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Research article

Evaluation of mechanically extracted banana fibers from pseudostem layers: A sustainable textile raw material

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ABSTRACT

The separation of banana fibers from the pseudostem layers and the properties of two Thai banana cultivars, *Musa acuminata* (Kluai Hom) and *Musa sapientum* L. (Kluai Namwa) were investigated. The pseudostems were divided into three layers: outer (layer 1), middle (layer 2), and inner (layer 3). Fibers were extracted using a semi-automatic machine and subjected to chemical treatments. Results showed that layer 3 of Musa sapientum L. pseudostems yielded the highest amount of fibers with the lightest color. Fibers from layer 1 of *Musa sapientum* L. exhibited the highest tensile strength (606.90 g/denier) and elongation at break (9.54 %), higher than in all layers of *Musa acuminata*. SEM analysis revealed that chemically treated Musa acuminata fibers were less separated and broken than *Musa sapientum* L. fibers because the chemicals disrupted the lignocellulose bonds. Cross-sectional images showed larger lumens and more pronounced fiber group separation in *Musa sapientum* L. The outer layer of *Musa sapientum* L. pseudostem provided fibers with superior strength and elongation, demonstrating high potential as a sustainable raw material for the textile industry.

1. Introduction

Plant-based natural fibers have a variety of applications including garments and textiles. Bananas are a productive crop with export potential. More than 120 countries are home to the precious bioresource known as the banana plant [1], with significant demand, particularly in the Japanese market. Natural fibers such as jute, coir, banana, sisal, and others are abundant in developing nations like Thailand, Europe, and a few African countries [2]. Thailand has 103,000 banana farms, with annual export production of 2000 to 2500 tons. In 2016, *Musa sapientum* L. had a harvested area of 181,902.34 ha, giving 918,539 tons with a yield of 5049.63 kg per farm. Post-harvest, banana pseudostems, accounting for 60–80 % of plant weight, are often discarded as waste or burned, contributing to environmental pollution. Utilizing these pseudostems for fiber production would reduce annual agricultural waste by up to 550,000 tons (estimated from 2016 *Musa sapientum* L. production data). The global textile industry had a market value of $1 trillion in 2021 and this is expected to grow to $1.4 trillion by 2030. Developing sustainable alternative fiber sources will reduce this industry's annual environmental impact, using 93 billion cubic meters of water and generating 1.2 billion tons of greenhouse gas emissions.

This study focused on evaluating the potential of banana fibers from pseudostems as an alternative raw material for the textile

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industry to significantly reduce agricultural waste, add value to products, and support the development of a more sustainable textile industry. Annual banana pseudostem utilization of over 550,000 tons of agricultural waste will increase economic growth and environmental sustainability in the agricultural and textile sectors.

Natural fibers have fewer health hazards, are safe for the environment, are recyclable, and do not require abrasion to process quickly. The affordability of natural fibers is also a key advantage [3]. Post-harvest, banana pseudostems are often discarded as waste or burned after drying, which results in significant environmental pollution [4]. This practice destroys potentially valuable natural resources and contributes to air pollution and other environmental issues. The world's largest producer of bananas is India, where the extreme rigidity and poor cohesive qualities of the fiber make it unsuitable for use in textiles [5]. Banana, or *Musa acuminata* Colla, is widely grown all over Sri Lanka, where a significant amount of pseudo-stem biomass waste has been produced as a result of increased acreage and production in response to the growing demand for bananas on the global market [6]. China, Brazil, Ecuador, and India produce half of the world's bananas. A significant quantity of trash is produced during the growing and harvesting of bananas including leaves, pseudo-stems, rhizomes, and peels [7].

Natural fibers are materials derived from plants, animals, or minerals without undergoing chemical synthesis processes. These fibers can be categorized into several types:

1. Plant-based fibers: These include cellulosic fibers such as cotton, linen, jute, and hemp as well as leaf fibers like pineapple, sisal, and banana. These fibers are commonly used in the textile and paper industries [8].
2. Animal-based fibers: Examples include wool, silk, and other animal hairs primarily composed of proteins. They are often used in high-quality clothing and specialty textile products [9].
3. Mineral fibers: Asbestos has been used in construction and insulation but its use has declined due to health concerns [10].

