# Biowaste Management: Comparison of Banana (*Musa acuminata*) and Bamboo (*Bambusa vulgaris*) Fibers

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Both developed and developing countries around the world are increasingly utilizing biodegradable products and bio-based materials. This is required to curb rampant environmental pollution caused by synthetic materials and their by-products. In this study, banana and bamboo fibers were prepared from agricultural and industrial wastes, respectively. Banana and bamboo fibers were obtained with aid of mechanical and waste extractions, respectively. Both fibers were subjected to a retting process for 24 hours, using normal warm water at a room temperature (27 ± 3 °C) to remove the impurities. Then, a comparative investigation and analysis was conducted concerning their properties and applications. The biomass level, physical, and chemical properties, structure, experimental analysis, and moisture regain behaviors of the plant materials were studied. Additionally, the antibacterial property of the samples was discussed. The biomass level was measured per hectare for banana (36.1 tons) and per plant for bamboo (65%), and the physical and chemical properties were identified *via* some basic testing techniques. The molecular, crystalline, and morphology structures were observed using Fourier-transform infrared spectroscopy, X-ray diffraction, and scanning electron microscopy. Finally, the industrial applications were elucidated to establish the possibility of using both fibers as promising sustainable, renewable, recyclable, and eco-friendly materials.

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## INTRODUCTION

At present, people are using many synthetic materials throughout their normal life. Some of the materials are classified as fiber-based materials. Fibers can be classified into two categories: man-made or synthetic and natural fibers (Balda *et al.* 2021). Natural fibers have some favorable properties in comparison to synthetic fibers, and their by-products are often less harmful for the ecosystem. Synthetic fibers are a non-renewable resource and do not contain a biodegradable property (Gupta *et al.* 2023). They exhibit environmental challenges, having high density, high cost of production, and difficulty in recycling. Therefore, these drawbacks of synthetic materials or fibers have necessitated the switch to natural fibers. Natural fiber is a promising alternative to save the earth (Kannigadevi *et al.* 2021, Tezara *et al.* 2022). This awareness is spreading globally to protect the environment. The ongoing support of the United Nations (UN) has been creating awareness to use natural products to protect the ecosystems. They often emphasize the importance of natural materials for all kinds of commercial industries and for people to the use the natural by-product to maintain and enrich the environmental quality (Priyadarshana *et al.* 2022).

Fibers constitute a category of hair-like materials that can exist as continuous filaments or discrete elongated pieces (Subramanya *et al.* 2017; Kavitha and Aparna 2021). It is the discontinuous fibers that can be spun into yarn, threads, or ropes and are utilized as integral components in composite materials. In recent decades, there has been a significant surge in the demand for natural fibers. This is primarily because of their perceived environmental friendliness, affordability when sourced locally, and their combination of low density with sufficient tensile strength and stiffness. Natural fibers also exhibit low toxic fume emissions during their recycling process. As the need for biodegradable, eco-friendly fiber materials continue to rise as an alternative to synthetic fibers, there is a growing interest in exploring potential sources of natural fibers, such as banana and bamboo (Cruz and Fangueiro 2016).

Based on statistical reports, the annual total production of ligno-cellulosic fiber is about 3 to 4 billion tons around the world, where almost 40 and 60% of them are forest and agricultural wastes, respectively. This is bigger than the other global commodities, including plastics and steel, with 0.1 and 0.7 billion tons, respectively (Subagyo and Chafidz 2018 and Saxena and Chawla 2021). This information created awareness about the opportunity for the utilization of cellulosic fibers. Scientists are continuously inventing various natural fiber applications and waste management. Natural fibers, such as cotton, banana, bamboo, pineapple, jute, hemp, linen, kettle, flax, and wool, among other plant fibers are recyclable and biodegradable (Padam *et al.* 2014). The banana is a crop primarily grown for its fruit, especially in tropical regions worldwide. However, after harvesting, a significant portion of its biomass, accounting for approximately 60%, including pseudo-stems, is often discarded as waste (Subagyo and Chafidz 2018). It is cultivated mostly in the equatorial region of the earth. India, China, Indonesia, Brazil, Philippines, among others are the major countries that are well known for banana cultivation (Vigneswaran *et al.* 2015; Abdul Motaleb *et al.* 2020).

Bamboo also produces large biomass after industrial usage, but less than that of banana. Bamboo widely grows in tropical, subtropical, and temperate climates around the globe, and it is found at altitudes up to 3500 m. There are more than 1000 species or varieties, similar to banana. Despite this, its area of growth is much larger than that of banana growing areas. Bananas grow in around 20 countries, but bamboo thrives in more than 50 countries. China is the major producer of bamboo; hence a great deal of attention is focused there on the applications of bamboo by-products (Fu *et al.* 2012). China manufactures and exports bamboo and their by-products (Liu *et al.* 2012). In addition, China exports a large volume of bamboo by-product making machines (Kumar *et al.* 2023). The goal of this novel study was to comparatively assess the biomass level, fiber recovery percentage, property analysis of their retting fibers, and finally the potential applications of banana and bamboo fibers.

