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Review Article

A Review on Ramie (*Boehmeria nivea* L. Gaudich.): From Textile to Medicine and the Threats of Pests and Diseases

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Abstract: Ramie (*Boehmeria nivea* L. Gaud.), also known as “China grass”, is a perennial herbaceous plant of the Urticaceae family. Ramie is considered one of the ancient and important economic and natural fiber crops today. Indeed, ramie fiber ranks first in durability, tensile strength, length of fiber cells, fineness, and color. Aside from its role in the textile industry, ramie is also known for its role in traditional herbal medicine. Indeed, ramie plant extracts have been documented to benefit various organ systems of the human body. This paper reviews the advances in ramie cultivation, taxonomy, ecology, chemistry, industry use, and medicinal and therapeutic properties. Then, we discuss the current pests and diseases affecting ramie plant growth and cultivation. For instance, ramie anthracnose may yield losses averaging 20% and ranging as high as 55%. Pests like Tarbinskiellus (Brachytrypes) portentosus can cause up to 50% damage by consuming young shoots and damaging rhizomes. In contrast, the Indian red admiral caterpillar, Vanessa (Pyrameis) indica, causes up to 30% infestations. Pest management strategies can make up 15-20% of plantation costs through chemical spraying. This review would be useful in maximizing the potential benefits of ramie in the fiber industry and medicine. This is also the first review of the biotic stress affecting ramie, which may be used as a guide for future research works that aim towards a sustainable and environment-friendly pest and disease management approach, ensuring sustainable and profitable ramie cultivation.

Keywords: China Grass, Ramie Fiber, Anthracnose, Leaf Spot, Ramie Moth

Introduction

Ramie (*Boehmeria nivea* L. Gaud.), also known as “China grass”, is a perennial herbaceous plant of the Urticaceae family. It is considered the oldest fiber crop to be domesticated by man. Ramie fibers were used for making clothes by the royal families of Egypt and for mummification of the deceased during the period 5000-3300 BC (Maiti *et al.*, 2010; Yu *et al.*, 2016). Ramie is native to China, Japan, and the Malay Peninsula and is primarily cultivated for its excellent fiber quality. It is one of the world's strongest natural fine textile fibers (Angelini *et al.*, 2013; Mitra *et al.*, 2013). Additionally, ramie is used as a feedstock and mulch and in manufacturing bioethanol and medicines (Ullah, 2016). It is also grown on the slopes of hilly areas to reduce soil erosion and water loss (Rong and XiaoNing, 2010). Ramie is cultivated in China, Brazil, India, Japan, Lao PDR, South Korea, Thailand, the Philippines, and other South Asian countries (Zhu *et al.*, 2014). China is the world's leading producer of ramie, with approximately 100,000 tons of ramie fibers harvested annually, accounting for about 95-97% of the world's total production (Kipriotis *et al.*, 2015; Rehman *et al.*, 2019). China exported 1000-4000 tons of ramie products from 2012 to 2017 (Cheng *et al.*, 2020). Japan and Europe are the main export markets for ramie products (Jiang *et al.*, 2023).

Ramie has been grown in China for many centuries, even before cotton entered in 1300 AD (Yu *et al.*, 2015). Commercially, ramie is mainly grown for its bast fibers. Ramie fibers are a high-quality textile material that contains 65-75% cellulose and 0.8-1.5% lignin (Cheng *et al.*, 2020). Fabrics made from ramie fibers transmit moisture, are breathable, and have natural bacteriostasis (Du *et al.*, 2013). Ramie farms, industries, and trade support the livelihoods of nearly 5 million people. China exports a significant amount of ramie yarn and fabrics each year. However, the ramie industry has declined dramatically during the last ten years. According to statistics, the total planting area of ramie in China has decreased significantly from more than 60,000 hectares in 2013 to less than 10,000 hectares in 2022. Consequently, the world's total production dropped from more than 100,000 tons in 2013 to less than 10,000 tons in 2022 (FAO, 2023). Several factors are contributing to the significant decline in ramie production. This includes the low profit margin of the ramie processing sector and the uncompetitive ramie textiles. The fiber portion, which makes up between 5 and 10% of the plant mass, is the only part now used by the ramie business. Plant parts, such as leaves, roots, and stalks, are not adequately utilized. Ramie processing also involves many procedures and requires a large workforce, which raises the cost of production. For many years, the price of ramie fibers has remained high, around $7000 per ton, making it uncompetitive compared to other textile materials like cotton, polyester, and linen. Due to these factors, over the past ten years, the export value of ramie from China has continuously decreased (Rehman *et al.*, 2019).

This paper reviews the advances in ramie cultivation, taxonomy, ecology, chemistry, industry use, and medicinal and therapeutic properties. Then, we discuss the current pests and diseases affecting ramie plant growth and cultivation. This review would be useful in maximizing the potential benefits of ramie in the fiber industry and medicine. This is also the first review of the biotic stress affecting ramie, which may be used as a guide for future research works that aim towards a sustainable and environment-friendly pest and disease management approach, ensuring sustainable and profitable ramie cultivation.

Cultivation of Ramie

Ramie, a natural fiber from the stinging nettle family Urticaceae, genus *Boehmeria*, and species epithet *nivea*, can reach a height of 1 to 2 meters (Singh, 1986). There are two types of ramie: 'white ramie,' also known as "China grass", and 'green ramie' or "Rhea". Green ramie has a limited distribution in the tropics. In contrast, white ramie is commonly cultivated and is the one we commonly consider. As a bast crop, the bark (phloem) of the vegetative stalks is used for fiber extraction, and the ramie fiber is principally used for fabric production (Yu *et al.*, 2015). Ramie can grow sufficiently with multiple harvests under favorable environmental conditions. It is sensitive to soil moisture and can grow well in sandy loam soils. Deep, fertile, loamy, or sandy loam soils are suitable for successful crop cultivation. The optimum pH is 5.5-6.5, but the crop can withstand mild acidity. Lime must be applied if the soil is acidic (pH range 4-5). Soil should be rich in organic matter for good crop growth. However, soils deficient in calcium and poor base exchange capacity are unsuitable for ramie cultivation. A warm, humid climate with an evenly distributed yearly rainfall of 1000-2000 mm is ideal for the lush growth of ramie. The crop can thrive in slightly dry conditions, although growth is stunted, and irrigation is required for optimal growth. Ramie is highly vulnerable to waterlogging, frost, and severe winds. The optimal temperature for growth spans between 25°C and 31°C, with a maximum of 35°C. The relative humidity (RH) should not be less than 21%, with an optimal RH of 80% (Mitra *et al.*, 2013).

Ramie is typically harvested two to three times per year. However, it can be harvested six times under optimal growing conditions. Harvesting occurs before or after flowering begins, when plant growth slows and the highest fiber content can be produced. Ramie planted in the Yangtze River Basin of China can produce three yearly cuttings (Peng, 2009). In the tropics, it can be harvested three to four times each year under favorable circumstances (Liu *et al.*, 2005). Moreover, it can also be harvested up to six times per year under favorable growing conditions. Previous studies reported that ramie has yielded up to 14 cuttings per year, providing as much as 300 tons of fresh material (42 tons of dry matter) per ha per year when grown for fodder purposes in tropical areas (Kipriotis *et al.*, 2015).