These natural fibers possess diverse strength, elasticity, and breathability making them suitable for wide ranging applications from clothing to composite materials. In the context of sustainability, natural fibers have gained increasing attention due to their biodegradability and lower environmental impact compared to synthetic fibers. However, despite numerous advantages, natural fibers face challenges in engineering applications due to their hydrophilic nature and moisture absorption. Lignocellulosic fibers absorb moisture and are often incompatible with polymer matrices leading to weak fiber-matrix interfacial bond strength and inadequate wetting of the fibers by the matrix resin, typically resulting in composites with poor mechanical properties.

Bananas are a significant dietary staple, particularly for rural households, and their role as a raw material for various industrial products is increasingly recognized. Oloroso et al. [11] highlighted their growing commercial value in food and non-food sectors. Abundant natural fibers such as abaca, jute, vetiver, palmyra, coir, banana, bagasse, and sisal are traditionally used to craft items like wall hangings, table mats, handbags, purses, yarn, rope, and mats. These fibers also play a crucial role in the paper and clothing industries, with materials like cotton, pineapple, and banana being key components [12]. In India, 8.3 lakh hectares are devoted to banana cultivation, producing 51.18 million metric tons of pseudostem waste annually. Wild banana species from the Andaman and Nicobar Islands such as *Musa balbisiana* var. cola and *Musa balbisiana* var. *andamanica* are harvested for their fibers. These fibers are woven into "agna", a sheer fabric used predominantly for men's shirts in certain Filipino regions and also crafted into handkerchiefs. In Sri Lanka, banana fibers are utilized in floor coverings and in crafting soles for high-end shoes. The substantial cellulose content in banana stems presents valuable opportunities [13]. As well as the traditional use of banana fibers in the textile industry, there is growing interest in utilizing these fibers in advanced processes like electrospinning to produce nanofibers and composites with unique properties for applications in tissue engineering, wound healing, and water filtration [14].

Musa plants are some of the largest herbaceous perennials, with cultivated varieties typically ranging in height from 2 to 9 m, while certain wild species grow 10–15 m tall. These plants feature a subterranean stem known as a corm, an aerial pseudostem, leaves, and an inflorescence, collectively defining their structure [15]. Bananas are one of the tallest herbs and are notable for their size and variable utilities [16]. The fibers derived from bananas have been traditionally used to make grease-proof paper and are also suitable for producing ropes and twines. Annual banana production in India is 27.01 million metric tons from an area of 0.765 million hectares [17], with Brazil also a leading global banana producer. Banana fibers are a viable cost-effective and environmentally friendly option to synthetic fibers [18].

Extensive research has been conducted on the potential applications of natural fibers, particularly in reinforcing thermoplastics utilized in various industrial sectors including the automotive, construction, and packaging industries. These fibers have become increasingly popular due to their notable engineering properties such as low density, cost-effectiveness, environmental sustainability, biodegradability, and recyclability. These attributes make natural fibers an appealing alternative to synthetic materials. Natural fibers are renewable and exhibit favorable mechanical properties, giving them a competitive edge over artificial fibers. Currently, global interest in synthetic polymeric materials is waning because of their less desirable properties compared to bio-fibers. However, despite numerous advantages, natural fibers face challenges in engineering applications due to their hydrophilic nature and moisture absorption. Lignocellulosic fibers absorb moisture, often resulting in incompatibility with polymer matrices leading to weak fiber-matrix interfacial bond strength and inadequate wetting of the fibers by the matrix resin, typically producing composites with poor mechanical properties. This issue highlights the key challenge of using natural fibers in composite materials. The interaction between the fiber and the matrix is crucial for enhancing overall composite performance.

The performance and chemical composition of natural fibers are influenced by various factors, affecting their suitability for different applications. These factors include:

(a) (b)

Fig. 1. Banana plant: (a) Banana agricultural plotม (b) Banana waste after harvest.

(a) (b)

Fig. 2. Banana pseudostem: (a) Pseudostem layers (b) Cut pseudostems.