## EXPERIMENTAL

### Materials and Methods

Banana and bamboo are classified under natural vegetable fiber. Both banana and bamboo were collected from the Southern part of India. Banana cultivation is prolific in this area; almost 20 to 26 varieties can be harvested. There are five states in this part of India, including both Tamil Nadu and Andhra Pradesh, that are known for the cultivation of wild species with many varieties. The northern part of India is also cultivating some types of bananas. However, this research used only poovan banana plant stem, which is a wild species type (*Musa acuminata*). The bamboo variety (*Bambusa vulgaris*) was collected from the Western Ghats region that is a nearby Madurai region of Tamil Nadu.

There are extraction methods, such as manual, mechanical, chemical, and enzymatic extractions for plant fibers (Preethi and Balakrishna 2013; Subagyo and Chafidz 2018). Mechanical extraction was used in this work through a machine that was developed by SP natural from South India. At present, most of the industries around this region are using automatic and semi-automatic machines (Ramamoorthy *et al.* 2021). After cutting the bamboo from the forest, it was brought to the bamboo stick manufacturing laboratory. Seven machines were used during this process. Fibers were obtained in the fourth process, which was a waste material when making the bamboo stick. The machines were developed by Anil Bamboo Industries, Indore, India. The extracted levels were measured for both fibers. Equations 1 and 2 were used to calculate the recovery of banana and bamboo fibers (Preethi and Balakrishna 2013):

$$Banana\ Fiber\ recovery = \frac{Total\ fiber\ Extracted(Kg)}{Total\ extractable\ sheath(Kg)} \times 100 \tag{1}$$

$$Bamboo\ Fiber\ recovery = \frac{Recovered\ fibers}{Bamboo\ culm\ weight} \times 100 \tag{2}$$

Some physical and mechanical properties were identified by using normal test equipment. The chemical composition method for lignin was identified using the Klason and fiber cellulose content measured using Krushner and Hoffer's method (Ronald Aseer *et al.* 2013). The most important analysis was to obtain the cellulose, lignin, and moisture contents of the fibers. They play a major role in by-product applications. The moisture content was determined by the normal methods from weighted and dried samples. The dried samples were tested in an oven at 104 °C for 3.5 to 4.0 h. The fiber cross-sectional and longitudinal views were taken by a scanning electron microscope (SEM). The micrographs were obtained using a FESEM INCA PENTAFET X3 7421 (Shimadzu Analytical India Pvt Ltd, New Delhi, India) instrument with 20 kV electron beam. The crystallinity index (CI) and organic molecule level were observed by X-ray diffraction (XRD) and Fourier-transform infrared (FTIR) spectroscopy (Subagyo and Chafidz 2018). The intensities of Bragg peaks for both banana and bamboo fibers were determined. Both fibers were analyzed in continuous scanning mode, using a Rigaku model Diffractometer (Rigaku Asia Pacific PTE LTD., Singapore) to study their phases and structures. The Cu-Kα tube was operated at 40 kV/30 mA, with a scanning speed of 0.5/min and a step size of 0.02. The FTIR spectra of the fiber samples were recorded in potassium bromide (KBr) pellets, using a Perkin Elmer model Spectrum RX1 FTIR spectrometer (PerkinElmer, U.S. LLC, Shelton, CT, USA), covering the range of 400 to 4,000 $cm^{-1}$ with a resolution of 2 $cm^{-1}$. The fibers were chopped into small particles and finely ground, as required for the preparation of the samples. The powder obtained was then mixed with KBr and pressed to create pellets for recording the FTIR spectra. The absorption level was calculated for both fibers, which were taken at different timings. The antibacterial property was discussed, but it was not analyzed in the laboratory. It was taken from a reliable literature review on banana and bamboo (Kumar *et al.* 2012; Krishnaveni 2016).

## Preparation of Fibers

Both banana and bamboo fibers were prepared by following certain steps, as shown in Figs. 1 through 4. Banana fruits were cultivated from the plant after 9 to 10 months, and then the plant could not be used for fruit cultivation. Therefore, the complete plant was cut and used for making value-added product. This was a subsequent usage in many applications. The fiber was prepared from the stem only, not from other elements of the plant. The stems were collected from the plant, and the sheaths were removed from the stem. The segregated extractable sheaths were taken to the storage unit and the fiber was extracted from the major parts of the sheaths, such as outer, middle, inner, and core. The semi-automatic machines were used to extract the fiber (Fig. 2). Afterwards, it was processed in water to remove unwanted substances and obtain fiber fineness because it has multi-cellular structure. The fibers were immersed in water for 24 h, and then dried at a room temperature under a roof. Both fibers were prepared, following processes depicted in Figs. 2 and 4.

