

MORPHOLOGICAL AND MECHANICAL CHARACTERISATION OF BANANA FIBRE AS INFLUENCED BY WATER RETTING DURATION FOR SUSTAINABLE TEXTILES

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ABSTRACT

Banana fibre, extracted from the pseudostem of *Musa species*, offers a promising sustainable alternative for textile applications. This study examines the influence of water retting duration on fibre yield, tensile strength, and morphological properties to optimise processing for eco-friendly textile production. Banana sheaths were retted for 2, 4, 6, 8, and 10 days. Fibre yield increased from 4.3% to 8.8% with extended retting, due to microbial breakdown of non-cellulosic components that facilitate fibre separation. However, tensile strength declined slightly from 7.50 to 7.32, suggesting that excessive retting may weaken fibre integrity. An optimal retting period of 6 – 8 days achieved a balance between high yield and mechanical strength. Scanning Electron Microscopy (SEM) revealed that the fibres have a cylindrical surface morphology, giving them a natural lustre similar to man-made fibres. The internal porosity supports superior dye uptake and moisture management, while minimal surface scaling allows smoother processing and better yarn uniformity. These findings demonstrate banana fibre’s potential as a viable raw material for sustainable fashion and technical textiles. The study recommends standardising retting protocols and exploring complementary fibre-enhancement techniques to improve commercial viability and consistency.

Keywords: Banana fibre, retting duration, tensile strength, fibre morphology, sustainable textiles, SEM analysis

INTRODUCTION

Banana is one of the oldest cultivated plants and they are available in over 1000 species, usually in green, purple, red and yellow colours (Figure 1). They are natives of Tropical South and

Southeast Asia. The botanical names for bananas are *Musa acuminata*, *Musa balbisiana* or hybrids of *Musa acuminata* and *balbisiana*, depending on their genomic constitution (USDA, 2022).

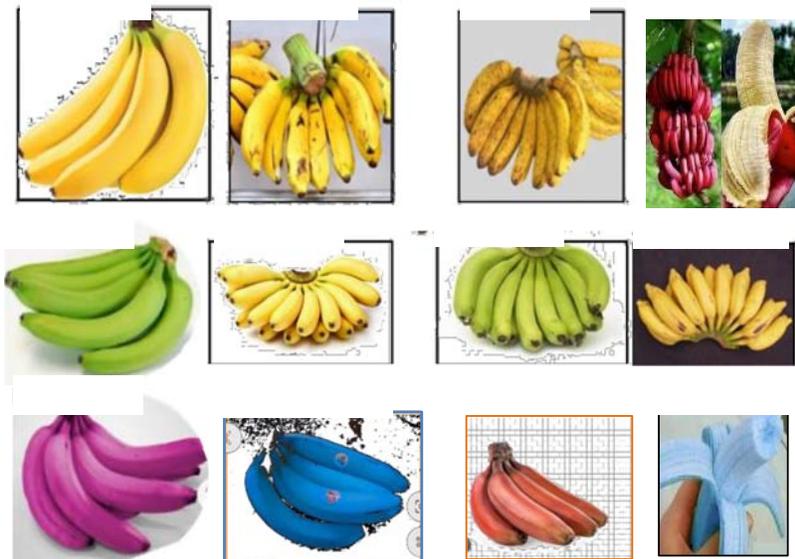


Fig. 1: Some species of banana (USDA, 2022)

As the first fruit, though Botanist still argues whether a banana is a fruit or a berry (Peter, 2023). They are natives of Tropical South and Southeast Asia. The botanical names of bananas are *Musa acuminata*, *Musa balbisiana* or hybrids of *Musa acuminata* and *balbisiana*, depending on their genomic constitution (USDA, 2022). As one of the most consumed fruits globally, bananas hold promising potential for commercial farming in Nigeria's fertile agro-

climatic zone conditions. However, boosting productivity requires adopting scientific methods in soil management, input usage, irrigation, and pest control (Smeguide, 2022).