Taxonomy and Ecology

Boehmeria nivea (L.) Gaudich. is considered one of the ancient and important economic and natural fiber crops today. It has been cultivated in China for at least 3,000 years, beginning in southern China (Li, 1970; Wilmot-Dear & Friis, 2013), and it is commonly known as China grass, Chinese grass, green ramie, ramie, rhea, and white ramie (Catling & Grayson, 1982, Kozlowski *et al.*, 2005; Saha *et al.*, 2010). It belongs to the polyphyletic genus *Boehmeria* Jacq. within the large nettle family Urticaceae Juss., which forms a monophyletic clade with Cecropiaceae C.C.Berg, based on the recent phylogenetic studies utilizing nuclear, chloroplast, and mitochondrial molecular data (Wu *et al.*, 2013). *Boehmeria nivea* is morphologically distinguishable from other *Boehmeria* and sister taxa *Cypholophus Wedd.* and *Pouzolzia* Gaudich. species by having leaves with broadly ovate or elliptic shape, mostly ≤ 1.5–2x as long as wide, 15–20 large, distinctive teeth along the leaf margin, heavy white tomentose (or green, spreading-hairy) on leaf lower surface, tangled fine hairs, and paniculate inflorescences with second to fourth order branching among other characteristics based on the recent taxonomic circumscription of the Old World *Boehmeria* species. The species is polymorphic generally in terms of leaf shape, leaf size, leaf marginal teeth length and proportion, leaf lower surface indumentum density, and stigma length, resulting in the formal establishment of various species, varietal, and formal taxa, but now recognized as heterotypic synonyms of *B. nivea* (Wilmot-Dear & Friis, 2013).

Ramie is distributed in various climatic zones, from equatorial to subtropical and temperate regions (Roy & Lutfar, 2012). The major domestic cultivation of Ramie is centered in China. However, it is also grown for fiber production in Japan, Taiwan, Brazil, the Philippines, Korea, Indonesia, and India (Rehman *et al.*, 2019). Ramie naturally thrives in evergreen forests, which are commonly found along water streams, presumably in Nepal, East Himalaya, Assam, Bangladesh, China North-Central, China South-Central, China Southeast, Hainan, Korea, Japan, Kazan-retto, Taiwan, Myanmar, Andaman Is., Nicobar Is., Laos, Thailand, Cambodia, Vietnam, and Cook Is. (Wilmot-Dear & Friis, 2013). The precise native distribution of *B. nivea* could not be defined as it is now common, extensively cultivated, and naturalized (Wilmot-Dear & Friis, 2013). This shrub or subshrub plant is naturalized in open forests and disturbed habitats, specifically in moist premontane forests, forest edges, ravines, thickets, limestone areas, waysides, ditches, and wastelands, of Virginia, District of Columbia, California, Texas, Louisiana, Alabama, Georgia, South Carolina, Florida, Mexico Southwest, Guatemala, Honduras, Costa Rica, Haiti, Dominican Republic, Puerto Rico, Leeward Is., Windward Is., Colombia, Trinidad-Tobago, Paraguay, Brazil South, Congo, Zaire, Rwanda, Gulf of Guinea Is., Gabon, Transcaucasus, Uzbekistan, Tajikistan, West Himalaya, India, Caroline Is., Malaya, Sumatera, Jawa, Marianas, Queensland, Marshall Is., Norfolk Island, Fiji, Society Is., Hawaii (Wilmot-Dear & Friis, 2004, 2013). It is distributed from 70 to 1,700 m altitude and can be harvested six times annually under suitable growing conditions. Ramie is treated as a least concern species as it is widely propagated worldwide (Saha *et al.*, 2010; Wilmot-Dear & Friis, 2013).

Though ramie is adapted to various climatic zones, the plant favors humid climates under moderate temperatures. In cultivation, ramie grows ideally in an area with a uniformly well-distributed rainfall of 1500-3000 mm annually and for an optimum fiber harvest, a temperature range of 20-31□C and 25% humidity suits the plant best (Rehman *et al.*, 2019). The crop grows poorly in a waterlogged environment, thus favoring sandy loam soil rich in organic matter with an optimum pH range from 6 to 7 at an altitude of 200-1500 m (above sea level) (Mitra *et al.*, 2013). The crop can reproduce sexually, producing a separate inflorescence for male and female plants, making them monoecious. However, in cultivation, the crop is preferred to be propagated asexually via rhizome cuttings, division of parent rootstock, laying, and stem cuttings (Mitra *et al.*, 2013). Ramie is praised for its long and strong textile fiber, which has been cultivated for at least 6000 years in an extensive distribution (Roy & Lutfar, 2012). *Boehmeria nivea* is not listed as a plant species of concern for conservation and preservation. The population of other members of the genus *Boehmeria* was cited as “stable”.

Phytochemistry of Ramie

Phytochemicals are bioactive compounds from plants widely studied for their medicinal properties (Adom & Liu, 2005). Ramie leaves were tested to have phytochemicals that can provide a wide variety of bioactivities, including antibacterial (Lee *et al.*, 2014), anti-inflammatory (Sung *et al.*, 2013), anti-obesity (Lee *et al.*, 2015), and antioxidant activities (Chen *et al.*, 2014). Some phytochemicals with solid antioxidant activities belong to phenolics and flavonoids. These compounds are secondary metabolites that play a significant role in the growth and reproduction of plants (Liu, 2007).

In a study by Chen *et al.* (2014), phenolics were determined to be the main phytochemicals in ramie leaves. The Folin-Ciocalteu colorimetric method is commonly used to determine the total phenolic content, with modifications depending on the extraction method employed. Phenolic contents are usually reported in mg of gallic acid equivalents (GAE) per gram of fresh weight (FW) or dry weight (DW). To easily compare between studies, phenolic content on FW basis is converted to DW basis using the reported moisture content. If not available, it is assumed that the ramie leaves have 78.7% moisture content (Wang *et al.*, 2019). The free phenolic content of *B. nivea* from Changsha, China, is 13.683 mg of GAE/g of DW, the fewest tested among *Boehmeria* leaves (Chen *et al.*, 2014). However, regarding the percentage of bound phenolics, *B. nivea* has the highest, 29.48%. The determined total phenolic content of the acetone extract is around 19.4021 mg of GAE/g of DW. This is much greater than the total phenolic content obtained from ethanol extract of *B. nivea* leaves from Wuhan, China, which was determined to be ranging from 0.52 to 2.41 mg of GAE/g of DW (Wang *et al.*, 2018). The extraction solvent used and the plant source can contribute to these differences.

Boehmeria nivea leaves contain the smallest amount of total flavonoids (9.8783 mg of CAE/g of DW) among the tested *Boehmeria* leaves (Chen *et al.*, 2014). They also have the highest percentage of bound flavonoids (44.71%) but the lowest percentage of free flavonoids (55.29%). In general, most of the phenolics and flavonoids in the ramie leaves are found in soluble rather than bound form (Chen *et al.*, 2014; Wang *et al.*, 2019). The identified phenolic compounds in ramie leaves were ferulic acid, caffeic acid, chlorogenic acid, *p*-coumaric acid, coumaroyl derivatives, benzoic acid, quinic acid derivatives, and malic acid derivatives (Chen *et al.*, 2014; Wang *et al.*, 2018; Wang *et al.*, 2019; Choi *et al.*, 2022). Some of the flavonoids identified in ramie are rutin, hyperoside, isoquercetin, kaempferol-3-*O*-rutinoside, epicatechin, and epicatechin gallate (Lee *et al.*, 2015; Cho *et al.*, 2016; Akter *et al.*, 2018; Wang *et al.*, 2018; Wang *et al.*, 2019; Choi *et al.*, 2022). Ferulic acid inhibits lipid peroxidation and oxidative spoilage of food (Graf, 1992). Caffeic acid can scavenge free radicals, providing antioxidative activity (Nardini *et al.*, 1995). Caffeic, chlorogenic, and ferulic acids slow tumor growth (Wattenberg *et al.*, 1980; Huang *et al.*, 1988). The α-glucosidase inhibitory activity of ramie was significantly correlated to *p*-coumaric acid, its derivatives, and rutin (Wang *et al.*, 2018). There is a high linear correlation between the amount of phenolic and flavonoid contents and the leaves' *in vitro* and *in vivo* antioxidant activities (Chen *et al.*, 2014). Likewise, *p*-coumaroylmalic acid and *p*-coumaric acid were significantly correlated with the antioxidant activity of ramie (Wang *et al.*, 2018). Specifically, isoquercetin, caffeic acid, and rutin displayed a dose-dependent antioxidant activity (Choi *et al.*, 2022).