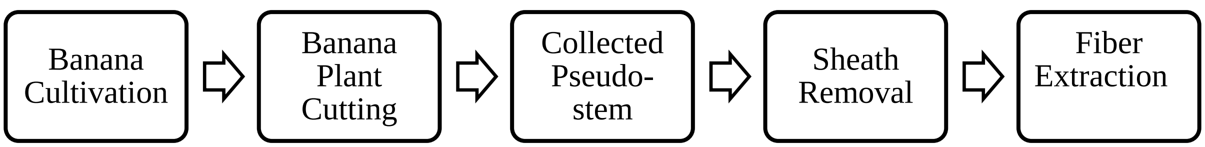


**Fig. 1.** Banana fiber preparation steps

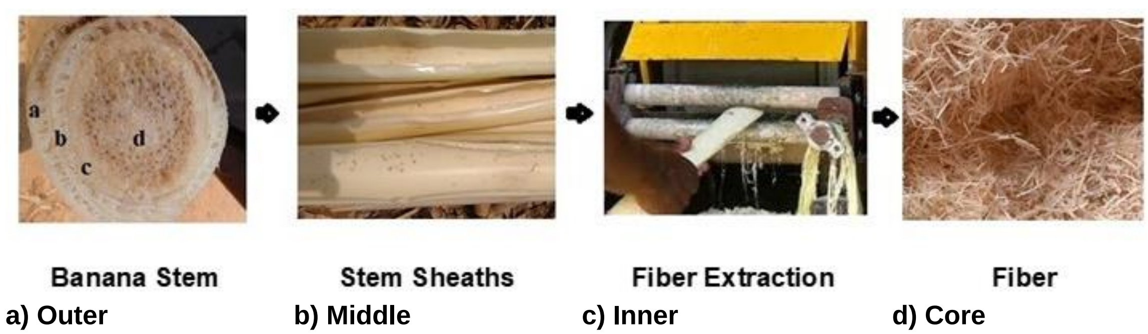


**Fig. 2.** Sequential images of banana fiber preparation

Bamboo fiber is the waste material when making bamboo sticks. The sticks can be used for other industrial applications. In this research, the recovered waste fiber was collected from the stick making machine. Bamboo fibers were not extracted fiber like banana. The fibers were extracted from each of the small culms. Their sizes are represented in Table 3. Eventually, the fibers were taken to normal retting process to remove the unwanted substances and make the fiber soft, when it was kept under water for a day (24 h). Generally, the fiber fineness is improved if the retting process time increased. The properties of the fibers were examined in close proximity to the actual raw fiber in this research. For this reason, the fiber has been submerged in water for 24 hours. The preparation process is comprehensively and clearly depicted in Fig. 4. The (g) and (h) in Fig. 4 is illustrated the slicing and stick making from the bamboo culms. There were 10 to 12 sticks/sliced (1.3 cm width) that were able to be produced using the machine. Afterwards, the fiber was dried at room temperature under a roof.


