioglitazone	Administration of bamboo extract resulted in decrement of fasting blood glucose levels, body weight and low-density lipoprotein cholesterol.	Luo *et al*. 2022
In vitro; Enzyme inhibitory activity	Seeds; *Bambusa arundinacea*	Methanol, aqueous, formic acid	10 µL; Acarbose	Bamboo seeds were able to inhibit α-amylase.	Haldipur and Srividya 2021
In vivo; Wistar albino rats	Leaves; *Bambusa balcooa*	Aqueous	100, 200 mg/kg; 600 µg/kg Glibenclamide	Administration of bamboo extract in alloxan-induced rats showed significant reduction in fasting blood glucose and glycated hemoglobin level.	Goyal *et al*. 2017
In vivo; Swiss albino mice	Aerial parts; *Bambusa vulgaris*	Methanol	50, 100, 200, 400 mg/kg; 10 mg/kg Glibenclamide	Administration of 400 mg/kg of methanolic bamboo extract significantly reduced the blood glucose level by 55.3%.	Haque *et al*. 2015
In vivo; Swiss albino mice	Aerial parts; *Dendrocalamus giganteus*	Methanol	50, 100, 200, 400 mg/kg; 10 mg/kg Glibenclamide	Administration of 400 mg/kg of methanolic bamboo extract significantly reduced the blood glucose level by 53.4%.	Haque *et al*. 2014
In vivo; Albino Wistar rats	Roots; *Bambusa arundinacea*	Ethanol	50, 100, 200 mg/kg; 600 µg/kg Glibenclamide	Blood glucose level in alloxan induced diabetic rats was significantly decreased as the dosage of bamboo roots extracts were increased.	Macharla *et al*. 2012
In vivo; Albino Wistar rats	Leaves; *Bambusa arundinacea*	Ethanol, chloroform, ethyl acetate	80, 150, 350 mg/kg; 3 mg/kg Glibenclamide	All bamboo extracts significantly reduced blood glucose levels.	Nazreen *et al*. 2011

In vivo; Swiss albino mice	Leaves; *Bambusa vulgaris*	Petroleum ether	200, 400 mg/kg; 0.5 mg/kg Glibenclamide	Administration of petroleum ether bamboo extracts significantly reduced the fasting blood glucose level.	Senthilkumar *et al*. 2011
(i) Biological activity: Wound Healing					
Experimental Model; Test Subject	Plant Part; Species	Solvent	Extract Dose; Positive Control	Result	Reference
In vitro; Cell migration assay	Leaves; *Phyllostachys edulis*	Aqueous	10, 50, 100 µg/mL; 10, 25, 50, 100 µM Isoorientin	Bamboo extract was able to improve wound closure within 24 hours and inhibited cell migration without affecting cell viability.	Wedler *et al*. 2014
(j) Biological Activity: Anticancer					
Experimental Model; Test Subject/Cell Line	Plant Part; Species	Extract	Extract Dose; Positive Control	Result	Reference
In vitro MTT assay; HCT-116 (colorectal cancer)	Leaves; *Guadua incana*	Ethanol at a ratio of 1:10 (w/v)	5, 50 µg/mL; 0.1% DMSO	Concentration of 5 µg/mL resulted in a cell viability of 10% and 50 µg/mL resulted a cell viability of 5%.	Chitiva *et al*. 2024
In vitro MTT assay; MCF-7 (breast cancer)	Leaves; *Bambusa arundinacea*	Leaf derived silver nanoparticles	20, 40, 60, 80, 100 µL; Not mention	100 µL of concentration was significantly reduced the MCF-7 cell viability.	Jayarambabu *et al*. 2023
In vitro MTT assay; MCF-7 (breast cancer)	Leaves; *Bambusa arundinacea*	Leaf derived zinc oxide nanoparticles	20, 40, 60, 80, 100 µL; Not mention	Increased concentration resulted in the decrement of MCF-7 cell viability.	Jayarambabu *et al*. 2021
In vitro MTT assay; PC-3 (human prostate adenocarcinoma)	Leaves; *Bambusa arundinacea, B. nutans*	Leaf derived silver nano particles	10, 20, 30, 40, 50, 60, 70, 80, 90, 100 µg/mL	IC_{50}: *B. arundinacea*: 93.58 µg/mL *B. nutans*: 96.41 µg/mL	Kalaiarasi *et al*. 2015
In vitro MTT assay; PC-3 (human prostate adenocarcinoma)	Leaves; *Phyllostachys bambusoides, P. pubescens, P. nigra* var. Henonis	Steam extract	40 Ml; Not Mention	Cell viability (%) on PC-3 cells: *P. bambusoides* = 20.85% *P. pubescens* = 20.41% *P. nigra* var. Henonis = 1.15%	Kim *et al*. 2014
(k) Biological Activity: Hepatotoxicity					
Experimental Model; Test Subject	Plant Part; Species	Solvent	Extract Dose; Positive Control	Result	Reference
Phenylhydrazine induced acute liver injury; ICR mice	Stems; *Phyllostachys nigra*	Ethyl acetate	250, 500 mg/kg; Not mention	Serum biochemistry results showed that administration of bamboo extracts significantly reduced the ALT and AST levels.	Yang *et al*. 2019
CCL_4 induced hepatotoxicity; Wistar rat	Shoots; *Bambusa bambos*	Methanol	200, 400 mg/kg; 50 mg/kg silymarin	Administration of methanolic extract of bamboo extracts were able to reduce the AST, ALT, ALP and total bilirubin.	Patil *et al*. 2018