Methanolic extract of dried and powdered *B. nivea* from Baeksu, Yeonggwang, Korea, was suspended in water and partitioned using different solvents. From the *n*-hexane fractions, two compounds were recrystallized under chloroform-methanol (Cho *et al.*, 2016). Each compound was recrystallized from the ethyl acetate and n-butanol fractions (Cho *et al.*, 2016). The compounds identified were β-sitosterol, (–)-loliolide, rutin, and pyrimidine dione. Among these four, β-sitosterol, (–)-loliolide, and rutin are known to have antimicrobial and antifungal activities (Pierre Luhata & Usuki, 2021; Moosavi *et al.*, 2020; Ganeshpurkar & Saluja, 2017; Ragasa *et al.*, 2005; Karioti *et al.*, 2002). Pyrimidine dione is a non-nucleoside reverse transcriptase inhibitor against HIV-2 (Buckheit *et al.*, 2001).

The number of phenolics and flavonoids from different vegetative parts of *B. nivea* must also be considered when extracting these compounds. The total phenolic content of leaves in the study of Wang *et al.* (2019) is about 20.116 mg GAE/g of DW, similar to the amount determined by Chen *et al.* (2014). Ramie buds have the highest total phenolic content (45.85 ± 3.20 mg GAE/g of DW), which is five-fold higher than the total phenolic content in ramie roots and petioles (Wang *et al.*, 2019). Regarding flavonoid content, ramie phloem had the highest total (27.55 ± 1.8 mg CAE/g of DW), while ramie roots had the lowest (6.369 ± 0.442 mg CAE/g of DW). In addition to antioxidative activities, the free extracts from different *B. nivea* plants also exhibited antiproliferative effects against human malignant melanoma A375 and cervical carcinoma KB cancer cells (Wang *et al.*, 2019).

From ethyl acetate extracts of powdered *B. nivea*, two triterpenoids and one fatty acid had antidiabetic activities: hederagenin, pomolic acid, and linolenic acid (Zhao *et al.*, 2019). These metabolites were identified using liquid chromatography–high–resolution mass spectroscopy (LC-HRMS) and nuclear magnetic resonance (NMR) spectroscopy. These compounds were demonstrated to have inhibitory activities against protein-tyrosine phosphatase 1B. This enzyme dephosphorylates the activated insulin receptor, which will suppress insulin action (Feldhammer *et al.*, 2013). Inhibiting this enzyme will prolong the insulin activity, which is important in patients with type 2 diabetes. A recent study by Wulandari *et al.* (2024) used GC-MS/MS analysis to profile the metabolites from bioactive ethanol extracts of *B. nivea* flowers. There were 81 different metabolites identified from *n*-hexane, dichloromethane, ethyl acetate, butanol, and water fractions. Among the notable metabolites is 9,12-octadecadienoic acid, which has antibacterial properties against *Staphylococcus aureus* and *Bacillus subtilis* (Kusumah *et al.*, 2020). The compound 2-butoxyethanol from the ethyl acetate extract is used in antibacterial soaps (Pringgenies *et al.*, 2018).

Ramie Fiber and Its Industry Use

The ramie plant has various uses (Figure 1). Ramie fiber (RF), categorized as bast or phloem fibers, is extracted from plant stems by harvesting mature stalks, decortication and degumming. (Li *et al.*, 2020; Khoo *et al.*, 2023). The decortication process separates and crushes the outer bark and removes the central woody portion. The decorticated fibers, devoid of cortical tissues, require a retting process to eliminate the gums (Bhattacharya & Shah, 2002; Saikia *et al.*, 2009), pectins, and other non-cellulosic tissues attached to the fibers (Wulandari *et al.*, 2021), resulting in single spinnable fibers (Cheng *et al.*, 2020). Ramie fibers are the longest natural plant bast fibers, with tensile strength surpassing linen and silk and a remarkable sevenfold strength compared to cotton (Mitra *et al.*, 2014; Habibie *et al.*, 2021). RFs are well known for their excellent shape, antibacterial properties, and resistance to mold, bacteria, and insects (Kochnar, 1981; Li *et al.*, 2016; Wei *et al.*, 2023). Moreover, ramie, along with lignocellulosic bast fibers, is one of the most important carbon-neutral and renewable natural resources for various industrial uses (Al Faruque *et al.*, 2022; Yang *et al.*, 2010), and land protection (Mitra *et al.*, 2014).

Among other textile bast fibers, including jute, flax, and hemp, RF ranks first in durability, tensile strength,

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length of fiber cells, fineness, and color (Dey, 2018) - characteristics that make RF important in the textile industry. The silkiness and luster make it a good option for clothing, apparel, home textiles, and blended fabrics. Degumming the fiber facilitates the separation of individual fibers, leaving them soft and clean while preserving their strength and other essential textile qualities, rendering them highly amenable to dry or wet spinning (Das Gupta *et al.*, 1976). The spinning method depends on the country's spinning systems, mill capabilities, and the blend of specific materials like jute, silk, cotton, or even polyester. In India, a modified spinning technique for decorticated ramie uses a standard jute/flax spinning system. This process results in 25–30% moisture content fibers, subsequently kneaded using a conventional jute softener machine, yielding ply yarns ideal for sewing twine (Mazumdar *et al.*, 1976). The Japanese pioneered a spun silk system that produces the finest yarns but is labor-intensive. Europe, Brazil, and the Philippines modified the procedure, reducing labor requirements and producing coarser yarns (Jose *et al.*, 2016). Blending kenaf fiber with RF produces high-quality yarns suitable for various value-added products for home textiles, interior fabrics, and furnishings (Kakoty *et al.*, 2020). Indonesia institutionalized a standardized RF production process to guarantee the creation of standard ready-to-spun fiber (RtDS), a raw material for fashion and functional textiles, bullet-resistant panels, fire-resistant clothing, and other industries (Wulandari *et al.*, 2023)

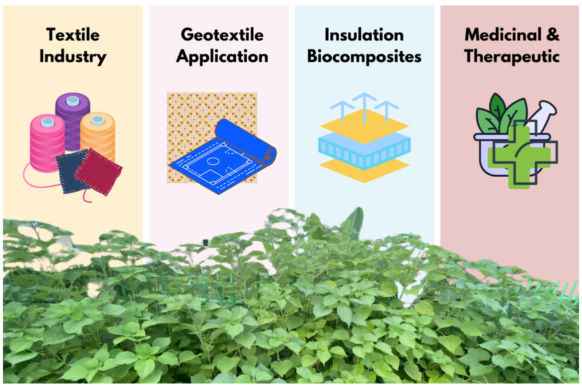

Fig. 1: The versatile uses of Ramie, from textile to medicine

One of the advantages of RF over jute, sisal, flax, and hemp is having a low fineness or tex, which plays a crucial role in determining its texture, feel, and performance in various applications, especially in textiles (Banerjee *et al.*, 2015). RF is finer than other textile fibers, making it an exquisite summer clothing item (Hwang, 2010). Conversely, hemp has coarser fibers, quite stiff and short, making it harder to spin. While RF is known for its natural luster and silky texture, its popularity has declined due to the challenges associated with its extraction and processing, resulting in low fiber yield. Efforts to improve fiber quality and yield have been ongoing for years, particularly in China. While these efforts have markedly improved RF production, advancements in fiber yield and quality are still far from reaching the desired goal. By taking advantage of molecular techniques, attempts were undertaken to dig deeper into the genomic level to analyze important agronomic traits. The genetic population structure of the available ramie germplasm collection was evaluated, and SSR markers associated with fiber production traits were identified (Luan *et al.*, 2017). Additionally, transcriptome studies and genomic variations mapping have been conducted to explore ramie plant expression profiles, enhancing the understanding of its growth and development (Wang *et al.*, 2019; Al-Ani *et al.*, 2018; Zeng, 2022)