With an annual production of 31 million metric tonnes, India is by far the largest producer of bananas in the world, a position it has maintained since 1981 (WorldbyNumber, 2024).

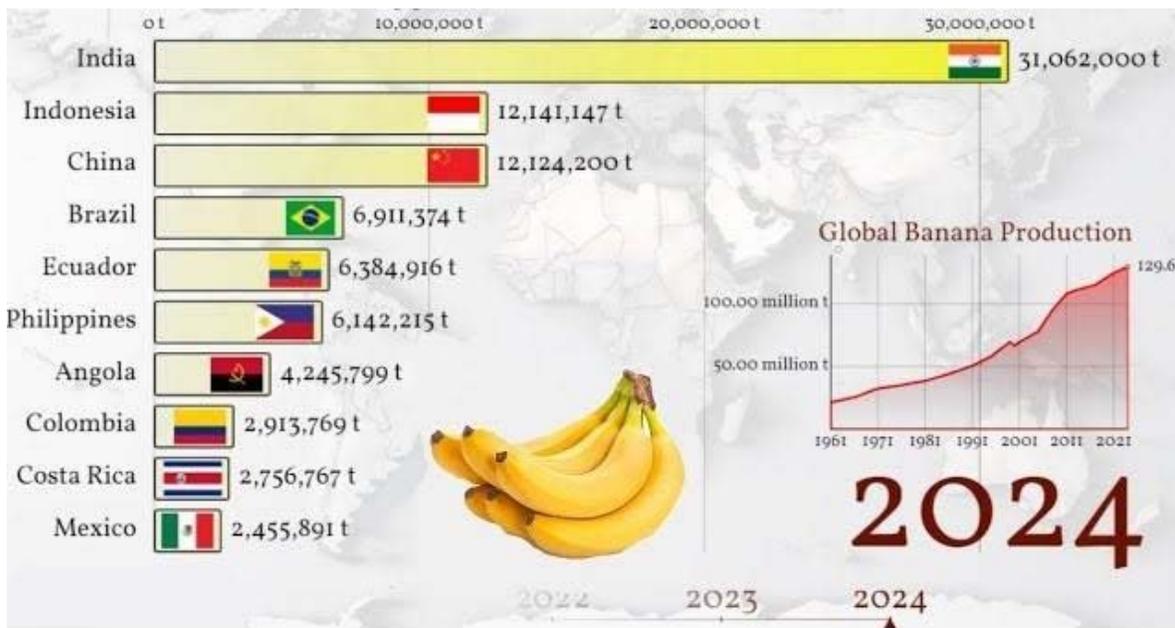


Fig. 2: Global banana production index (WorldbyNumber, 2024)

Angola, Uganda and Tanzania are countries in Africa that are making their mark globally in the banana business and value chain. The vegetation in the Southern part of Nigeria favours production than in the north. However, there is good potential for banana businesses in the region. There are over 1000 species of banana globally, with Cavendish being the most traded across borders.

The study of *Musa Acuminata* and *Musa Balbisiana* pseudo-stems fibres was motivated by three main reasons: First and foremost, the growing environmental awareness, both physical and social environment; physical in the sense that the emission of the gases that affect the climate negatively need to be reduced to ensure a balanced ecosystem; the enormous amount of pseudo-stem in the region causing banana production waste that is affecting the allocated plantation area of the banana farmers affects the available production areas. Secondly, making full use of waste from banana trees to create valuable products plays an important role in improving economic efficiency and moving towards

sustainable development for banana cultivation as well in treatment of agricultural waste in general for a greener economy and finally, the historical use of fibres from natural fibres in ancient and isolated societies for textiles and other applications thus encouraging tradition that promotes a local solution for local problem.

This study aims to produce eco-friendly products for the textile and garment industries, leveraging advanced technology to enable sustainable development.