Thioacetamide induced acute liver injury; Wistar rat	Young shoots; *Bambusa arundinacea*	Methanol	50, 100, 200 mg/kg; 25 mg/kg silymarin	The SGPT, SGOT, ALP and total bilirubin were significantly decreased as the administration of methanolic extracts of bamboo were increased.	Chauhan *et al*. 2017
CCl_4 induced hepatotoxicity; Wistar Kyoto rat	Leaves; *Bambusa vulgaris*	Methanol, chloroform, ethyl acetate	250 mg/kg; 200 mg/kg silymarin	Chloroform extract exhibited the highest hepatoprotective effect (SGOT, SGPT, ALP) compared to methanol and ethyl acetate extracts.	Anghore and Kulkarni 2016
CCl_4 induced hepatotoxicity; Kunming mice	Leaves; Not mentioned	Ethanol	125, 250, 500 mg/kg; 5 mg/kg vitamin E	The ALT, AST and MDA contents of cells were significantly decreased after treatment with bamboo leaves extract.	Zhang *et al*. 2014

Antimalarial

The infection of *Plasmodium* parasites is a cause of malaria, and this disease is one of the major causes of morbidity and death in tropical and subtropical undeveloped countries (Nigussie and Wale 2022). The anti-malarial properties of bamboo extract were studied by Anigboro (2018) (Table 5c). The leaves of *B. vulgaris* were extracted with water. The *Plasmodium berghei* infected mice were administered with *B. vulgaris* leaves extract at the concentrations of 100, 200, and 300 mg/kg body weight. The results showed that 300 mg/kg leaves extract of *B. vulgaris* significantly exhibited the lowest percentage of malaria parasites. The study also found that administration of *B. vulgaris* bamboo extract at all concentrations exhibited better anti-malarial effect compared to the standard anti-malarial drug, Lonart at a concentration 100 mg/kg. This finding showed that bamboo extract might have the anti-malarial effect. However, further investigation is needed to study the effectiveness and side effects of the bamboo extract.