Composite materials, combining different materials, are valued for their strength, durability, and lightness. Traditionally, they are made of synthetic fibers like glass or carbon. However, rising environmental concerns have sparked interest in natural fibers. Ramie fiber (RF) was developed and used instead of glass fiber in Fiber Reinforced Polymers (FRPs) (Yang *et al.*, 2010; He *et al.*, 2021; Prasad *et al.*, 2023). Researchers have improved RF quality for specific composite applications using chemical and microbial degumming methods to achieve the desired tensile strength, elastic modulus, and elongation at break for use in polyhydroxyalkanoates (PHAs) composites. Ismadi *et al.* (2020) demonstrated that combining epoxy, one of the most versatile adhesion materials, with RF increased the tensile and flexural strength and overall mechanical properties, leading to the manufacture of green composites. It was also found that treating RF with alkaline improved its properties, making PLA/ramie composite materials with the highest tensile strength and tensile modulus (Jamilah *et al.*, 2021). These ramie fabric-reinforced PLA composites can meet the standards for aircraft interior structures (Wang *et al.*, 2018).

Geotextiles, high-performance permeable fabrics, are used in civil engineering to improve soil properties for separation, filtration, drainage, and reinforcement (Lawrence, 2014). Traditionally, manufacturers have made geotextiles from synthetic polymers as fibers (Shackelford, 2003). The emphasis on sustainability and reducing environmental impact has increased interest in renewable resources and natural fiber-based geotextiles. There has been an increased use of materials like sisal, kenaf, hemp, jute, and ramie, replacing almost 50% of geosynthetics with natural geotextiles (Wu *et al.*, 2020; Tanasă, 2022). Indonesia recognizes RF as a superior eco-friendly substitute for conventional geotextiles in geobag dykes, protecting mangrove seedlings from coastal erosion (Pandey, 2007). It has been reported that the current mechanical properties of RF do not meet the standard geotextile parameters, indicating the necessity for modification (Rildova *et al.*, 2024).

Insulating materials are essential for energy management and comfortable room temperatures. However, most are synthetic and can harm human health and the environment. Consequently, efforts are underway to utilize natural fibers. For this purpose, the RF is one of the best alternatives. The prepared ramie fabric-reinforced resin matrix composites not only have high specific strength and low energy consumption but also have the functions of sound insulation, vibration damping, and noise reduction (Gokulkumar et al., 2020; He et al., 2021). These characteristics give it excellent development potential in civil construction, aerospace, and automotive machinery. A mixed panel made of Cyperus pangorei and RF has a lot of holocellulose and empty spaces inside it, making it better at absorbing sound. These lightweight panels serve as sound absorbers at higher frequencies, ideal for applications that require effective damping and sound absorption (Kanniyappan & Selvaraj, 2024). RF's flammability is another limitation as a natural fiber. However, coating the RF with ammonium polyphosphate (APP) or reinforcing with an epoxy/glass produces flame-retardant composites with outstanding flame resistance, providing a practical solution to enhance the fire safety of natural fiber-reinforced composites (Jiang *et al.*, 2023; Thiyagu et al., 2023).

Technological advancements and the demand for sustainable materials drive new applications for ramie fiber composites, which require continued research and industry collaboration.

Medicinal and Therapeutic Properties

Aside from its role in the textile industry, ramie is also known for its role in traditional herbal medicine. Historically, this plant was used to treat colds, swelling, high fever, fetal hypersensitivity, inflammation of the kidneys, urinary tract infections (UTI), and abortion risk (Choi *et al.*, 2022). Other traditional indications for using Ramie leaf include gynecological and bone-related disorders (Lee *et al.*, 2023). This section explored the beneficial effects of *B. nivea* on the various organ systems of the human body. No articles have been published on the ramie plant's direct beneficial effect on human skin. However, *B. nivea* as a material for surgical sutures has already been examined by Kandimalla *et al.* (2016) for its effect on the skin of adult male rats during surgical wound closure. Biocompatibility, or the ability of a material to perform with an appropriate host response, specifically in wound healing, was tested in the study mentioned above regarding the effect of the suture on hemolysis and whether or not it caused cytotoxicity. Results of the study showed that the surgical suture from the Ramie plant did not cause any adverse effects (i.e., hemolysis and cytotoxicity). The suture was also examined for its antibacterial property, effect on inflammation during wound closure, and histological effect on wound healing, showing favorable results.

Traditionally, the ramie plant leaf extract was also used to treat bone-related disorders, such as osteoporosis, in humans. However, studies have not scientifically explored its efficacy in treating human osteoporosis. To date, the highest level of evidence explaining the effect of *B. nivea* on the skeletal system is a randomized controlled trial on ovariectomized Sprague-Dawley rats by Lee *et al.* (2023). The study showed that ramie plant extract effectively prevented a rapid decrease in bone density in ovariectomized rats and decreased the number of osteoclasts (bone-depleting cells) and reactive oxygen species. Overall, this study could provide a basis for using Ramie leaf extract to prevent osteoporosis or bone loss in menopausal women (in addition to its estrogenic effect discussed under the Endocrine System subsection).

There is also a paucity of studies regarding the effect of *B. nivea* on the muscular system. One study by Sancheti *et al.* (2011) explored the effect of *B. nivea* extract on the muscle glycogen content in diabetic rats. It was noted that the root extract benefits diabetic rats, as shown by the increased skeletal muscle glycogen content, indicating decreased glycogenolysis and increased glycogen synthesis. This study, however, highlights the anti-diabetic properties of the Ramie plant more than its direct effect on muscle growth and function. There were not enough studies on the neurological benefits of *B. nivea*. However, the leaf and stem extracts of *B. nivea* exhibit neuroprotective activity and antioxidant benefits (Choi *et al.*, 2022).

A significant decrease in lipid profile parameters, including total cholesterol and triglyceride levels alongside the prevention of diabetes mellitus. A study by Sancheti *et al.* (2011) showed a reduction in the total cholesterol and triglyceride levels in a 21-day therapy using 500 mg/kg of root extract of *B. nivea* in streptozotocin-induced diabetic rats. Furthermore, a dramatic increase in high-density lipoprotein (HDL-C), a cardioprotective lipoprotein, thus improves the balance of lipoprotein metabolism. There were no published articles about the benefits of *B. nivea* in the respiratory system. Instead, *B. nivea* can induce IgE hypersensitivity, which is established to be an allergen and a cause of bronchial asthma (Miura, 1993).