**Fig. 3.** Bamboo fiber preparation steps

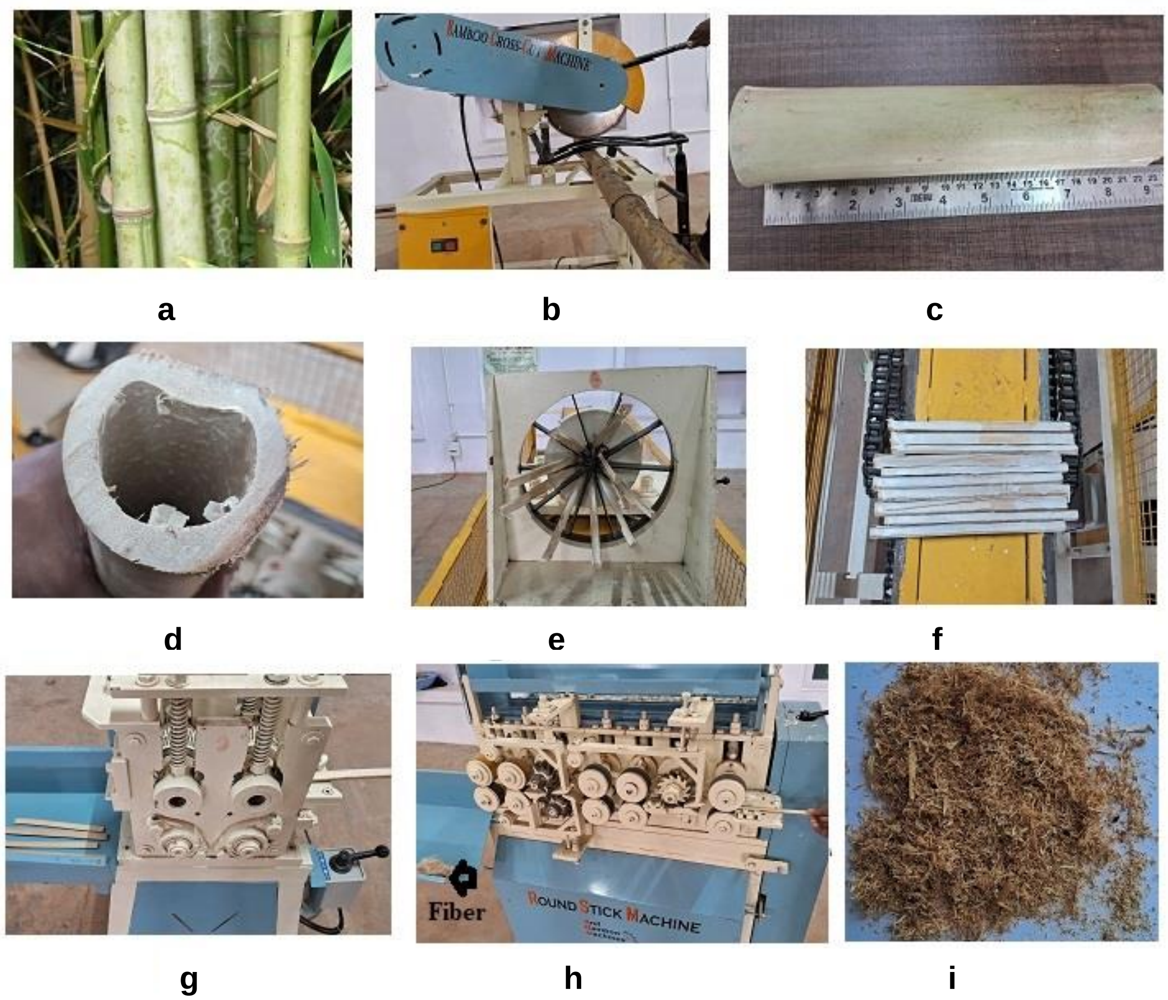


**Fig. 4.** (a) Bamboo plants, (b) bamboo cutting machine, (c) culm length, (d) culm top view, (e) bamboo culm splitting, (f) split culm, (g) slicing machine, (h) bamboo stick making, (i) fiber waste

## RESULTS AND DISCUSSION

Fiber waste was calculated after fiber was extracted, and its recovery percentage was measured prior to the SEM analysis, physical and chemical properties, elemental analysis, absorption, and antibacterial properties.

### Biowaste Level

Calculation was obtained after the cultivation, as examined for a hectare and an acre. The approximated values are presented for all of the results obtained. The banana plant weights were 19.5 to 20.5 kg. The minimum and maximum values were around 19.5 and 20.5 kg, respectively. The SD was able to take 20.0 kg. The traditional wild species of banana and bamboo were used. The biomass is presented in Table 1 and the element-wise waste percentage is presented in Table 2. Generally, all elements of banana are used for various purposes. Precisely, the stem or stalk of banana with weight of 12.0 to 13.2 kg was used. The percentage levels of waste were 26 to 28, approximately. The fiber content is available in parts of banana and plantain plant or tree. The fiber extraction was easily taken from pseudo-stem, not from the others. However, the peduncle was also used to obtain fiber and the hard extraction process was followed.

**Table 1.** Banana Plant Waste

| Area | Plant Wastes (tons) | Plant Weight (Avg) (Kg) |
|---|---|---|
| 1 hectare | 36.06 | 20.0 |
| 1 acre | 14.60 | |

**Table 2.** Banana Element Waste Percentage

| Banana Samples (%) | Stem | Peels and Peduncle | Leaf | Fruits | Others |
|---|---|---|---|---|---|
| Plant 1 | 28 | 12 | 29 | 13 | 18 |
| Plant 2 | 26 | 11 | 32 | 12 | 19 |
| Plant 3 | 28 | 13 | 31 | 12 | 16 |

Three samples were taken for the bamboo waste calculation. The length of the bamboo varied according to the samples. The minimum and maximum weights were 1.42 and 1.60 kg, respectively. The whole bamboo was cut to obtain different culms, according to the node.

The top portion of the bamboo was not included in this work, due to low fiber content, such that it is not suitable for preparing bamboo stick. There were seven or eight culms obtained, each is used for making stick. Some of the culms with their lengths and weights are presented in Table 3 and then their wastes were examined withn the scope of this study.

**Table 3.** Bamboo Waste Level

| Bamboo Samples | Bamboo Culm Weight (in/g) | Use for Stick Making (g) | Waste (approx) (g) |
|---|---|---|---|
| Sample 1 | 9.0 / 114 (top) | 32 | 8 |
| Sample 2 | 9.3 / 117 (middle) | 31 | 7 |
| Sample 3 | 9.4 / 119 (bottom) | 37 | 11 |

## Fiber Recovery Level

The fiber recovery level was determined for both fibers. Fibers were obtained from the extractable sheath of banana. Mostly, the fiber sample was taken from the outer sheath and tested. The weight, fiber content, and fiber recovery percentage levels are presented in Table 4. Fiber was also extracted from the other sheath with a lower weight, but the fiber recovery percentage level was the same even from the inner sheaths. The core element fiber was not taken or used. From bamboo, three samples were taken from its bottom, middle, and top. The masses of the culms and their fiber recovery percentages are presented in Table 5. The bamboo fiber recovery percentage was better than that of banana, but the quantity of the fiber was considerably less than that of banana. However, the fiber recovery percentage level was almost equal in all the culms.