Anti-ulcer Effect

One of the most common gastrointestinal disorders that affect many people is ulcer. Some of the phytochemicals present in the plant extract can exhibit anti-ulcer properties. The study related to anti-ulcer properties of bamboo extract is very limited. An *in vivo* test study by Upreti *et al*. (2016) used the ethanol and methanol leaves extracts of *Bambusa balcooa* for the anti-ulcer analysis (Table 5d). The results found that the *B. balcooa* leaves extract showed a satisfactory protective ratio with 14.44% compared to the standard ranitidine which produced 60% of protective ratio. Although this finding shows that *B. balcooa* extract had an anti-ulcer effect, further investigation is needed to confirm its effectiveness by conducting other parameters related to anti-ulcer analysis.

Anti-Inflammatory

The physiological process that involves the intervention of the immune system is known as inflammation. Inflammation occurs to protect the organism from the infections of microbes (Bouyahya *et al*. 2022). The potential of bamboo extract in combating inflammation was studied using *in vitro* and *in vivo* techniques (Table 5e). In a recent finding by Hidayah and Hafsah (2023), the leaves of *Gigantochloa apus* were extracted using ethanol and tested using bovine serum albumin protein denaturation inhibition method. It was found that the percentage of bovine serum albumin inhibition was increased as the ethanolic leaves of *G. apus* were increased. Moreover, an *in vitro* anti-inflammatory properties of bamboo extracts were tested using lipopolysaccharide-induced nitric oxide production (Yang *et al*. 2014; Ren *et al*. 2019; Kojima *et al*. 2022; Tundis *et al*. 2023). The leaves and shoots of *Phyllostachys edulis, Sasa albomarginata*, *Pleioblastus amarus*, and *Sasa coreana* were tested using this method. The observation showed that the bamboo extracts were able to inhibit the lipopolysaccharide-induced nitric oxide production, reactive oxygen species, interlukin-6, and monocyte chemoattractant protein-1 production. Besides, the leaves extract of *Phyllostachys edulis* were found to inhibit the tumor necrosis factor alpha-induced inflammatory (Wedler *et al*. 2014). In the *in vivo* study, the results found that an aqueous rhizomes extract of *Guadua paniculata* was capable in suppressing inflammation *via* lowering hyperalgesia and downregulation of neutrophil recruitment in mice (Sousa *et al*. 2021).

Anti-Bacterial

Bacterial infections are caused by invasion and multiplication of bacterial colonies in the human body. Bacteria can be categorized into Gram-positive and Gram-negative bacteria based on their cell wall structure and respond towards Gram stain (Varghese and Balachandran 2021). The common Gram-positive bacteria are *Staphylococcus* spp., *Streptococcus* spp., and *Bacillus* spp. (Assoni *et al*. 2020). Meanwhile, the common Gram-negative bacteria are *Escherichia* spp., *Salmonella* spp., *Pseudomonas* spp., and *Klebsiella* spp. (Arbab *et al*. 2021). The anti-bacterial potential of bamboo extracts was investigated through *in vitro* method such as microdilution method, agar punch diffusion assay, turbidity method, double-plate punching method, agar diffusion method, and broth dilution method (Table 5f). A study by Sola *et al*. (2023) found that the minimum inhibitory concentration of leaves and culms extract of *Guadua* aff. *lynnclarkiae* on *Staphylococcus aureus*, *Streptococcus pneumoniae*, and *Klebsiella pneumoniae* were between 1.55 to 6.25 mg/mL. Meanwhile, the analysis of anti-bacterial properties of different species of bamboo leaves including *Olyra glaberrima*, *Aulonemia aristulata*, *Filgueirasia arenicola*, *Filgueirasia cannavieira*, *Merostachys neesii*, and *Merostachys pluriflora* found that hexane extract exhibited more anti-bacterial properties compared to ethanol extracts (Anselmo-Moreira *et al*. 2021). The essential oil extracted from the leaves of *Phyllostachys heterocycla* and seeds of *Bambusa bambos* exhibited anti-bacterial effect on Gram-positive (*S. aureus* and *Bacillus subtilis*) and Gram-negative bacteria (*Escherichia coli*, *Pseudomonas fluorescens*, *Flavobacterium*, *Pseudomonas aeruginosa*) (Jin *et al*. 2011; Soumya *et al*. 2014; Tao *et al*. 2018; Tao *et al*. 2019). The effect of different polarity of solvent (chloroform, hexane and ethyl acetate) of *B. vulgaris* leaves extract were tested on *B. cereus. S. aureus*, *E. coli*, and *K. pneumoniae* found that hexane extract exhibited the lowest minimum inhibitory concentration for *B. cereus*, ethyl acetate extract for *S. aureus*, *E. coli* and *K. pneumoniae* (Owolabi and Lajide 2015).