There is growing evidence about the potential anti-HBV properties of *B. nivea.* A study by Wei *et al.* (2014) on HBV-positive human cells discovered that *B. nivea* leaf extract significantly suppressed HBsAg and HBeAg secretion into the medium and inhibited HBV DNA replication without any recorded cytotoxic effects. Interestingly, the inhibitory effect of a fraction of *B. nivea* leaf extract was similar to that of the *B. nivea* root extract. The exact mechanism is unclear, but it was believed that the mechanisms behind these effects may involve the extracts' ability to decrease SGOT and SGPT liver enzymes caused by D-galactosamine hepatotoxicity, which is similar to human viral hepatitis (Lin *et al.*, 1997).

Ramie plant is also a promising natural laxative due to its high dietary fiber content and potential to modulate gut motility. Mohanty *et al.* (2000) showed that ramie leaf extract contains several dietary fibers, such as cellulose, hemicellulose, pectin, wax, and lignin. These fibers are crucial in promoting bowel movements by increasing stool bulk and softening its consistency, similar to the mechanism of osmotic laxatives (Gordon *et al.*, 2016). A study by Lee *et al.* (2020) further supports the laxative potential of ramie leaf extract. The extract increased fecal count, weight, and water content in rats with loperamide-induced constipation, indicating enhanced bowel motility and a laxative effect.

Peroxisome proliferator-activated receptor gamma (PPARγ), a nuclear receptor, plays a pivotal role in improving insulin sensitization and adipokine regulation, emerging as a treatment for diabetes (Grygiel-Górniak, 2014). Notably, a study by Kim *et al.* (2013) demonstrated the potential of a *B. nivea* extract in enhancing glucose uptake in muscle cells via PPARγ activation. This mechanism significantly improved metabolic parameters in mouse models, including reduced body weight, total cholesterol, fatty liver, and enhanced fasting glucose levels and glucose intolerance. This finding suggests that *B. nivea* could potentially be used as a natural PPAR-γ agonist to improve insulin sensitivity and manage diabetes, a similar mechanism seen in PPAR-γ drug agonists like thiazolidinediones (Soccio *et al.*, 2014). The plant also has estrogenic properties, suggesting that ramie could be a potential source of natural estrogen or a dietary supplement for menopausal women. (Lee *et al.*, 2023). A study by Choi *et al.* (2022) on human estrogen receptor-positive breast cancer cells demonstrated a significantly increased cell proliferation, which was noticeably suppressed by combination treatment with a pure ER antagonist in *B. nivea* leaf extract.

Boehmeria nivea has a history of therapeutic use in China and Taiwan for its diuretic properties (Huang *et al.*, 2006). Although the exact mechanism is unclear, traditional practices in Guizhou, China, involve using the whole plant, prepared through grinding and decoction, as an oral soup to promote its diuretic effect (Liu *et al.*, 2021). In traditional Chinese herbal medication, the roots of *B. nivea* are used to decrease the risk of abortion (Cho *et al.*, 2016). *Boehmeria nivea* (L.) Gaud. was commonly used to treat miscarriages clinically. The flavone glycosides in roots and rhizomes could inhibit pregnant uterine contraction in mammals by promoting progesterone secretion, inhibiting ATPase activity, and disrupting Ca2+ transport in uterine smooth muscle cells, consequently resulting in a reduction of uterine contraction (Tian *et al.*, 2011) however, it might cause cytotoxicity in cultured embryonic stem cells at a high dose.

Several allergic disorders caused by inflammation due to suppressed mast cells can be treated using *B. nivea.* According to Arsul *et al.* (2021), therapies using *B. nivea* have been proven effective in controlling allergic reactions and have been able to suppress the development of histamine and β-hexosaminidase in mast cells. The extract could suppress inflammatory cytokines by downregulating MAPK and NF-B routes, suggesting that it has therapeutic potential effects on various allergic diseases. In a study by Lim *et al.* (2020), treatment with *B. nivea* during an IgE-mediated local allergic reaction reduced ear pigmentation and swelling caused by allergens, indicating that the extract controlled the activation of the skin. The chlorogenic acid of *B. nivea* also displayed an antimicrobial effect. An in vitro study by Yang *et al.* (2016) showed a significant increase in the inhibition area diameter of *Escherichia coli* by increasing the chlorogenic concentration. Also, in another study by Nho *et al.* (2010), an antifungal activity was demonstrated by *B. nivea* unsaturated fatty acids (Z)-12-keto-7,8,9-trihydroxy-10-hexadecenoic acid, (Z)-7,8,9-trihydroxy-10-hexadecenoic acid, (Z)-9,10,11-trihydroxy-12-octadecenoic acid, and (E)-8,11,12-trihydroxy-9-octadecenoic acid.

Antioxidant activity is also one benefit of *B. nivea.* A study by Sancheti *et al.* (2011) revealed that its root extract exhibited potent α-glucosidase inhibition and good antioxidant activity. Furthermore, leaf extracts of *B. nivea* have significant oxygen radical scavenging capacity and hydrophilic peroxyl radical scavenging capacity (Chen *et al.* 2014). The leaves and roots of ramie are also listed in the Chinese Pharmacopoeia due to their medicinal function in hemostasis and prevention of miscarriage (Wang *et al.*, 2019). Chlorogenic acid in *B. nivea*, which has hemostatic activities, might also be linked to the treatment of threatened miscarriage (Tian *et al.*, 2011).

Diseases of Ramie and their Management

Ramie is hosted by several fungi, viruses, and nematodes, which reduce yield and fiber quality. The reported diseases include leaf spot disease, anthracnose, leaf blight, white fungus disease, seedling rot, cane rot, eye rot, collar rot, brown rot, yellow mosaic, corchorus golden mosaic virus, and root-knot nematodes, which are reported in various countries (Table 1).

Leaf Spot

It has been previously reported in a review paper by Sarma *et al.* (1981) that the two notable species of *Cercospora* causing leaf spot disease on ramie-*Cercospora boehmeriae* Peck and *Cercospora krugiana* Muller & Chupp (Chupp, 1953; Chowdhury, 1957; Dempsey, 1975). These two species of fungi were recorded in Uganda (Hansford, 1943), Taiwan (Yamamoto, 1934), and India (Chowdhury, 1957). The observed symptoms of the disease include rusty brown spots with grey centers surrounded by concentric rings on the upper surface of the leaves, the center of older spots becomes pale and greyish brown, adjacent spots coalesce, and elongated spots appear on petioles. The highly affected leaves become yellow and fall prematurely. The disease has been recorded throughout the year, with the worst infections occurring between late

September and early January. The disease tended to develop in cold, humid conditions. According to Chowdhury (1957) and Petruszka (1977), leaf spots can be controlled with fertilizer applications, clean culture, and spraying of Bordeaux mixture. Summers (1960) also recommends spraying maneb and zineb.