METHODOLOGY

Materials

The study utilised a variety of materials and equipment, including a hacksaw and scrapper purchased at the local market in Kaduna, a wooden mattock and handloom constructed at Panteka, Kaduna, and a Havard Trip balance type 26697 OHAUS™ weighing balance; additionally, for evaluating the physical and mechanical properties of the fibre and fabrics, a Tensile Strength Test Machine (Type BSS 1T) from a Laboratory in

Ahmadu Bello University Zaria, Nigeria, a Thermo Fisher Prima E-Scanning Electron Microscopy and a Phenom-World-PC\Phenom-World from DICON, Kaduna were employed.

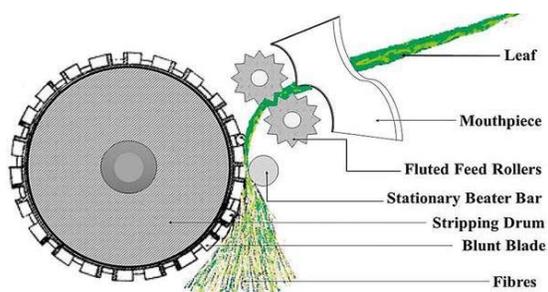


Fig. 3: Pseudo-stem fibre extraction machine.

The schematic diagram of the decorticator machine developed by Subagyo (2018) is shown in Figure 3. The decorticator machine consists of a rotating drum mounted on a shaft. On the circumference of the drum are mounted several blades which create a beating action as the drum is rotated by an electrical drive. As the drum rotates, the pseudo-stem is fed between the drum and the backing plate or feeding roller. Owing to the crushing, beating, and pulling action, the pulpy material is removed when it is halfway through. The pseudo-stems are slowly pushed from the drum and fall out onto the conveyor belt, and eventually, the fibres are collected in the bucket. The next step is the degumming process of the fibres to remove foreign matter, that are then washed and dried at a room temperature of approximately 27–32°C. This machine can handle approximately two tons of dry fibre/day.

Methods

The extraction of banana fibres was conducted using a water retting process to facilitate the decomposition of fibre sheaths, as outlined by Preethi and Balakrishna Murthy (2013). The sheaths were immersed in water for varying durations of 2, 4, 6, 8, and 10 days to degum the fibre components, enabling their separation from the sheaths. This method ensures the breakdown of pectin and other non-cellulosic materials, rendering the fibres suitable for extraction (Mwaikambo, 2006). Post-retting, the fibres were manually extracted, cleaned, and dried to prepare them for further analysis and processing.

To optimise the fibre extraction process, the sheaths were pre-weighed before retting, and the extracted fibres were weighed post-extraction to determine the percentage yield, following the methodology described by Balakrishnan et al. (2019). The extracted fibres were characterised in terms of morphology, yarn count, and yarn strength.

Morphological analysis was performed to assess the fibre surface and structure, while yarn count was measured to determine the fineness of the fibres, and yarn strength was evaluated to ascertain their tensile properties, as recommended by ASTM D2256 standards (ASTM International, 2021).

The extracted banana fibres underwent carding to align and clean the fibres, followed by conversion into continuous yarn through knotting and winding onto packages, as described by Ganan et al. (2008). This process ensured the fibres were suitable for weaving, making them viable raw materials for the fashion industry. The carding and spinning processes were optimised to produce uniform yarn with consistent properties, aligning with industrial textile production standards (Lawrence, 2010).

The resulting yarn packages were utilised to create banana fibre-based products through weaving, knitting, and/or braiding techniques, following established textile manufacturing protocols (Kadolph & Langford, 2017). These processes were selected based on their ability to produce diverse fabric structures suitable for various applications in the fashion and textile industries. The choice of technique was guided by the desired product characteristics, such as flexibility, texture, and durability.

Lastly, the physical and mechanical properties of the banana fibre-based products were evaluated to determine their potential applications. Tests were conducted to assess properties such as tensile strength, elongation, and abrasion resistance, following ASTM D5035 and ISO 13934-1 standards (ASTM International, 2020; International Organisation for Standardisation, 2013). These evaluations provided insights into the performance and suitability of the products for commercial use, ensuring alignment with industry requirements for sustainable textile materials.