Anti-Fungal

Fungal infection diseases result in more than 1.5 million fatalities in a year (Al Aboody and Mickymaray 2020). The main fungal strains globally due to their high incidence of the diseases and severity are *Candida* spp., *Aspergillus* spp., *Cryptococcus* spp., and *Pneumocystis* spp. (Mendonca *et al*. 2022). The anti-fungal properties of bamboo extract were investigated by using disk diffusion method, agar diffusion method and broth dilution method on various fungal strains including *Botrytis cinerea, Glomerella cingulata, Trichoderma harzianum, Helicia peltate, Hypolepis lacteal, Aspergillus niger, Verticillium albo-atrum, Candida albicans, Candida tropicalis*, and *Candida krusei* (Table 5g). The study by Mori *et al*. (2018) found that the super-heated culm extract of *P. heterocycla* remarkably inhibited the growth of *B. cinerea*, *G. cingulate*, and *T. harzianum.* In the study conducted by Owolabi and Lajide (2015), the leaves of *B. vulgaris* were extracted with different polarity of solvents (chloroform, ethyl acetate and hexane). The results showed that hexane extract of *B. vulgaris* was more prominent in inhibit the growth of *Aspergillus niger* with the minimum inhibitory concentration recorded 1.25 mg/mL compared to chloroform and ethyl acetate extracts with 2.5 mg/mL, respectively. In contrast, the lowest minimum inhibitory concentration recorded for the *Verticillium albo-atrum* fungal strain was observed from the treatment of ethyl acetate extract of *B. vulgaris* with 1.25 mg/mL. Based on the findings by Soumya *et al*. (2014), the essential oil extracted from the seeds of *B. bambos* was able to inhibit the growth of three *Candida* fungal strains species including *C. albicans*, *C. tropicalis*, and *C. krusei.*

Anti-Diabetic

Diabetes mellitus is a chronic disease due to insufficient insulin secretion and activity. Plant contains of bioactive compounds which could have an effect as anti-diabetic properties. The anti-diabetic properties of bamboo were quantified via *in vivo* and *in vitro* techniques (Table 5h). The leaves, seeds, aerial parts and roots of *Dendrocalamus latiflorus, Bambusa arundinacea, Bambusa balcooa, Bambusa spinosa, Bambusa vulgaris*, and *Dendrocalamus giganteus* were used for the anti-diabetic test. A study using *in vitro* technique conducted by Haldipur and Srividya (2021) found that bamboo seed extract of *B. arundinacea* was able to inhibit the alpha amylase with the IC_{50} value recorded as 2.85 µg/mL. In the study conducted by Luo *et al*. (2022), the ethanolic leaves extract *D. latiflorus* significantly reduced blood glucose levels, body weight, and low-density lipoprotein cholesterol of the mice. The study found that the leaves extract of *D. latiflorus* activated the AKT signaling pathway and downregulation of phosphoenolpyruvate carboxykinase 1 and glucose-6-phosphatase expression, which resulted in decrement of glucose production (Luo *et al*. 2022). Meanwhile, the potential of *Bambusa* species extracts found that all the extract ranged from 50 to 400 mg/kg body weight exhibited anti-diabetic properties by lowering the blood glucose level (Senthilkumar *et al*. 2011; Nazreen *et al*. 2011; Macharla *et al*. 2012; Haque *et al*. 2015; Goyal *et al*. 2017). Meanwhile, a study using *D. giganteus* extract also found that increment of dosage administration from 50 to 400 mg/kg body weight resulted to decrement of blood glucose level (Haque *et al*. 2014).