**Table 4.** Banana Fiber Recovery Level

| Banana Stem | Sheaths Weight (kg) | Fiber Weight (kg) | Recovery(%) |
|---|---|---|---|
| Sample 1 | 4.10 | 0.116 | 2.82 |
| Sample 2 | 3.67 | 0.091 | 2.47 |
| Sample 3 | 3.92 | 0.093 | 2.37 |

**Table 5.** Bamboo Fiber Recovery Level

| Bamboo | Culm Weight (g) | Fiber Weight (g) | Recovery (%) |
|---|---|---|---|
| Sample 1 | 114 | 7.21 | 6.32 |
| Sample 2 | 117 | 6.86 | 5.86 |
| Sample 3 | 119 | 9.47 | 7.95 |

## SEM Analysis

The SEM examination was performed for both fibers, and the images obtained depicted a multicellular fiber. This is the common structure of vegetable fibers (Gupta *et* al. 2021; Unal *et al.* 2022). The fiber surface morphology and cross-sectional view are shown in Fig. 5. Both fiber structures were captured over the retting process, where almost 50% of the impurities were removed, generally dissolved in water. The morphological structure was fairly similar for both fibers. The banana fiber length was greater than that of the bamboo fibers. Fibers were not subjected to alkali and acid treatments. Both fibers showed uniform structure. The scanned banana images are shown in Figs. 5 (a and b), whereas micrographs of bamboo are depicted in Figs. 5 (c and d). Some banana fibers were damaged during the extraction process (Fig. 5a). During the manual extraction, the fiber damage was avoided, but the fiber preparation was slower when compared with the machine extraction. The bamboo fibers did not experience damage, because the machine blade straightly scraped the culms.

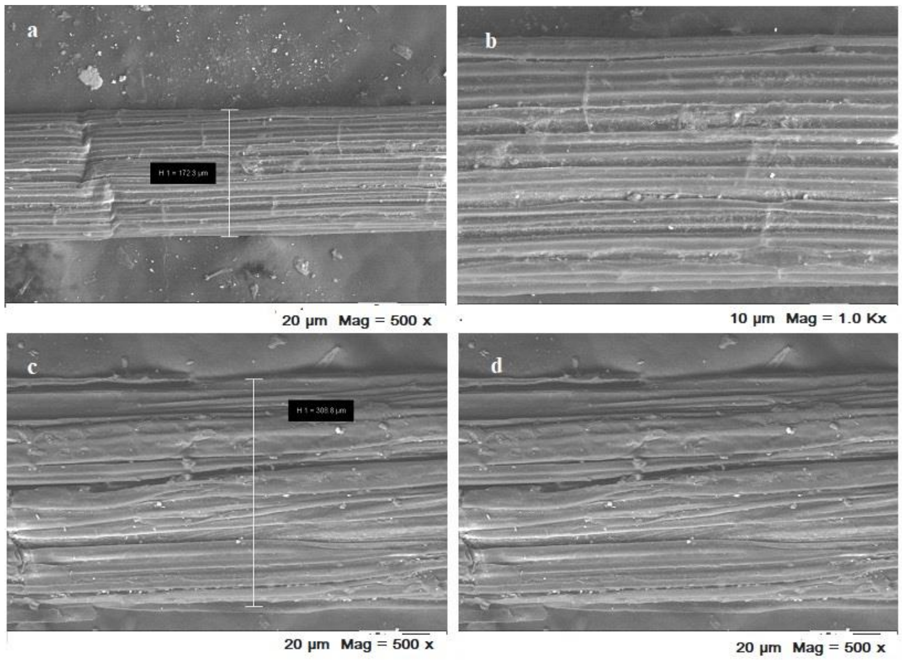


**Fig. 5.** SEM analysis of (a and b) banana and (c and d) bamboo fibers

## Physical and Chemical Properties

Physical and chemical properties of both ret treated fibers were obtained from the banana and bamboo varieties. Other varieties of banana and bamboo recorded a small variation. The fiber length was taken. Banana fiber length was related to the sheath length. The bamboo fiber length was shorter, due to its culm length. The diameters of the fibers were approximately 170 to 230 µm. The tensile strength, Young's modulus, and elongation were higher in banana, whereas density, failure strain, and moisture regain were approximately equal in both fibers. Tables 6 and 7 present the comparison between physical properties and chemical composition of both fibers, respectively.