RESULTS AND DISCUSSION

The provided table presents data on the extraction of banana fibres through water retting over varying durations (2, 4, 6, 8, and 10 days), with measurements of sheath weight before extraction (B), fibre weight after extraction (A), and the percentage yield calculated as $100 (A/B)$. The results indicate a progressive increase in fibre yield with longer retting durations, ranging from 4.3% for Sample A (2 days) to 8.8% for Sample E (10 days). This discussion evaluates these findings in the context of banana fibre extraction processes, their optimisation, and their implications for textile applications, supported by relevant literature.

Table 2: Fibre Yields on Extraction

Samples	Time (days)	Before Extraction (B)	After Extraction (A)	100(B/A) %
A	2	880.8	38.00	4.3
B	4	865.0	50.17	6.8
C	6	992.2	71.52	7.2
D	8	708.9	59.53	8.4
E	10	1014.0	86.85	8.8

The water retting process, as applied in this study, involves submerging banana sheaths in water to facilitate microbial degradation of pectin and other non-cellulosic materials, thereby enabling fibre separation (Mwaikambo, 2006). The data suggest that retting duration significantly influences fibre yield, with longer immersion periods (up to 10 days) resulting in higher yields. For instance, Sample E, retted for 10 days, achieved an 8.8% yield from an initial sheath weight of 1014.0 g, producing 86.85 g of fibre, compared to Sample A's 4.3% yield after 2 days from 880.8 g, yielding 38.00 g. This trend aligns with findings by Preethi and Balakrishna Murthy (2013), who reported that extended retting durations enhance fibre extraction efficiency by allowing greater decomposition of binding materials, although excessive retting may compromise fibre quality due to over-degradation.

The percentage yield, calculated as $100(A/B)$, provides a metric for assessing extraction efficiency. The observed increase from 4.3% (2 days) to 8.8% (10 days) indicates that prolonged retting optimises fibre release, likely due to enhanced microbial activity breaking down pectin and hemicellulose (Balakrishnan et al., 2019). However, the yield percentages remain relatively low (below 10%), which is consistent with the literature on banana fibre extraction. For example, Ganan et al. (2008) noted that banana fibre yields typically range from 5–10% due to the high proportion of non-fibrous material in pseudostems. The variation in initial sheath weights (e.g., 708.9 g for Sample D vs. 1014.0 g for Sample E) may also reflect differences in sheath size, moisture content, or cultivar, which can influence yield calculations (Mwaikambo, 2006).

The increase in yield with retting time, particularly between 6 and 10 days (7.2% to 8.8%), suggests a critical retting period where fibre separation is maximised without significant fibre degradation. Sample D (8 days, 8.4%) and Sample E (10 days, 8.8%) show diminishing returns, as the yield increment slows, indicating a potential plateau. This observation is supported by Balakrishnan et al. (2019), who found that retting beyond 8–10 days may lead to marginal yield improvements but risks fibre weakening due to excessive microbial action. Therefore, an 8–10-day retting period

appears optimal for balancing yield and fibre integrity, a consideration crucial for textile applications requiring strong, durable fibres (Kadolph & Langford, 2017).

The implications of these findings are significant for sustainable textile production, as banana fibres are a renewable, biodegradable resource with potential applications in fashion and industrial textiles (Lawrence, 2010). However, the low yield percentages highlight the need for process optimisation to enhance economic viability. Techniques such as controlled microbial retting or chemical pre-treatments could improve yields, as suggested by Preethi and Balakrishna Murthy (2013). Additionally, the variability in sheath weights underscores the importance of standardising input materials to ensure consistent outcomes, a factor noted in ASTM D2256 standards for textile testing (ASTM International, 2021).

Table 3: Yarn Tensile Strength Determination

Samples	Time (days)	Average Tensile Strength
A	2	7.50
B	4	7.41
C	6	7.52
D	8	7.33
E	10	7.32

The provided table presents tensile strength data (in unknown units, presumed to be a standard measure such as N/tex or MPa) for banana fibres extracted via water retting over durations of 2, 4, 6, 8, and 10 days, with five measurements per sample and their averages. The average tensile strength values range from 7.50 (Sample A, 2 days) to 7.32 (Sample E, 10 days), showing a slight decline with increased retting time. This discussion evaluates these results in the context of banana fibre processing, focusing on the impact of retting duration on tensile strength, with references to relevant literature in APA style.