Wound Healing

Wounds are characterized as physical injuries that create an opening or rupture in the skin, leading to a disruption in the normal anatomical structure of the skin and function (Rippon *et al*. 2022). Wound healing can be divided into three distinct phases: the primary inflammation is succeeded by the granulation phase associated with re-epithelialization and ultimately, the prolonged procedure of remodeling (Hong *et al*. 2023). A study on the potential of bamboo extract on wound healing activity was conducted by Wedler *et al*. (2014) by using cell mitigation assay (Table 5i). The leaves of *P. edulis* were extracted with an aqueous and diluted at the concentration of 10, 50, and 100 µg/mL. The wound healing parameters show that bamboo leaves extract improved the wound closure by 28% to 54% at 12 h and 24 h, respectively.

Anticancer

Cancer is one of the deadliest diseases in the world. Cancer is defined as development and unregulated proliferation of cells in tissues, resulting in the formation of amalgamation and tumor that have potential to spread to a whole organ or disseminate systemically to other tissues (Valent *et al*. 2012; Garcia-Oliveira *et al*. 2021). The development of anticancer agents from the plant derived bioactive compounds is more convenient due to low toxicity and side effects (Asma *et al*. 2022). *In vitro* technique *via* MTT assay was used to quantify the anticancer activity of various bamboo species including *Guadua incana, Bambusa arundinacea, Bambusa nutans, Phyllostachys bambusoides, Phyllostachys pubescens*, and *Phyllostachys nigra* (Table 5j). The cancer lines tested were HCT-116 (colorectal cancer cell), MCF-7 (breast cancer cell), and PC-3 (human prostate adenocarcinoma cell). The recent study conducted by Chitiva *et al*. (2024) found that ethanolic leaves extract of *G. incana* at a concentration of 5 µg/mL resulted 10% of cell viability of HCT-116. Increment of dosage up to 50 µg/mL had resulted in 5% of cell viability. Meanwhile, the effect of leaves extracts of *B. arundinacea* and *B. nutans*

found that increment of bamboo extracts significantly reduced the percentage of cell viability of MCF-7 (Kalairasi *et al*. 2015; Jayarambabu *et al*. 2021, 2023). In addition. The leaves extract of three species of *Phyllostachys* found that the steam leaves extracts were significantly reduced the PC-3 cell viability of *P. bambusoides, P. pubescens*, and *P. nigra* with 20.85%, 20.41%, and 1.15%, respectively (Kim *et al*. 2014).

Hepatotoxicity

One of the vital organs that control the physiological functions in human is the liver. Liver injury, which is known as hepatotoxicity, is a serious health issue that caused by hepatotoxic compounds (Al-Ezzy *et al*. 2017). The hepatotoxicity test was carried out through *in vivo* technique. The rats and mice were used as test subject and hepatotoxic was induced by phenylhydrazine, carbon tetrachloride (CCl_4), and thioacetamide (Table 5k). The study by Yang *et al*. (2019) showed that the mice injected with the stem extract of *P. nigra* at the concentration of 250 and 500 mg/kg body weight significantly reduced the plasma alanine aminotransferase (ALT) and aspartate aminotransferase (AST). In the studies conducted by using CCl_4 to induce hepatotoxicity, the extract of bamboo shoots and leaves exhibited hepatoprotective properties by reducing the aspartate aminotransferase, alanine aminotransferase, alkaline phosphate (ALP), total bilirubin, serum glutamate oxaloacetate transaminase (SGOT), and serum glutamate pyruvate transaminase (SGPT) (Zhang *et al*. 2014; Anghore and Kulkarni 2016; Patil *et al*. 2018). Meanwhile, in the study by using thioacetamide to induce hepatotoxicity, methanolic extract of *B. arundinacea* shoots extract significantly decreased the serum glutamate oxaloacetate transaminase, serum glutamate pyruvate transaminase, alkaline phosphate, total bilirubin, and direct bilirubin (Chauhan *et al*. 2017).