**Table 6.** Comparative Study on Physical Properties of Banana and Bamboo Fibers

| Physical Properties | Banana | Bamboo |
|---|---|---|
| Fiber length (mm) | 920 to 1070 | 2 to 4 |
| Diameter (mm) | 0.172 | 0.218 |
| Tensile strength (MPa) | 641.0 | 179.4 |
| Density (g/cm$^3$) | 0.86 | 0.62 |
| Young's modules (GPa) | 29.00 | 8.70 |
| Failure strain (%) | 2.53 | 2.02 |
| Elongation (%) | 10.35 | 0 to 0.8 |
| Moisture regain (%) | 12.20 | 13.03 |

**Table 7.** Comparative Study on Chemical Compositions of Banana and Bamboo Fibers

| Fiber | Sample | Cellulose | Hemicellulose | Lignin | Pectin |
|---|---|---|---|---|---|
| Banana | 1 | 59.12 | 12.02 | 11.87 | 3.71 |
| | 2 | 58.71 | 11.39 | 12.03 | 3.90 |
| Bamboo | 1 | 62.34 | 11.85 | 10.56 | 3.04 |
| | 2 | 63.15 | 11.94 | 9.84 | 2.90 |

The chemical compositions of both ret treated banana and bamboo fibers were almost the same (Li *et al*. 2010; Bhatnagar *et al*. 2015). The same experiment was followed for both. The bamboo cellulose content level was more than that of banana, as it increased only from 4 to 7%. However, others were equally distributed. The banana lignin content was better than that of bamboo. Noticeably, the lignin content should be reduced or removed to achieve hygiene in textile applications. This is also common for vegetable fibers, such as sisal and ramie.

## Elemental Analysis

*X-ray diffraction method*

Figure 6 shows the XRD pattern of retted banana and bamboo fibers. From banana, there were five peaks observed at 16°, 17°, 22°, 29°, and 30°, whereas bamboo recorded three peaks at 17°, 18°, and 21°. Similar level directions were obtained in hemp, ramie, and sisal fibers. There were small changes between them. The CI value showed that the fiber crystalline region was 55 to 65% and the remaining material was amorphous. These values were associated with the lignin and hemi-cellulose contents of the fibers.

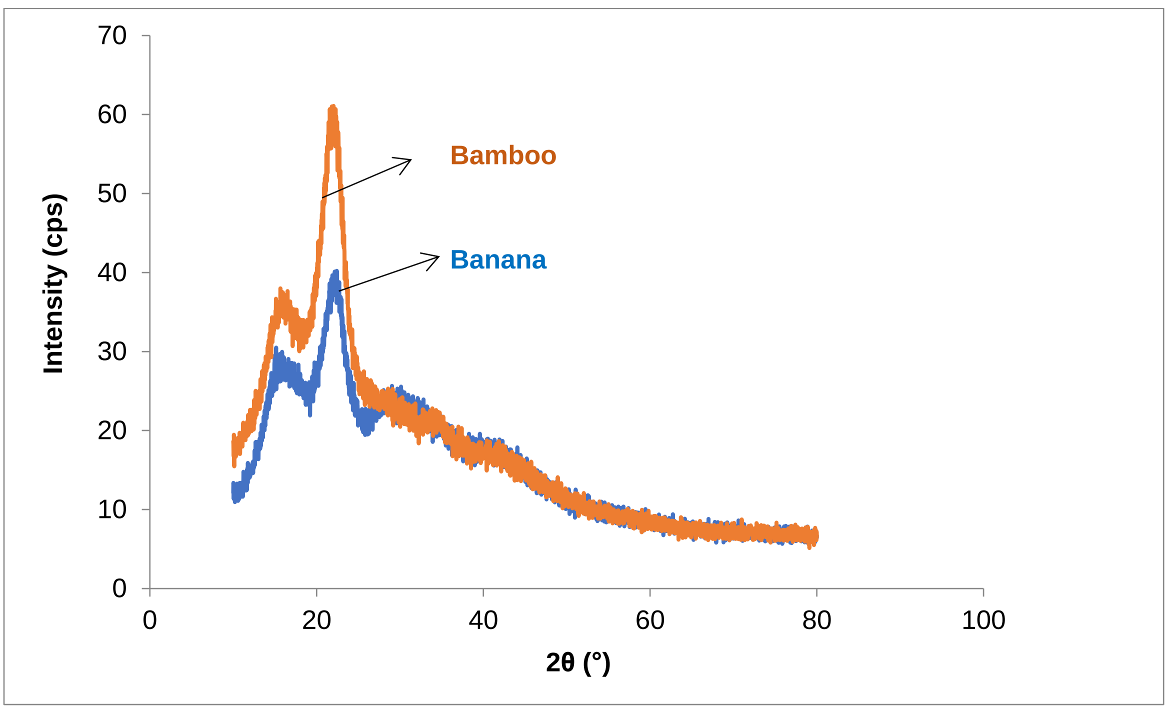


**Fig. 6.** X-ray diffraction analysis of banana and bamboo fibers

The crystalline phase was higher in bamboo, but lower than sisal and jute fibers of 71.0 and 71.3%, respectively (Kanimozhi *et al.* 2020; Guptha *et al.* 2021). The CI value is likely to change with variety, considering the several varieties of both banana and bamboo. Hence, the CI value changes based on many factors. The amorphous phase generally decreases after fibers are treated with alkali or acid, whereas the crystalline phase increases at this stage, because the new hydrogen bonds form between cellulose chains. This happens with removal of hemicelluloses and lignin, which separate the cellulose chain. Essentially, the lignin and cellulose parts are amorphous and crystalline in nature, and this can be identified by the XRD pattern.