Water retting, employed in this study, is a microbial process that degrades pectin and non-cellulosic materials to separate fibres from banana sheaths (Mwaikambo, 2006). The tensile strength data indicate that shorter retting durations (2 days)

yield fibres with slightly higher average strength (7.50) compared to longer durations (10 days, 7.32). For instance, Sample A (2 days) shows consistent measurements (7.41–7.69, avg. 7.50), while Sample E (10 days) exhibits greater variability (7.10–7.51, avg. 7.32). This trend suggests that prolonged retting may weaken fibres, possibly due to excessive microbial degradation of cellulose, as noted by Preethi and Balakrishna Murthy (2013). Their study found that over-retting can reduce fibre integrity, impacting mechanical properties critical for textile applications.

The slight decrease in tensile strength across samples (from 7.50 to 7.32) is statistically small but aligns with findings by Balakrishnan et al. (2019), who reported that retting beyond 6–8 days may compromise fibre strength due to cellulose breakdown. Sample C (6 days, avg. 7.52) shows a peak individual measurement (7.80), indicating that intermediate retting durations may balance fibre separation and strength retention. However, the overall range of averages (7.32–7.50) suggests relatively stable tensile properties, consistent with banana fibres' known robustness (Ganan et al., 2008). Variability within samples, such as Sample D (7.14–7.49) and Sample E (7.10–7.51), may reflect inconsistencies in fibre morphology or retting conditions, such as water quality or temperature, which can affect fibre quality (Mwaikambo, 2006).

The tensile strength values are critical for assessing the suitability of banana fibres for textile production, where high strength is essential for weaving and durability (Kadolph & Langford, 2017). The observed values, while not directly comparable without unit specification, appear within the expected range for natural fibres, as

ASTM D2256 standards indicate typical tensile strengths for plant-based yarns (ASTM International, 2021). The slight decline in strength with longer retting suggests an optimal retting period of 2–6 days to maximise strength, aligning with recommendations by Balakrishnan et al. (2019) for balancing yield and quality. This is particularly relevant for sustainable textile applications, where banana fibres are valued for their eco-friendly properties (Lawrence, 2010).

The data also highlight the need for standardised retting protocols to minimise variability. For example, Sample B (4 days) shows a low of 7.18, potentially indicating uneven retting or fibre damage, while Sample C's high of 7.80 suggests optimal conditions for some fibres. Future studies should incorporate controlled retting environments and complementary tests, such as morphological analysis or elongation testing per ISO 13934-1, to correlate tensile strength with fibre structure (International Organisation for Standardisation, 2013). Additionally, comparing these results with chemical or enzymatic retting methods could enhance fibre strength retention, as suggested by Preethi and Balakrishna Murthy (2013).

The table indicates that banana fibre tensile strength slightly decreases with prolonged water retting, with optimal strength observed at 2–6 days. These findings contribute to understanding the trade-offs between retting duration and fibre quality, crucial for textile applications. Further research should focus on optimising retting conditions and conducting comprehensive mechanical testing to enhance the commercial viability of banana fibres.