1. Plant species and variety: Different plant species, and even varieties within the same species, produce fibers with varying chemical compositions and physical properties. The cellulose content in cotton fibers is typically higher than in bast fibers like jute or hemp.
2. Growing conditions: Environmental factors such as soil quality, climate, and agricultural practices significantly impact fiber development. Drought stress also affects the cellulose content and fiber strength in plants.
3. Fiber location within the plant: The part of the plant from which the fiber is extracted also influences its properties. In banana plants, fibers from different layers of the pseudostem exhibit varying characteristics, as demonstrated in this study.
4. Harvesting time: The maturity of the plant at harvest affects fiber quality. Premature harvesting often results in weaker fibers, while over-maturity leads to lignification and reduced flexibility.
5. Extraction method: The process used to extract fibers from the plant material impacts their physical and chemical properties. Mechanical extraction preserves fiber length but often causes more damage compared with chemical methods.
6. Post-harvest treatments: Various treatments applied to fibers after extraction such as chemical modifications or physical treatments alter their surface properties, chemical composition, and performance characteristics.
7. Storage conditions: Humidity and temperature during storage affect fiber moisture content, leading to degradation or changes in mechanical properties.

The chemical composition of natural fibers, typically consisting of cellulose, hemicellulose, lignin, pectins, and waxes varies based on these factors. The cellulose content largely determines fiber strength, ranging from 60 to 80 % in cotton, 70–80 % in flax, and 60–65 % in banana fibers. Understanding these influencing factors is crucial for optimizing fiber extraction, processing, and application in various industries including textiles and composites.

This study focused on separating fibers from Musa acuminata and Musa sapientum L. bananas and examining the properties of mechanically extracted banana fibers from pseudostem layers in Thailand. The fiber layer from the banana sheath displayed greater acid resistance compared to the *Musa acuminata* variety, exhibiting the highest tensile strength at break and the greatest percentage of elongation before break among the fibers tested. The physical and mechanical properties of treated and untreated banana fibers revealed that treated fibers exhibited improved mechanical locking. This enhancement is particularly beneficial for the manufacture of composites, resulting in stronger and more durable materials. This finding underscored the importance of fiber treatment processes in optimizing the performance of natural fiber-reinforced composites.

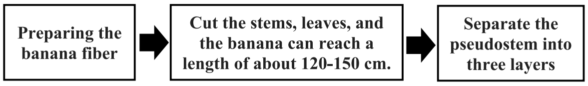


Fig. 3. The banana fiber preparation process.

(a) (b)

Fig. 4. Banana pseudostem (a) banana pseudostem extraction, (b) dried banana fiber.

Fig. 5. Extraction process of banana fibers.

2. Material and methods

2.1. Material

This research used two types of banana plants: *Musa acuminata* and *Musa sapientum* L. The remaining 7-month-old bunches were cultivated in agriculture plots in Pathum Thani Province (Fig. 1(a)). After harvesting, the pseudostems were collected as agricultural waste which could be utilized for fiber extraction (Fig. 1(b)).

2.2. Methods

2.2.1. Preparing the banana fiber

The banana fiber was prepared from the pseudostems of Musa acuminata and Musa *sapientum* L. bananas. After cutting off the leaves, banana stems 120–150 cm long remained. The pseudostem was divided into 3 layers as the outer pseudostem (layer 1), the middle pseudostem (layer 2), and the inner pseudostem (layer 3) (Fig. 2(a)). After separation, the pseudostems were cut into smaller pieces for fiber extraction (Fig. 2(b)). The banana extraction process is presented in Fig. 3.

2.2.2. Extracting the banana fiber

The banana fiber was mechanically extracted by feeding the banana pseudostem lengthwise into a fiber extractor. The machine extracted the fibers by scraping the outer banana pseudostem (Fig. 4(a)). The extracted fibers were then dried at room temperature (Fig. 4(b)). The complete extraction process is illustrated in Fig. 5.

2.2.3. Testing the characteristics and physical properties of banana fibers

The fibers of *Musa acuminata* and *Musa sapientum* L. banana were then determined for strength by measuring the fiber length and percentage of elongation. The pulling speed was tested at 25 mm per minute using a piece of yarn 2.54 cm long (ASTM D 3822-01 standard). The temperature was maintained at 21 °C with relative humidity 65 % as the ideal conditions for choosing fibers for further used in the textile industry.

2.2.4. FTIR spectra

The characterization of banana fibers using the FTIR technique was conducted on raw banana fibers extracted for use as textile raw materials without any finishing treatment. To create a translucent sheet, the samples and KBr pellets were combined at a ratio of 1/100 and then ground into powder. A Nicolet-380 Spectrometer was used to record the FTIR spectra at wave numbers between 4000 and

Table 1
Images of the pseudostem layers of banana fibers.

Banana separation	Layer 1	Layer 2	Layer 3
Banana pseudostem			
Raw banana fiber			

400 cm^{-1}.