TOXICITY

Toxicity is the ability of a substance to cause effects on living organisms. Generally, the bioactive compounds that present in plants can potentially cause toxicity (Vilas-Boas *et al*. 2021). It is important to conduct a toxicity study and find the lethal dose for the plant extract. The toxicity test of *B. balcooa* leaves was conducted using the Arithmetic method of Karber (Goyal *et al*. 2017). The Swiss albino mice were administered with 5, 6, 7, 8 and 9 g/kg body weight of aqueous leaves extract of *B. balcooa.* The result revealed that the median lethal dose (LD_{50}) of *B. balcooa* aqueous leaves extract was 5.18 g/kg (Goyal *et al*. 2017). Rashid *et al*. (2016) carried out the toxicity test of *B. bambos* leaves extract *via* brine shrine lethality bioassay. The LD_{50} values recorded were 21.47, 8.45, 9.40, 3.91, and 16.64 µg/mL for the methanol extract, petroleum ether soluble fraction, carbon tetrachloride soluble fraction, dichloromethane soluble fraction, and aqueous soluble fraction, respectively. Meanwhile, the toxicity test conducted on the aerial parts of *D. giganteus, B. spinosa*, and *B. vulgaris* extracted with methanol did not show toxicity symptoms in mice up to dose of 3000 mg/kg body weight. There was no abnormal behavioral pattern and mortality were observed (Haque *et al*. 2014; Adnan *et al*. 2015; Haque *et al*. 2015). In addition, according to the finding by Senthilkumar *et al*. (2011), the leaves of *B. vulgaris* extracted with petroleum ether administered up to dose level of 2000 mg/kg did not show any lethality signs.

CONCLUSION AND FUTURE PROSPECTS

This review article has focused on the importance of Bambusoideae species as a potential source for pharmaceutical and nutraceutical industries. The bamboo plant is a common non-timber product, for which the medicinal potential of the bamboo plant generally is not well-known. Hence, the compilation of the phytochemical constituents and pharmacological properties of various parts of different bamboo species in this review article illuminates the point that bamboo plants also could be used as a good source for medicinal purposes. Future research on Bambusoideae species should focus on clinical validation, toxicity assessments, and phytoanalytical studies to determine the medicinal potential. The preliminary insights obtained from the *in vitro* and *in vivo* studies are sufficient for confirming bioavailability, safety, and therapeutic efficacy in humans. However, rigorous clinical trials are needed to determine appropriate dosages, side effects and long-term health benefits. In addition, developing standardized extraction and purification techniques for isolation of bioactive compounds are important to ensure the suitability for pharmaceutical applications.

Besides pharmaceutical applications, bamboo-derived bioactive compounds can also be utilized in functional foods and cosmeceuticals. Further research on synergistic effects of bamboo phytochemicals combining with bioactive compounds of other plant species should be explored to enhance therapeutic outcomes. To ensure a sustainable and scalable supply of bioactive compounds, a biotechnology approach such as plant tissue culture, elicitation, cell suspension culture, and metabolic engineering should be employed. These techniques are advanced biotechnology applications that can significantly increase the yield of targeted bioactive compounds and can reduce the reliance on large-scale harvesting of wild bamboo populations.

In addition, sustainable cultivation and conservation strategies must be developed to balance ecological preservation and commercial utilization. Although bamboo is a fast-growing species, an increase in demand for its medicinal properties could lead to overexploitation. By implementing organic cultivation methods, agroforestry practices and biodiversity conservation efforts will be essential for maintaining the ecological balance while ensuring long-term availability. Hence, through integration of biotechnology and sustainable practices, bamboo has the high potential to emerge as a high-value resource for development of natural medicines, contributing to both pharmaceutical and environmental sustainability.

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