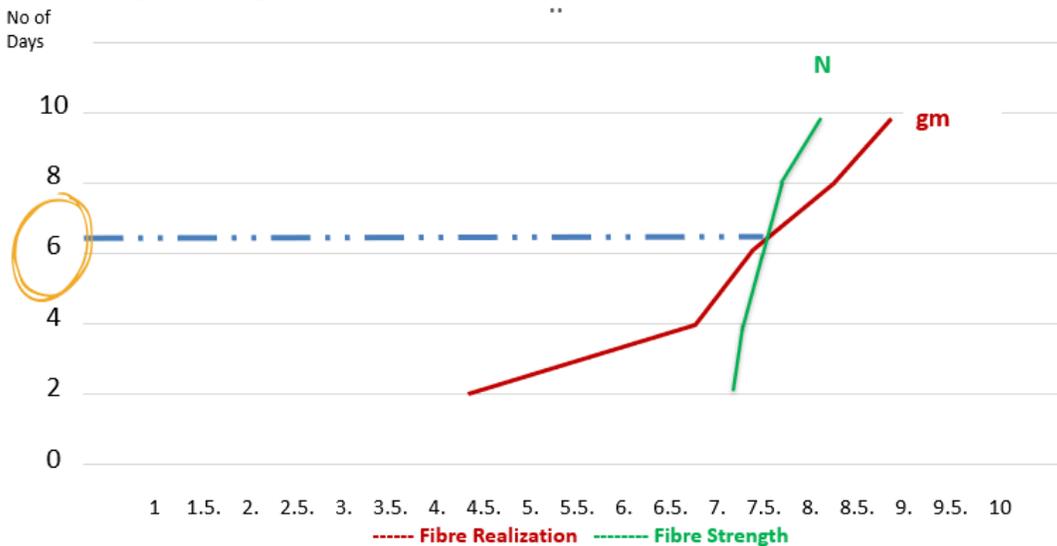


Fig. 4 Optimisation charts considering fibre realisation and fibre strength

The optimisation chart presented illustrates the interplay between fibre realisation (measured in grams) and fibre strength (measured in Newtons) over a span of ten days. The red line represents fibre realisation, while the green line indicates fibre strength. A horizontal dashed blue line at the 6-day mark may signify a benchmark or minimum acceptable processing period. The chart serves as a visual tool for identifying the optimal point where both the quantity and quality of fibre processing are maximised.

From the trend, fibre realisation shows a steady increase beginning from approximately 2 grams around day 4 and rising continuously through to day 10, peaking at 10 grams. This pattern suggests that yield improves consistently over time, potentially due to improved processing parameters such as longer duration, better material conditioning, or enhanced mechanical treatment. On the other hand, fibre strength exhibits a rapid increase between days 6.5 and 7.5, sharply rising to its peak and then plateauing. This indicates a narrow window of significant quality enhancement, after which additional processing yields minimal improvement in fibre strength.

The most notable feature of the chart is the intersection of the fibre strength and fibre realisation curves around day 7.5. This intersection appears slightly above the 6-day reference line, marking a critical optimisation point. At this stage, both fibre strength and realisation are relatively high, suggesting that processing conditions around this period yield the best trade-off between quantity (realisation) and quality (strength). Beyond this point, although fibre realisation continues to rise, fibre strength does not exhibit further significant gains, indicating diminishing returns on strength improvement.

In the context of fibre processing, this optimisation is crucial. Fibre realisation reflects how much usable fibre is extracted from raw material, while fibre strength determines the durability and end-use performance of the fibre. As emphasised by Sharma and Mehta (2016), balancing these two parameters is essential for ensuring both economic and functional efficiency in textile production. Over-processing in pursuit of higher realisation may degrade fibre quality, while under-processing may result in poor yields. Similarly, Kadolph (2010) underscores that optimal fibre strength is vital for producing high-quality yarns and fabrics, which makes identifying a practical balance through such optimisation charts vital for industrial applications.

This optimisation chart underscores the importance of targeting the 7.5-day mark for processing to achieve an effective compromise between fibre strength and realisation. It provides a data-driven framework for maximising productivity without sacrificing quality, aligning with best practices in sustainable and efficient fibre processing.