*FTIR analysis*

FTIR was used to identify the functional groups of the materials. The organic molecular structures of retted banana and bamboo fibers were investigated. The results obtained from the FTIR analysis are shown in Fig. 7.

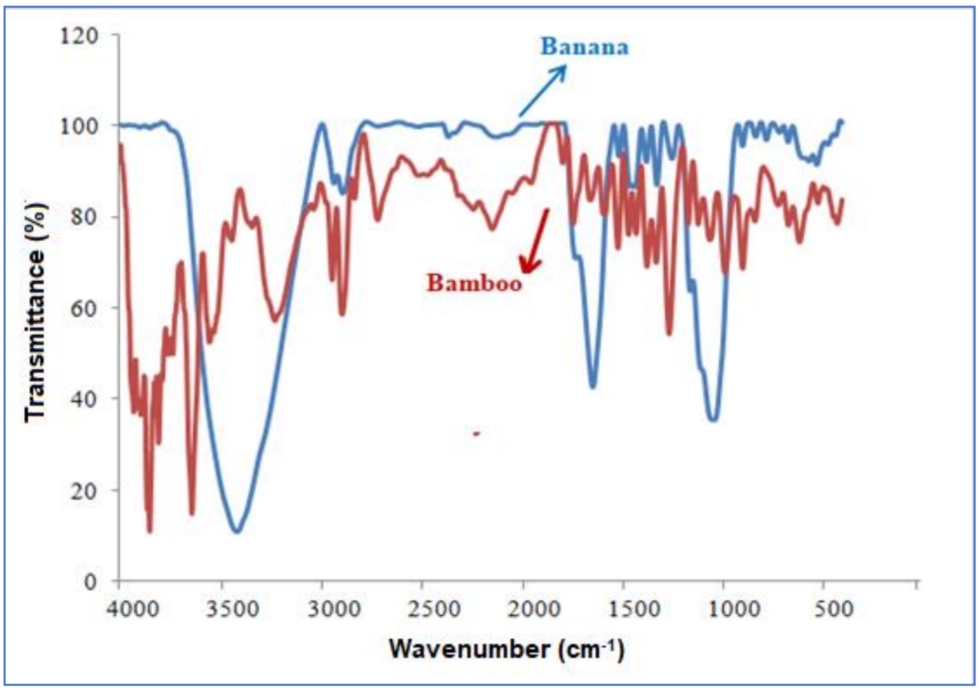


**Fig. 7.** FTIR analysis of banana and bamboo fibers

Both fibers were examined during this test. In general, vegetable fiber material contains alkenes, esters, ketones, aromatics, and alcohols along with different oxygen containing functional groups. The main spectrum of the fiber showed the vibration mode, such as O-H stretching, which was observed around 3417.9 $cm^{-1}$ for banana and around 3671.4 and 3865.2 $cm^{-1}$ for bamboo. The C-H stretching absorption was less in banana, and recorded around 2891.3 $cm^{-1}$, whereas bamboo recorded three peaks around 2900.8, 2896.2, and 2765.0 $cm^{-1}$. The bands at 1300 to 1400 $cm^{-1}$ were attributed to lignin content in both fibers, which was more in banana than bamboo. The carbonyl band between 643.4 and 1750 $cm^{-1}$ was ascribed to the C=O stretch, which was less than in bamboo. The hydrophilic tendency of banana fiber was associated with −OH groups, which were evident from the broad absorption band in the region 3650 to 3000 $cm^{-1}$. However, the region was not broad for bamboo; it was 3986 to 3000 $cm^{-1}$. The small peak at 900 to 650 $cm^{-1}$ indicated the typical structure of celluloses, which was higher in bamboo.

## Absorption and Antibacterial Properties

There is a relationship between antibacterial and absorption properties of a material. Table 8 presents the water absorption levels with timings for both fibers. The banana outer sheath fiber possessed a better absorption behavior than the middle part, whereas the bottom bamboo sheath was better than the top. Bamboo outer level fibers were taken for this test. The inner level fibers were avoided, due to their less absorption capacity. Furthermore, the inner sheath is not suitable for making bamboo stick, because its fiber content is considerably smaller than the outer parts. Moreover, it was evident from the antibacterial test that the banana pseudo-stem had good antimicrobial properties. (Prang Rocky *et al.* 2021). Through calculating the bacteriostatic rate value, the antimicrobial properties were observed in the fibers. Banana recorded a greater antibacterial ability than some vegetable fibers (Barman *et al.* 2018; Subagyo and Chafidz 2018). Bamboo exhibited a greater antibacterial property than many natural fibers, but lower than that of banana. Banana fiber's water absorption was also higher than bamboo, when both fibers were continuously immersed in water. Consequently, banana fiber is used for many medical applications.