2.2.5. Chemical treatment of banana fiber

The chemical treatments for conditioning the fibers of *Musa acuminata* and *Musa sapientum* L. bananas included extraction at two levels: 50 % concentration of sodium hydroxide solution and 50 % concentration of sulfuric acid solution at 5 % and 10 % volume per volume (v/v). Six types of banana fiber were recorded as *Musa acuminata* layers 1, 2, and 3 and *Musa sapientum* L., layers 1, 2, and 3. The banana fibers were soaked in the chemicals for half an hour, washed well, and then air-dried in the sun.

2.2.6. Scanning electron microscopy (SEM) analysis of banana fibers

2.2.6.1. Sample preparation.

- The raw and chemically treated banana fibers from *Musa acuminata* and *Musa sapientum* L. cultivars were cut into small pieces (approximately 5 mm in length).
- The fiber samples were then mounted onto aluminum stubs using double-sided carbon tape.
- The samples were coated with a thin layer of gold using a sputter coater to ensure conductivity and prevent charging during SEM analysis.

2.2.6.2. SEM imaging.

- The prepared samples were placed into the SEM chamber and the working distance was adjusted to obtain optimal focus and magnification.

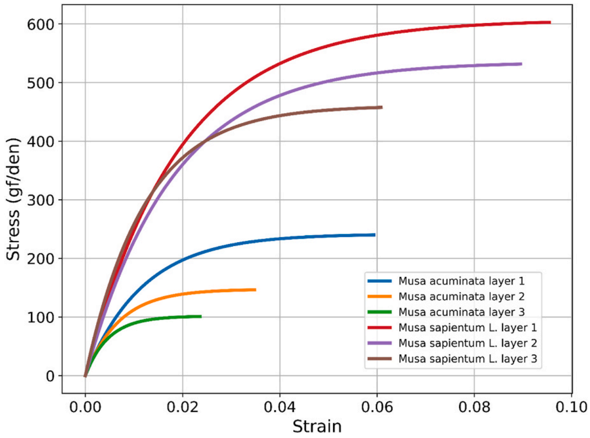


Fig. 6. Stress-strain curves of banana fibers from different layers of *Musa acuminata* and *Musa sapientum* L. pseudostems.

- High-resolution images of the fiber surface morphology and cross-sections were captured at various magnifications (500x, 1000x, 2000x).
- The key morphological features such as surface roughness, fiber diameter, lumen size, and fiber group arrangement were observed and recorded.

2.2.6.3. Image analysis.

- Image analysis software was used to measure the diameter of individual fibers and the size of lumens from the captured SEM images.
- The morphological characteristics of raw and chemically treated fibers from both banana cultivars were compared.
- The effects of chemical treatments on the fiber structure such as the degree of separation and breakage of fibers were analyzed.
- The observed morphological features were related to the mechanical properties of the banana fibers.

2.2.7. Water absorption testing of the fibers

The banana fibers were subjected to water absorption testing following the ASTM D2402-07 (2012) standard. The fibers were oven-dried at 105 °C for 4 h, and the weight of the dried fibers (X_2) and beaker (X_1) was recorded. The fibers were them immersed in distilled water for 24 h. After removing the fibers from the water, the surface water was blotted with paper to remove excess water, and the weight of the wet fibers (X_3) was recorded. The moisture regain% and moisture content% were calculated using Eqs. (1) and (2):

$$\text{Moisture regain\%} = [(X_2 - X_3)\ /\ (X_3 - X_1)] \times 100 \tag{1}$$

$$\text{Moisture content\%} = [(X_2 - X_3)\ /\ (X_2 - X_1)] \times 100 \tag{2}$$

3. Results and discussion

3.1. Effectiveness of banana fiber using mechanical extraction

The fibers were extracted from each pseudostem layer, with results shown in Table 1.

Musa acuminata banana pseudostems and *Musa sapientum* L. banana pseudostems in layer 3 had the highest amount of fiber with a light color, followed by banana pseudostems in layer 2 which had more fiber and were lighter in color than banana pseudostems in layer 1. The mechanical properties of banana fibers impact their high cellulose content [32]. Gopinath [33] recognized banana pseudostem as a source of fine-quality fiber. Further developments in the mechanical extraction processes have facilitated the separation of banana fiber, simplifying the process to a considerable degree [34].