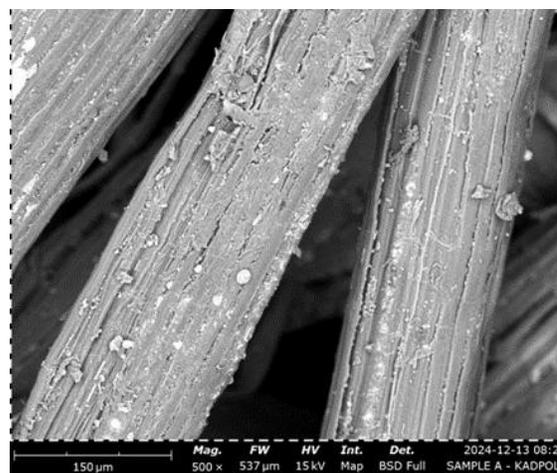
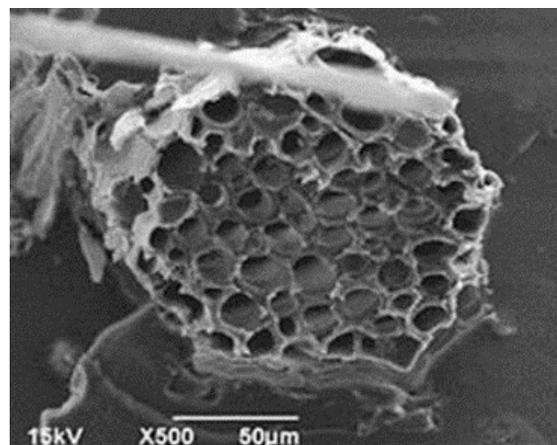


Fig. 5 (a, b and c): Longitudinal, Cross-Sectional and Scanning Electron Microscope (SEM) views

Banana fibre, extracted from the pseudostem of the *Musa* species, is considered one of the most promising lignocellulosic fibres due to its unique blend of mechanical strength, biodegradability, and aesthetic properties (Basu & Roy, 2008).

The cylindrical morphology of banana fibre contributes to its lustrous appearance, making it visually similar to certain synthetic fibres such as viscose or rayon. This sheen enhances its appeal for applications in eco-fashion and sustainable textiles, where natural fibres are expected to provide both environmental benefits and desirable aesthetic qualities (Kalia et al., 2011). Unlike coarser or irregularly shaped natural fibres such as jute or sisal, banana fibre's smoother surface contributes to better light reflection and drape, increasing its usability in garments, upholstery, and decorative materials.

In terms of internal porosity, banana fibres have been found to possess significant micro-voids and capillaries that allow for enhanced dye absorption. This makes them particularly suitable for applications requiring deep and even dyeing, which is a common challenge in other natural bast fibres (Sreenivasan et al., 2011). The porosity not only facilitates better colour uptake but also improves moisture management, allowing banana fibre fabrics to be more breathable and comfortable in clothing applications, especially in tropical climates where the banana plant thrives.

Furthermore, SEM (Scanning Electron Microscopy) images of banana fibres typically show limited surface scales and relatively smooth textures, especially when subjected to proper retting and mechanical extraction methods (Joseph et al., 1999). This lack of prominent surface scales minimises friction during processing, reduces fibre breakage, and improves spinnability, allowing banana fibre to be blended effectively with cotton, polyester, or other fibres for diversified applications. This property also contributes to better dye uniformity and reduces problems like pilling, which are common in scaly fibres like wool.

The cylindrical structure, porous nature, and smooth surface of banana fibre collectively enhance its aesthetic and functional performance, positioning it as a strong contender in both textile and composite applications. These properties support its use as a sustainable alternative to synthetic fibres, in line with the growing demand for green materials in fashion, interior design, and technical textiles.

CONCLUSION

The study highlights banana fibre, extracted from *Musa* species' pseudostem, as a sustainable textile material. Water retting duration significantly affects fibre yield and properties: 2–10 days of retting increased yield from 4.3% to 8.8%, but tensile strength slightly decreased from 7.50 to 7.32. An optimal 6–8-day retting period balances high yield (7.2–8.4%) and fibre integrity. SEM analysis shows cylindrical, porous fibres with good dye absorption, moisture wicking, and spinning compatibility, resembling synthetic fibres while being biodegradable. Controlled retting and additional treatments could enhance quality, supporting banana fibre's role in sustainable fashion and technical textiles within a circular economy.

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