Table 1: Identification and Occurrence of Important Diseases of Ramie

Disease	Causal Organism	Country	References
Leaf spot	*Cercospora boehmeriae*	Uganda	Hansford 1943
	Cercospora krugiana	Taiwan	Yamamoto 1934
		India	Chowdhury 1957
	Phyllosticta spp.	India	JARI 1970
	Pseudocercospora boehmeriae	Indonesia	Rachmat *et al*. 1994
	Corynespora cassiicola	Brazil	Salcedo *et al*. 2019
		China Malaysia	Farr and Rossman 2019
	Alternaria alternata	China	Yu *et al*. 2016
Anthracnose	*Colletotrichum boehmeriae*	China	Li and Ma 1993
	Colletotrichum gloeosporioides	China	Wang *et al*. 2010
	Colletrotrichum higginsianum	China	Wang *et al*. 2011
Leaf blight	*Curvularia eragrostidiis*	India	Mitra *et al*. 2013
White fungus	*Rosellinia necatrix*	Japan, Philippines, Vietnam	Oshiumi 1951, Summers 1960, Garcia 1964, Dempsey 1963
Seedling rot	*Thanatephorus cucumeris* (*Rhizoctonia solani*)	USA	Summers 1960
Cane rot	*Macrophomina phaseolina* (*Rhizoctonia bataticola*)	India	Mustafee 1977
Eye rot	*Myrothecium roridum*	India	Mukerjee and Bose 1974 Mustafee 1976
Collar rot	*Sclerotium* sp.	India	Mitra *et al*. 2014
Brown rot	*Pythium vexans*	China	Yu *et al*. 2016
Yellow mosaic	Viral disease	India	Li *et al*. 2010 Liang *et al*., 1994
Corchorus golden mosaic virus (CoGMV)	Viral disease	India	Biswas *et al*. 2016
Root-knot nematode	*Meloidogyne incognita*	Philippines	Madamba 1971

JARI (1970) reported a leaf spot disease of ramie in Sorbhog, India, caused by *Phyllosticta* spp. The symptoms of the disease include reddish-purple circular spots, which are small, round (4-11mm in diameter), and unevenly distributed on the upper surface of the leaves and generally attack the lower leaves and their petioles. The reddish-purple color of the spot will eventually turn to greyish-white at the center and remain dark red at the margin. These spots may coalesce to form a large area of necrosis. This minor disease is seldom severe enough to need control measures. Another leaf spot disease of ramie was reported by Rachmat *et al.* (1994) in Java, Indonesia. It was described as an angular leaf spot disease caused by the fungus *Pseudocercospora boehmeriae,* identified based on its morphological characteristics. It occurs throughout the year but spreads rapidly in the rainy season and slightly in the dry season. The heavy infestation of the disease significantly reduced the yield brought by growth retardation of ramie. The disease has been observed only on ramie in Indonesia.

Yu *et al.* (2016) reported the first record of black leaf spot disease on ramie plants in major producing provinces in China- Hunan and Hubei. The symptoms of the disease include the appearance of dark green to black big spots on leaves, often resulting in upwardly curled leaf margins. The pathogen of the disease was identified as *Alternaria alternata* (Fr.) Keissler based on its morphological characteristics and sequence similarity of 99-100% to the published data for internal transcribed spacer (ITS) and glyceraldehyde-3-phosphate dehydrogenase. Salcedo *et al.* (2019) first reported that leaf spot disease in Ramie in Brazil was caused by the necrotic fungus *Corynespora cassiicola.* The pathogen identification was clarified based on morphological and molecular evidence, and pathogenicity to ramie was demonstrated. *Corynespora cassiicola* is a common and cosmopolitan species, especially abundant in the tropics, with a wide range of host plants (Ellis and Holliday, 1971; Dixon *et al.*, 2009; Lopez *et al.*, 2018). The observed symptoms of the disease are young leaves of adult and younger plants developed circular to irregular, 4-8mm diameter necrotic dots. These turned dark brown, with concentric rings reaching 2 mm in diameter. This disease was recorded in China and Malaysia (Farr and Rossman, 2019).

Anthracnose

One of the most widespread and severe diseases of ramie is anthracnose. In China, ramie anthracnose is found in approximately 10,000 ha, with yield losses averaging 20% and ranging as high as 55% in some fields. Wang *et al.* (2010, 2011) first reported ramie anthracnose disease in China caused by two *Colletotrichum* species – *Colletotrichum gloeosporioides* and *Colletotrichum higginsianum*. The symptoms of the former include small lesions that are scattered, round, and gray with brown margins on leaves. In contrast, the lesions on diseased leaves were small, scattered, bluish-white, and water-soaked. Later, as the disease progressed, irregular spots developed and expanded until the leaves withered. Moreover, initial lesions on the stem were fusiform and expanded, causing the stem to break, and the fibers eventually ruptured.

Li and Ma (1993) previously reported that the initial inoculum source for the disease development of *Colletotrichum boehmeriae* was mainly from plant debris. Disease infection was favored by the daily temperature (20-30°C), rainfall (>10mm), and relative humidity (>80%). Disease severity was also affected by the cultivar, manure, and fertilizer treatments. The disease can be managed by applying fungicides; 40% WP banzhongshuan was proven effective, and sprays should be applied at 800-1600 ppm. Applying lime also gave some control and increased the yield when dusted on the fields during winter tillage after harvest.

Leaf Blight

Mitra *et al.* (2013) first reported leaf blight of ramie caused by the fungus *Curvularia eragrostidis.* The symptoms appeared on leaves as rusty, reddish brown, irregular lesions, ring-shaped spots surrounded by chlorotic tissue, then rapidly expanded to be oblong and gradually coalesced and enlarged around the leaf surface. The infected leaf is completely girdled within 6-8 days after infection, disrupting the plant's photosynthetic activity and reducing the quality and quantity of fiber yield. Among all the genotypes, genotype R-1452 and seedlings generated from the seed population were found to be highly susceptible to this devastating disease. The culture of this pathogenic fungus was also sent to the Indian Type Culture Collection (ITCC), New Delhi, for further confirmation and finally identified and deposited as *Curvularia eragrostidis* with allocated ITCC ID number 9150.13

White Fungus

White fungus disease of ramie caused by *Rosellinia necatrix* (Prill) was recorded in Japan (Oshiumi, 1951), Vietnam (Dempsey, 1963), and the Philippines (Summers, 1960; Garcia, 1964). The disease commonly attacks the root system of the plant. The observed symptoms of the disease include weakness and slenderness of the plants, followed by yellowing, wilting, and falling of leaves. According to Kirby (1963), the disease can be managed by excavating quarantine ditches around the plant, uprooting all pieces of diseased roots, and disinfecting the area with a chloropicrin solution. Furthermore, Oshiumi (1951) recommended soaking rhizome cuttings for 3 hours in a 1:1000 mercuric chloride solution before planting in previously affected areas.

Seedling Rot

Summers (1960) identified *Thanatephorus cucumeris* (*Rhizoctonia solani* Kuhn) as the causal agent of seedling rot, a severe ramie disease in Florida, USA. The fungus infects the stem's base, destroying fields of young plants and causing stems to bend at the site of infection. The same author also suggested that treating planting material with captan could help manage the disease.

Cane Rot

Mustafee (1977) documented cane rot of ramie produced by *Macrophomina phaseolina* (*Rhizoctonia bataticola* (Taub.) Butler) in Sorbhog, India. The disease causes necrotic lesions on the leaves, progressively spreading across the entire leaf blade. The leaves crumple, rot, stick to the cane, and eventually fall. The root system weakens and turns brown. Brown, shrunken, circular, or elongated lesions occur on ramie stalks, especially in the basal areas. The affected areas are brown, with black sclerotia. They increase in size, and numerous lesions develop to girdle the stem. When lesions form streaks along the stem, they shrivel and dry. The disease becomes more prevalent in mature clumps during the rainy season. Accordingly, control measures are rarely needed.

Eye Rot

Mukerjee and Bose (1974) and Mustafee (1976) reported cases of ramie eye rot caused by *Myrothecium roridum* in India. The pathogen affects the leaves, resulting in qualitative and quantitative fiber loss. The first symptoms are tiny, tan-colored spots about 1 mm in diameter on the upper surface of the lamina. As the disease progresses, the spots become circular to irregular, measuring 6-16 mm in diameter and brown to dark brown. When mature, the sporodochia develop concentric rings of black dot-like structures in the center of the spots. Mustafee (1976) stated that severe cases comprise 7-10% of the disease's prevalence. The disease can be controlled by using copper fungicides.