**Table 8.** Water Absorption Properties of Banana and Bamboo Fibers

| Timings (min)/ Samples Absorption % | 5 | 10 | 25 | 60 | 80 | Mean |
|---|---|---|---|---|---|---|
| Banana 1 (outer) | 17 | 24 | 44 | 56 | 61 | 58.5 |
| Banana 2 (middle) | 15 | 21 | 36 | 48 | 56 | |
| Bamboo 1 (bottom) | 16 | 20 | 31 | 40 | 48 | 46 |
| Bamboo 2 (top) | 14 | 19 | 28 | 36 | 44 | |

## Industrial Applications

Considering the biodegradable property of both fibers, they can be used for several applications. They can be recycled or upcycled for textile, automobile, and paper industries (Kannigadevi *et al.* 2021). Both fibers do not harm the atmosphere, and hence they help protect the ecosystem. In the textile industry, both plant fibers are used as fiber, yarn, blended yarn, and fabrics. The banana fiber can be blended with cotton fiber at 20, 30, 40, and 50% (Kanimozhi *et al.* 2020). However, bamboo fiber was better at 20 and 25% when hybridized with cotton fiber due to its low spinnability. In this research, the bamboo fiber length was found to be less, and it has been recommended that both fibers should retted for more than 1 week to get good spinnability (Subagyo and Chafidz 2018). Banana fiber has a better spinnability than bamboo: thus, it can be blended with cotton in different percentages. Similarly, banana fiber was found to have a better antibacterial property than bamboo. Therefore, banana fiber could be a better choice for medical textiles than bamboo. Additionally, bamboo filament can be made from its pulps after chemical treatment or process and its filament can be used for some medical applications (Krishnaveni 2016). Banana fiber can be used directly. Most studies confirmed the suitability of only bamboo filament, not banana filament.

Banana fiber is suitable to make 5-11Ne (yarn count or diameter) yarn directly and can be used for textile applications (Kanimozhi *et al.* 2020). Bamboo fibers are chemically treated, and then the fibers can be converted to produce some textile yarns and cloths. Apart from this, the sanitary napkins are made from different regenerated fibers. Researchers are focusing on making napkin from banana and bamboo fibers as well as other vegetable fibers, such as sisal, coir, kenaf, pineapple, jute, and hemp, among others. They are both used for pads of children and aged people. The synthetically made pads are associated with many health issues, especially skin allergies among women. Additionally, the natural fibers can be mixed with cotton to produce some types of sanitary napkins (Barman *et al.* 2018). The use of those products is highly appreciated in the developed countries. Moreover, most composites are made more from bamboo fiber than banana. This is because the availability of banana is less than bamboo around the world (Kumar *et al.* 2023). The bamboo plantation is bigger than a banana farm. The northern regions of several countries are producing many bamboo products, especially composites and some kinds of shelter works (Liu *et al.* 2012). Banana is more suitable to produce reinforcement for polypropylene, used to prepare under floor protection sheets and panels (Ramesh *et al.* 2014). Furthermore, one of the best options is to make fiber-reinforced composites using banana and bamboo (Kumar *et al.* 2023). Both fibers are also can be used in the paper industry for bond paper, but the manufacturing cost is generally too high. Both fibers are used in aerospace, plane parts, railway coaches, building construction materials, automobile parts, and storage materials (Liu *et al.* 2012; Vigneswarn *et al.* 2015). The bamboo sticks and plywood are used for many applications in household and other industries. The sticks are used in decorative items. Unfortunately, sticks and plywood cannot be made from banana stem material.

Recently, a train interior component was manufactured using bamboo materials and combined fiber materials in China. Both fiber types are also used in the packaging industry. Japanese industries are importing banana fiber from India. India is the leading producer of banana fiber and fiber-based materials. Hence, both fibers are much more useful for multiple applications that could support more profitable businesses. Additionally, farmers and rural communities are supported in creating job opportunities and involving those who are not regularly employed; this is also an excellent chance to empower rural people, particularly women, to become successful entrepreneurs and improve their social and economic status.

## CONCLUSIONS

In an attempt to support bio-waste management, a comparative study on banana (*Musa acuminata*) and bamboo (*Bambusa vulgaris*) fibers, as potential alternative, sustainable, renewable, recyclable, and environmentally friendly materials was considered in this article. From the experimental results obtained, the following concluding remarks can be deduced:

1. From the examination of recovery levels of biomass and fiber, the banana waste level was higher than that of bamboo. However, the cultivation amount of banana is less than that of bamboo.
2. The physical properties of both fibers have some differences, but the chemical composition was found to be quite similar, except for the cellulose content.

3. The experimental analysis, using Fourier transform infrared (FTIR) spectroscopy and X-ray diffraction (XRD) established that bamboo fiber possessed greater cellulose content than banana fiber at its highest peak. The amorphous region was higher in banana.
4. The water absorption ability of banana fiber was found to be more than bamboo fiber because the length of bamboo was much less in this research. Both fibers exhibited antibacterial property, but it was greater in banana fiber than bamboo fiber.
5. In general, banana fiber is judged to be suitable for textile and other light industrial applications, while bamboo is suitable for manufacturing paper, filament, or blended filament with banana fiber or some other fibers.

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