3.2. Physical properties of bananas

Fig. 6 presents the stress-strain curves for *Musa acuminata* and *Musa sapientum* L. fibers from different pseudostem layers. The curves demonstrated the superior mechanical properties of *Musa sapientum* L. fibers, particularly from layer 1, which exhibited the highest

Table 2
Average tensile strength and percentage of elongation of the banana fibers.

Type of banana fiber	Tensile strength (gf/den)	Elongation before break (%)
Musa acuminata layer 1	241.54	5.93
Musa acuminata layer 2	147.07	3.48
Musa acuminata layer 3	101.37	2.36
Musa sapientum L. layer 1	606.90	9.54
Musa sapientum L. layer 2	535.09	8.95
Musa sapientum L. layer 3	460.61	6.08

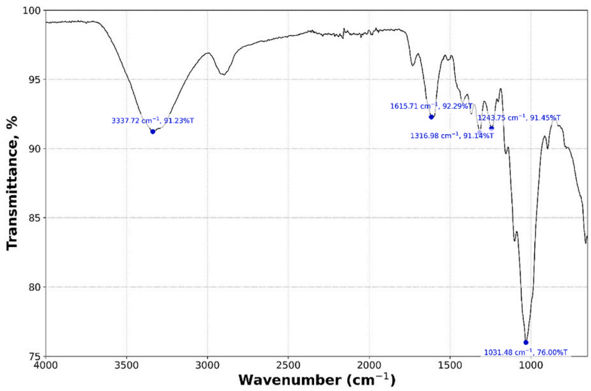


Fig. 7. FTIR spectrum of raw, untreated banana fiber.

stress and strain values. This graphical representation confirmed the tabulated data and provided a visual understanding of fiber behavior under tension. The non-linear nature of the curves indicated the complex structural response of the fibers, with initial elastic deformation followed by plastic deformation until failure. The steeper initial slopes of *Musa sapientum* L. curves, especially for layer 1, suggested a higher Young's modulus, indicating greater stiffness compared to *Musa acuminata* fibers.

Physical properties of tensile strength and elongation before break of banana fibers are shown in Table 2.

Musa sapientum L. banana fibers, particularly from layer 1, exhibited the highest tensile strength at break (606.90 gf/den) and the highest percentage of elongation before break, surpassing *Musa acuminata* banana fibers (Table 2). Results suggested that all layers of *Musa sapientum* L. fibers demonstrated superior strength and elasticity compared to *Musa acuminata*. Vigneswaran et al. [19] noted that the banana plant's outermost layers yielded coarser fibers, while the subsequent sheaths provided softer, lustrous fibers and the middle sheaths, except for the innermost, yielded very soft fibers. Generally, raw banana fiber consists of 57.64 % cellulose, 29.05 % hemicellulose, and 13.30 % lignin. The outermost banana fiber layer (layer 1) has high tensile strength and elongation capability corresponding to high cellulose content [20].

Yilmaz et al. [21] found that banana bunch stem fibers offered superior firmness, and breaking strength with inversely related elongation ratio. In Sri Lanka banana cultivars, fibers from the middle layer of the pseudostem are the finest and strongest [22]. Sangamithirai and Vasugi [23,35] advocated banana fiber as a sustainable alternative to synthetic fibers in the textile industry, owing to its agro-waste origins and eco-friendly nature.

The structural and anatomical qualities of banana fibers including their high tensile strength, support their potential as a sustainable raw material for the textile industry [22,24,36].