Collar Rot

Mitra *et al.* (2014) documented collar rot caused by *Sclerotium rolfsii*. The pathogen usually attacks ramie stems, although it can infect any portion of a plant under suitable climatic conditions. The initial signs of infection, typically undetectable, are dark-brown lesions on the stem at or near the soil level; the first noticeable symptoms are progressive yellowing and wilting of the leaves. Ramie seedlings are highly vulnerable and die quickly once infected. Mustard-like Sclerotial bodies germinate quickly in the field when ideal conditions exist. The primary factors contributing to the development of this disease are frequent rain and warm temperatures ranging from 20 to 30 degrees Celsius. The disease is effectively controlled by drenching with 0.25% copper oxychloride.

Brown Rot

Yu *et al.* (2016) first reported that the brown rot disease on ramie in Hunan, China, was caused by *Pythium vexans.* The disease caused severe yield loss (>40%) on the ramie plantation field. The observed symptoms were stunted plant growth, reduced ramets of each plant, and brown to purple-black discoloration of the diseased root. The identity of the pathogen was revealed through morphological features and sequence identity (99-100%) to the published data for internal transcribed spacer (ITS), 18S, and 28S rDNA sequences. The pathogenicity was confirmed on healthy fibrous roots of seedlings and detached storage roots under greenhouse conditions.

Yellow Mosaic (Viral)

Liang *et al.* (1994) studied the ramie mosaic systematically from 1987 through 1991. They observed that the disease incidence was more significant in the first and second harvests than in the third harvest. A temperature of 15 to 26°C was favorable to the spread of the disease. However, the disease symptoms disappeared when the temperature rose to 28°C or more. Mosaic-like symptoms include intermingled regions of normal, light green, or yellowish colors on diseased plant leaves and yellowing of the entire network of veins in the leaf blade. In severe infections, the younger leaves turn yellow, reduce in size, and the plant is severely stunted. In a field, most plants may be infected, and infection can occur at any stage of plant growth. The virus rarely kills plants, but it does reduce crop quality and quantity, especially if the plants are infected while young. The infection was highest between September and December. Infection was in the range of 30 to 70% on different genotypes of ramie when the temperature was 15 to 28°C (Mitra *et al.*, 2014).

Corchorus Golden Mosaic Virus (CoGMV)

Biswas *et al.* (2016) first reported the *Corchorus golden mosaic virus* (CoGMV) infecting Ramie in India. They observed the disease in 2013 in an experimental field at the CRIJAF research farm in Barrackpore, India. The observed symptoms were the prominent vein clearing on young leaves and complete yellowing on older leaves, and plants were stunted and bushy. They confirmed the identity of the pathogen using molecular techniques. The incidence of CoGMV in ramie is relatively low, but in the future, it may negatively affect the yield.

Root-Knot Nematode

Madamba (1971) surveyed the Philippines and found that root-knot nematodes, *Meloidogyne incognita*, and at least eleven other species all harm ramie. Observations showed that the ramie roots were severely galled. The reduced nematode population in beds treated with DBCP (Dibromochloropropane) soil fumigant was constant up to four months after treatment. Rootstocks for transplanting were nematode-free after 10 minutes of soaking in 0.7% a.i. Dibromochloropropane, 70 ex. or 2.5% a.i. Oxydemeton-methyl, 25 e.c.

Arthropod Pests of Ramie

Early records of insect infestation in Ramie, mainly from South and East Asia, include notable damage of the mole cricket, L., reaching 8-10% during the early vegetative stage coupled with attack by caterpillars of the moths and, L., and Ill. beetles on leaves during nursery and field stages (Durnovo and Pogodina, 1933). Another gryllid, (Lichtenstein), has been reported to cause up to 50% damage by consuming the young shoots, and its tunneling behavior damages the rhizomes. Peaking during the summer months of March to April, the cricket population decreases dramatically by the rainy season's onset. Farmers were advised to use 5% aldrin dust during this time for persistent infestations (Chatterjee, 1966). The generalist has also been reported to cause concern during the monsoon in the 1970s in Assam, leading to the skeletonization of leaves. Extensive root damage and rhizome consumption of the grubs of the scarab beetle Arrow have also been reported in Debijhora, India (Pandit, 1995). In recent years, rami cultivation in India has decreased and is limited to areas of Assam and Bengal. The Indian red admiral caterpillar, , has recently been recorded as a major pest in India, causing up to 30% infestations peaking from December to January. Microtermes termites were also problematic when planting Ramie using stem cuttings. At the same time, Pleuroptya caterpillars and Lepidiota beetles cause defoliation, especially from October to November and April to May, respectively (Gawande *et al.*, 2016).

Acari infestation has also been recorded on the lower leaves of ramie in China. However, the presence of the Eriophyid mite *Paraphytoptus niveae* on the leaves did not result in any apparent damage (Wang *et al.*, 2022). In Japan, the Tetranychid mite *Tetranychus phaselus* has also been recorded as a minor pest in the variety *concolor* Makino *f. nipononivea* [Koidz.] (Gotoh *et al.*, 2015). Moreover, *Tetranychus piercei* and *Tetranychus ludeni* were collected from Ramie in Okinawa (Ohno *et al.*, 2010). Currently, the ramie moth (previously Gn.) has become a significant pest in the fiber crop (Zeng *et al.*, 2015) and even in non-Boehmeria crops outside of its native range (Au and Wright, 2022). It has been regarded as a major pest in Japan since the 1930s, when several generations of its caterpillars, together with , Hbst., attack the crops during the summer months and overwinter as imago (Hirose, 1936). In the 1960s, 15-20% of costs in plantations in Cotabato, Philippines, went into the management of *A. coerula* (as) and the weevil T sp. by carbaryl spraying (Belen and Quemado, 1965). Close observations on the caterpillar's preferences using the Chinese ramie showed that it preferred feeding on the fully opened shoots over buds, in the canopy section, than leaves in the understory. This preference in*A. coerula* has been attributed to the fast regrowth of shoots in the canopy region and the larvae's ability to overcome the plant's chemical defenses in the opened shoots versus the more concentrated buds (Ide, 2006).

Later, some attempts were made to improve ramie's pest resistance. Comparative analysis of the transcriptome profiles of insects challenged and unchallenged showed 750 upregulated and 1,230 downregulated genes. Among these differentially expressed genes in infested ramie, 87 were found to be transcription factors, and 16 were involved in host defense (Zeng *et al.*, 2016). Breeding for resistance includes techniques using transformation of wherethe CryIA gene from Wild Chinese Grape () and CpTI from cowpea () were inserted into the Zhongzhu 1 variety and the Bt gene into the Ramie Luzhuqing variety.

Conclusion

Research Gap and Prospects

This paper reviewed the advances in ramie cultivation, taxonomy, ecology, chemistry, industry use, and medicinal and therapeutic properties. Except for waterlogged soil, Ramie can be grown on large scales in versatile environments, including tropical, subtropical, and temperate regions. The plant favors humid climates under moderate temperatures. Ramie is also one of the most important carbon-neutral and renewable natural resources for various industrial uses (Al Faruque *et al.*, 2022; Yang *et al.*, 2010). Ramie plant parts also contain phytochemicals that have medicinal properties. Aside from its role in the textile industry, ramie is also known for its role in traditional herbal medicine. Indeed, ramie plant extracts have been documented as beneficial to the various organ systems of the human body.