3.3. FTIR analysis

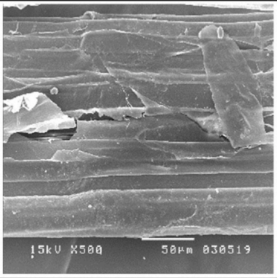
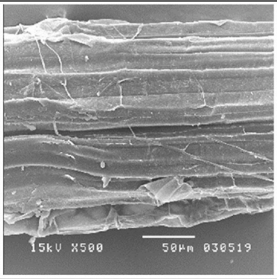
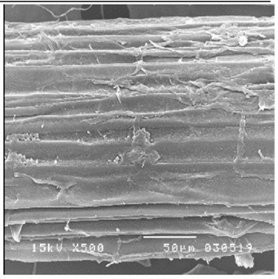
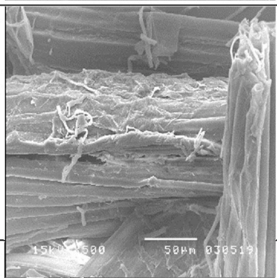
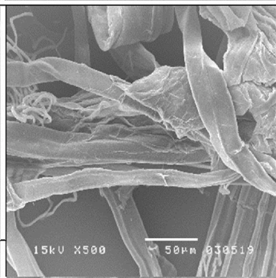
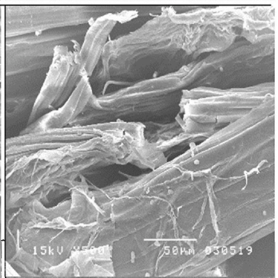
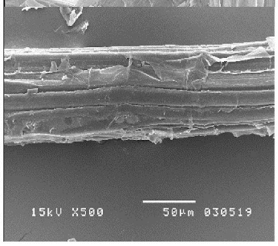
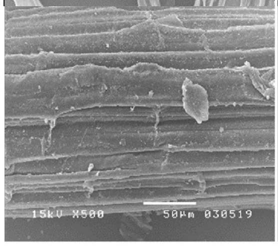
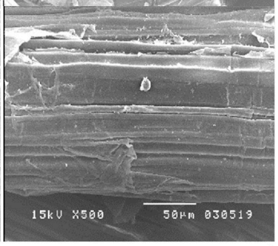
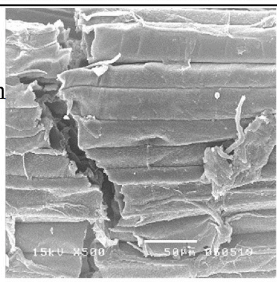
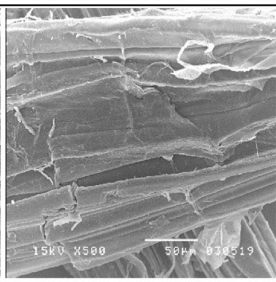
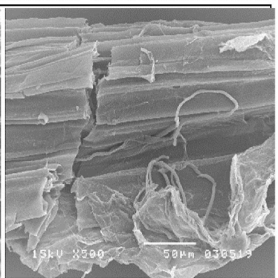
Banana fibers have hydroxyl groups in their cellulose structure. The functional groups were analyzed using the FTIR technique, with results shown in Fig. 7. Raw, untreated banana fibers exhibited a carbonyl (C=O) stretching peak at a wavelength of 1615.71 cm^{-1} and a carbon-oxygen (C-O) stretching peak at 1316.98 cm^{-1} in the –O-(C=O)-CH_3 group. Notably, these peaks did not appear in the FTIR spectrum of pure cellulose [25]. Chai et al. [26] studied the structures of raw pomelo peel and characterized the absorption peaks at 3408, 2921, 1751, 1633, 1373, 1232, and 1053 cm^{-1}.

3.4. Conditioning separated by chemical treatment and testing the physical properties of banana fibers

The differences in characteristics and longitudinal images of *Musa acuminata* and *Musa sapientum* L. banana fibers separated by chemical and mechanical methods are shown in Tables 3 and 4.

Results in Table 3 show that the raw banana fibers had distinctive long grooves with clusters of fiber groups. The chemical pretreatment process revealed reduced separation and breakage of *Musa acuminata* fibers compared to *Musa sapientum* L. fibers, which

Table 3
The characteristics and longitudinal appearance of the banana fibers.

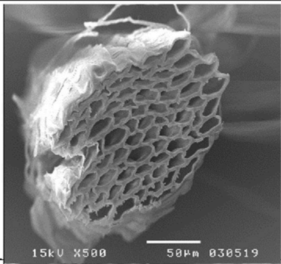
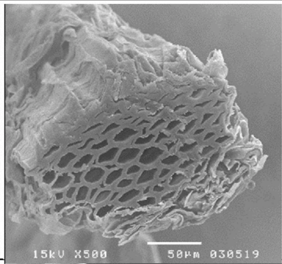
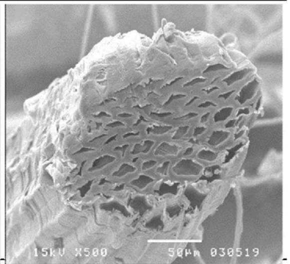
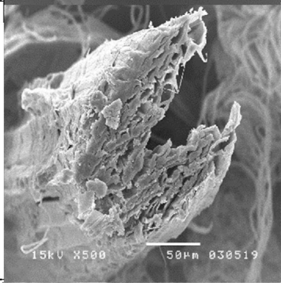
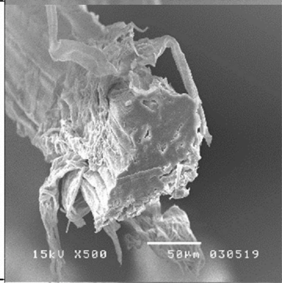
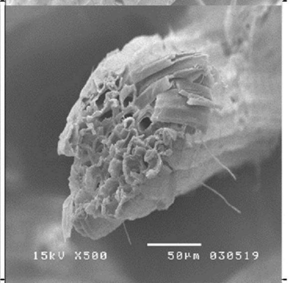
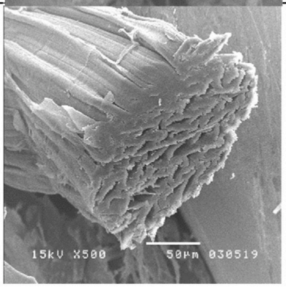
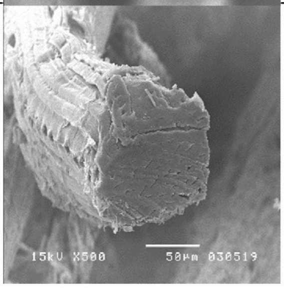
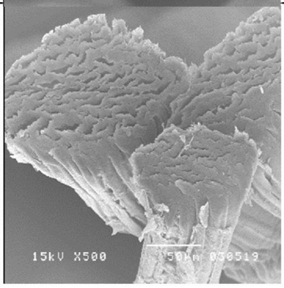
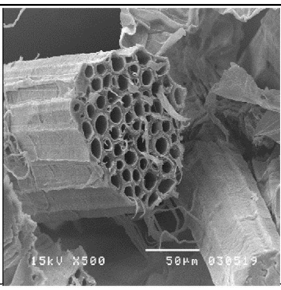
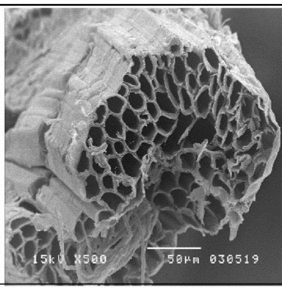
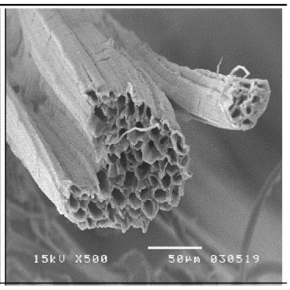
Type of fiber	Layer 1	Layer 2	Layer 3
Musa acuminata (Raw)			
Musa acuminata treatment with 5% sulfuric acid			
Musa sapientum L. (Raw)			
Musa sapientum L. treatment with 5% sulfuric acid			

maintained an average length of 0.5–1.5 cm. This size difference arose because the chemicals involved in the pretreatment disrupted the bonds within the lignocellulose compounds. Badanayak et al. [4] recorded that the surface of raw fibers appeared rough but chemical degumming smoothed the surface.

Krishnan et al. [3] suggested that the surface of chemically treated fibers became rougher, with the fibers exhibiting greater separation but the general integrity of the fiber structure was maintained. Berhanu et al. [27] characterized banana fiber bundles as having a rough surface and some stiffness, with a cross-sectional view elongated to circular. This description provides insights into the physical attributes of banana fibers, which influence their application in various products, particularly those requiring specific structural or aesthetic qualities. This array of physical characteristics underlines how different treatment methods impact the potential applications of banana fibers in various industries.

Musa sapientum L. bananas exhibited a larger lumen and more pronounced separation of fiber groups compared to *Musa acuminata* bananas (Table 4). Ganapathy et al. [28] explained that this differentiation was due to the effect of sulfuric acid, which broke down the interconnecting bonds within the lignocellulose compounds. This degradation allowed the fiber bundles to be broken down, either

Table 4
The characteristics and cross-section appearance of the banana fibers.

Type of fiber	Layer 1	Layer 2	Layer 3
Musa acuminata (Raw)			
Musa acuminata treatment with 5% sulfuric acid			
Musa sapientum L. (Raw)			
Musa sapientum L. treatment with 5% sulfuric acid			

mechanically or chemically, to achieve the necessary fineness for various applications.