This paper also reviewed pests and diseases affecting ramie plant growth and cultivation. There are 16 fungal species associated with leaf spot, anthracnose, leaf blight, and rot in ramie. Two viral pathogens and a nematode are also associated with viral symptoms and root-knotting. Leaf diseases are the predominant diseases of ramie, and they can cause yield reductions of up to 50%. Several gaps need to be addressed to achieve sustainable ramie cultivation. One important gap for growing ramie is soil nutrient optimization and water management. Sustainable fertilization strategies, including biofertilizers and organic amendments, need further research to enhance productivity while reducing environmental impacts. Ramie is known to be sensitive to water stress. However, there is limited research on optimal irrigation schedules, water-use efficiency, and drought-tolerant varieties, especially with the adverse impact of climate change. Another major gap is the lack of high-yielding and disease-resistant varieties. Although some breeding efforts are conducted, there is still a need to develop genetically improved cultivars resistant to ramie major diseases like anthracnose, leaf spot, and root knot-nematodes. In addition, pest and disease management strategies require further development; integrated pest management (IPM) strategies using biocontrol agents, resistant cultivars, and cultural practices remain under-researched. On the utilization side, the present challenge is the mechanization of harvesting and fiber processing; ramie harvesting is labor-intensive, and inefficient fiber extraction methods lead to fiber loss and quality deterioration. It is necessary to develop automated or semi-mechanized harvesting techniques to enhance productivity and fiber uniformity. Lastly, ramie fiber has limited market research and value chain analysis. Ramie is only known for textile production, and alternative utilization is under-researched; expanding research on value-added products (biocomposites, paper production, medicinal uses, etc.) can improve the economic viability of ramie cultivation and encourage wider adoption by farmers. Addressing these research gaps will contribute to ramie's sustainable and optimized cultivation, ensuring higher yields, better fiber quality, and improved economic benefits for farmers and industries.

Insect pests also affect ramie production. Some known insect pests of ramie include mole cricket, gryllid, Indian red admiral caterpillar, and ramie moth. The expression of the target proteins among transformed ramie plants shows that the transformation of is a promising avenue to develop pest-resistant fiber crops, beginning with Ramie. Ramie's resistance to the Ramie Moth is tied to leaf compounds like phenols, tannins, and oxalates (Zeng *et al.* 2011), making these markers for breeding resistant varieties. Transcriptome analysis of infested and non-infested leaves (Zeng *et al.* 2016) reveals that moth infestation drastically alters ramie gene expression, impacting numerous biological pathways. Defense-related pathways, such as ribosome function and Alpha-Linolenic Acid metabolism, are activated, indicating increased protein production for defense. Conversely, pathways related to photosynthesis were significantly downregulated during infestation, suggesting a potential impact on the plant's vigor. Several transcription factors, crucial for activating defenses and signaling pathways, are also affected. These findings allow breeders to identify and utilize key genes involved in defense responses and those suppressed during infestation for genetic improvement. Markers linked to resistance genes will allow faster and more accurate selection of resistant plants in breeding programs. Furthermore, these genes serve as targets for genetic modification. Gene-enhancing defense compounds or stress responses can be introduced. At the same time, those suppressing photosynthesis can be modified to maintain plant health. This approach enables the development of ramie varieties with enhanced resistance and sustained vigor, reducing losses from ramie moth infestation

Although there are several documents on diseases affecting ramie, gray areas remain that need further investigation. First, comprehensive epidemiological studies are needed to understand the distribution, host range, and environmental factors affecting disease development. Second, there is a lack of comprehensive pathogen identification and genomic studies. Exploring the genetic diversity and virulence of pathogens such as *Colletotrichum* species and *Curvularia eragrostidis* is crucial for developing resistant varieties. Whole-genome sequencing of major pathogens should be conducted to identify virulence factors and develop precise diagnostic tools. A thorough understanding of host-pathogen interactions at the molecular level could pave the way for innovative control measures. Third, breeding programs focused on resistance to multiple diseases are also lacking and should be prioritized. Advanced breeding techniques, including CRISPR and traditional selection methods, could enhance resistance against prevalent diseases. Fourth, the influence of climate change on disease dynamics and the economic impact of outbreaks requires serious attention. For example, the viral diseases *Yellow mosaic virus* and *Corchorus golden mosaic virus* need further investigation into transmission mechanisms and control measures. Additionally, root-knot nematodes lack studies on biological control and resistant varieties. Lastly, a comprehensive investigation into the synergistic effects of combining biological, cultural, and chemical control methods could provide actionable insights for sustainable ramie production.

With a long history of traditional use, ramie is now being studied for its potential benefits in different organ systems. Research suggests that its fibers may aid wound healing. At the same time, extracts from its leaves and roots could offer protection against bone loss, boost muscle glycogen, and provide neuroprotective and anti-lipidemic effects. Ramie leaf extracts also show promise in liver health, digestion, blood sugar regulation, hormone balance, and abortion risk reduction. Research on identifying and producing the phytochemicals associated with the bioactive extracts would be worthwhile. Ramie extracts may combat allergies and oxidation and promote blood clotting. Studies presented to support these claims, however, have been primarily performed on animal models or are, at most, *in vitro* studies. Further research must be systematically performed on higher animal forms and in vitro, before the ramie plant can be ethically applied to human studies to establish its medicinal effects. Nonetheless, these pioneering studies generally lead toward establishing *B. nivea*'s beneficial effects on humans. To date, no specific human clinical trials confirm the direct medical applications of the ramie plant (*Boehmeria nivea*) in modern medicine. While traditional practices have utilized ramie for different medicinal properties, such as antioxidant and anti-inflammatory properties, and various health conditions, including bone-related disorders, diabetes, and wound healing, most scientific studies have been limited to animal models or in vitro experiments. Despite promising results in these preclinical studies, the efficacy and safety of ramie-based treatments for human use remain largely unexplored. Moreover, without rigorous clinical studies, the translation of these benefits to human physiology is uncertain. Further clinical trials are necessary to establish its role in evidence-based medicine and are essential for developing new treatments (Novitzke, 2008). Modern medicine relies on well-controlled human trials to determine any therapeutic agent's efficacy, dosage, safety, and potential side effects before it can be widely recommended. Until further research is conducted to substantiate its therapeutic potential, ramie will continue to be regarded primarily as a traditional herbal remedy rather than a scientifically validated medical treatment.

Like other plants with many identified phytochemicals, the challenge is to translate these phytochemicals into effective medicinal or therapeutic applications. Most of these phytochemicals are only being tested in vitro, with a few in vivo studies that will prove their efficacy. The activities of these phytochemicals may be synergistic. This suggests that the crude extract may be a better choice for development into therapeutics rather than isolating the secondary metabolites if this area of research is pursued further.

The information presented in this paper will be useful in maximizing the potential benefits of ramie in the fiber industry and medicine. Further, the information on the biotic stress affecting ramie may be used as a guide for future research works that aim towards a sustainable and environment-friendly pest and disease management approach, ensuring sustainable and profitable ramie cultivation. The demand for ramie fiber is growing due to the increasing preference for eco-friendly and sustainable materials. This demand spans not only textiles but also extends to home furnishings and composite materials. As global demand increases, developing environmentally friendly extraction and fiber processing methods, including degumming, must be prioritized. Additionally, value-added products should be developed to benefit ramie farmers more. To boost ramie production, the government should offer comprehensive support services to farmers, including farm inputs and advisory services.

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Leny Galvez: Funding Acquisition

All authors contributed to the study's conceptualization and design, participated in writing the original draft and reviewed and approved the final version of the manuscript.

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Conflicts of Interest

The authors have no competing interests to declare relevant to this article's content. The authors also have no relevant financial or non-financial interests to disclose.

Ethics

This paper does not involve any human participants and/or animals. Ethical approval is not required and this paper did not perform any experiment or research that requires informed consent.

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