Ernest and Peter [29] emphasized the broad range of banana fiber benefits across multiple fields, highlighting its significant utility. Mumthas et al. [6] observed that mechanically extracted banana fibers often present cloudy and unclear surfaces due to the entanglement and breakage of single fibers, a consequence of the decortication technique used.

Benedetto et al. [30] discussed how surface treatments on banana fibers induced substantial structural changes, resulting in mechanically stronger composites. Ezeamaku et al. [31] found that chemical modification of banana fibers with acetic acid altered their surface topography and crystallographic structure while effectively cleansing surface impurities. Chemical modification improved the performance of the fibers in composite materials by enhancing their matrix compatibility and suitability for various industrial applications.

3.5. Water absorption testing of banana fibers

The banana fibers exhibited a moisture regain% of 14.1202 % and a moisture content% of 12.3731 % from the water absorption test. Results indicated that the banana fibers had high water absorption capacity, attributed to the hydrophilic nature of cellulosic fibers and the presence of hydroxyl (-OH) groups in the fiber structure.

4. Conclusions

This study successfully investigated the extraction and properties of banana fibers from the pseudostem layers of *Musa acuminata* and *Musa sapientum* L. cultivars. Results revealed that the inner layer (layer 3) of *Musa sapientum* L. pseudostems yielded the highest amount of fibers with the lightest color. Fibers from the outer layer (layer 1) of *Musa sapientum* L. exhibited superior tensile strength and elongation at break compared to *Musa acuminata* in all layers.

Chemical treatments disrupted the lignocellulose bonds, resulting in reduced separation and breakage of *Musa acuminata* fibers compared to *Musa sapientum* L. fibers. SEM analysis provided insights into the structural differences between the two cultivars, with *Musa sapientum* L. fibers showing larger lumens and more distinct fiber group separation.

FTIR analysis revealed the presence of carbonyl (C=O) and carbon-oxygen (C-O) stretching peaks in raw banana fibers, which were not present in pure cellulose. This finding indicated the presence of additional functional groups in banana fibers, potentially contributing to their unique properties. The FTIR results corroborated the observed differences in mechanical properties between the two cultivars and different pseudostem layers.

The findings of this study highlight the excellent properties of *Musa sapientum* L. fibers, particularly fibers from the outer layer of the pseudostem. These fibers demonstrate high potential as a sustainable and alternative raw material for the textile industry. The superior strength and elongation of *Musa sapientum* L. fibers make them suitable for various applications that require durability and flexibility.

The chemical composition analysis, coupled with the mechanical and structural characterization, provided a comprehensive understanding of banana fiber properties. This multifaceted approach allowed a more informed assessment of the potential applications and limitations of banana fibers in the textile industry.

The unique properties of banana fibers, as revealed by the FTIR analysis and mechanical testing, make them a promising raw material for various applications in the textile industry and beyond. The presence of additional functional groups in banana fibers, compared to pure cellulose, contributes to their enhanced mechanical properties such as high tensile strength and elongation at break, particularly in the case of *Musa sapientum* L. fibers from the outer pseudostem layer. These superior mechanical properties suggest that banana fibers show potential for the production of high-performance textiles such as technical fabrics for industrial or automotive applications. The natural origin and biodegradability of banana fibers also make them an attractive option for sustainable and eco-friendly textile products such as apparel, home furnishings, and packaging materials.

The chemical composition of banana fibers containing lignin, hemicellulose, and cellulose has unique properties that can be used to develop novel composite materials. Banana fiber-reinforced composites have applications in various sectors including the construction, automotive, and packaging industries, offering a sustainable alternative to synthetic fibers. The potential of banana fibers extends beyond the textile industry, with possible applications in paper, handicrafts, and other biomass-based products. The utilization of banana pseudostem waste as a source of fibers also aligns with the principles of the circular economy, contributing to reduction of agricultural waste and promoting sustainable practices.

CRediT authorship contribution statement

Chanakarn Ruangnarong: Writing – review & editing, Writing – original draft, Methodology, Investigation, Conceptualization. **Sujira Khojitmate:** Writing – review & editing, Supervision, Project administration, Methodology, Conceptualization. **Supanicha Srivorradatphisan:** Resources, Methodology, Investigation. **Natthapong Panyathikun:** Methodology, Investigation, Data curation. **Sakorn Chonsakorn:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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