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Physical Properties of Banana Pseudo Stem for Sustainable Textile Application

Oluwaseyi Omotayo Taiwo
Department of Metallurgical and Materials Engineering, Nnamdi Azikiwe University, Awka, Anambra State, Nigeria.

Chukwuemeka Frank Okoyeh
Department of Metallurgical and Materials Engineering, Nnamdi Azikiwe University, Awka, Anambra State, Nigeria.

Ifeoma Maduemezia
Department of Metallurgical and Materials Engineering, Nnamdi Azikiwe University, Awka, Anambra State, Nigeria.

Paul Obike
Department of Metallurgical and Materials Engineering, Nnamdi Azikiwe University, Awka, Anambra State, Nigeria.

*Corresponding Author's Email: oo.taiwo@unizik.edu.ng

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ABSTRACT

Banana fiber is gaining attention as an environmentally friendly and sustainable material for textile applications. This article investigates the chemical composition and physical properties of banana pseudo-stem fiber as a sustainable and economically viable alternative for textile applications. Banana fibre was extracted using the manual decortication process from banana pseudo-stem and subjected to chemical and physical tests. The chemical composition test shows the percentage composition of cellulose, hemicellulose, lignin, pectin and other content of the fibre to be 43.889%, 19.494%, 28.789%, 0.820%, 7.008% respectively. Physical test carried out include moisture regain, moisture content, water absorption and vertical wicking. Moisture regain and moisture content of banana fibre are 0.75% and 0.7% respectively. The water absorption and vertical wicking was compared with that of cotton and wool and result shows that the banana fibre has moderate water absorption and vertical wicking when compared with cotton and wool.

1. Introduction

Sustainability has become a central concern across numerous human endeavors, including the fashion industry (Bertola and Colombi, 2024). In response to the demand for alternatives to conventional textile materials, researchers have extensively investigated natural fibers derived from both plants and animals over the past twenty years (Dhir, 2022). These natural fibers are gaining preference over synthetic options due to their eco-friendly properties, such as biodegradability, renewability, low density, and favorable mechanical and biochemical characteristics (Balda et al., 2021). Among the various plant-based fibers studied—like sisal, coir, jute, kenaf, and banana fiber has emerged as particularly noteworthy. This is largely because bananas are one of the most widely consumed fruits globally, with a production volume reaching approximately 120 million tonnes in 2022 and cultivation occurring in over 130 countries. As a result, banana plant waste is abundantly available and offers a promising resource for sustainable textile development (FAOStat, 2021).

In addition to being cost-effective, banana plants stand out for their versatility in sustainable applications, as nearly every part—including the fruit, peel, flower bud, leaves, and pseudo-stem—can be repurposed for various industrial uses (Balda et al., 2021). Among these, the pseudo-stem (or trunk) represents the largest portion of banana waste and is a valuable source of high-quality fiber.

This fiber holds significant promise for use in several industries, including the production of sanitary products, textiles, paper and pulp, as well as in the automotive, construction, and aerospace sectors (Akinyemi, 2020; Chodijah et al., 2019; Paz et al., 2020).

Research has demonstrated the potential and processing techniques of banana fiber for use in the textile industry. Khan et al., (2024) focused on creating sustainable yarns and fabrics using tri-blends of banana, cotton, and Tencel fibers. In that study, three different blend ratios of banana:cotton:Tencel yarns were produced, all of which exhibited superior mechanical properties compared to the conventional 50:50 cotton:Tencel benchmark. The blended fabrics incorporating banana fibers demonstrated enhanced performance, including a 6.61% increase in tear strength, 18.8% greater air permeability, 20% more elongation, and 12% higher tensile strength relative to cotton:Tencel blends. Sangamithirai and Vasugi examined the potential of banana fibers as sustainable alternatives in textile manufacturing, emphasizing their eco-friendly nature and benefits such as cost-effectiveness and job creation. Ortega et al., (2016) assessed the feasibility of producing weavable yarns from banana fibers through an environmentally friendly enzymatic treatment process. Long banana fibers were cut into 50 mm lengths and treated in an enzymatic bath, using Biopectinase K (at 100% of fiber weight) at 45°C, pH 4.5, for six hours, with the bath renewed halfway through. The optimal treatment conditions led to fibers suitable for textile applications.

Chemical compositions and physical properties of fibres are important consideration for textile applications. This study targets chemical compositions such cellulose, lignin, hemicelluse, pectin and others. The analysis of its chemical composition is crucial for understanding its properties and potential uses (Balda et al., 2021). Physical properties focused on in this study include the moisture regain, moisture content, water absorption and vertical wicking. Moisture regain is the amount of water a fiber can absorb from the air, expressed as a percentage of the fiber's dry weight. Moisture content represents the amount of water present in the fiber as a percentage of its total weight. Moisture regain and mositure content are important where dimensional stability and mechanical strenght is critical. These properties, combined with its biodegradability, make banana fiber an attractive material for sustainable and environmentally friendly products. The water absorption capacity of fibers is a crucial property that influences their applications in various fields, including textiles, composites, and filtration systems. Vertical wicking is refers to the ability of a fabric to transport moisture along its length against gravity, is an essential property for materials used in performance clothing, medical textiles, and other applications where efficient moisture management is crucial. In other words, vertical wicking plays a significant role in assessing the comfort of textile garments as well as in functioning of technical textiles

In a study by Chokshi et al., (2016) to review the chemical properties properties of a wide variety of natural fibres. Chemical compositions including cellulose, lignin, hemicellulose and pectin constituents were investigated. The review shows that cellulose is derived from 26.00% to 91.00% for bamboo fibre and ramie fibre respectively of total chemical properties. Lignin is derived from 0.60% to 45.00% for ramie fibre and piassava fibre respectively of overall chemical properties. Hemicellulose is derived from 3.00% to 38.50% of total chemical properties for cotton fibre and alfa fibre. Pectin is derived from 0.45% to 10.00% of total chemical properties for sansevieria ehrenbergii fibre and seagrass fibre respectively. Yu et al., (2020) also investigated the effect of warm water retting pretreatment on the physical properties of banana stem and fibres. With the highest moisture regain observed to be 13.56%, the study reported that a longer retting time corresponded with a lower content of fibre impurities, more thorough degumming, and less difficult extraction.

Patel and Patel (2020) explored methods to soften banana fibers using chemical agents such as sodium hydroxide (NaOH) and hydrochloric acid (HCl), as well as bacterial treatments involving *bacillus* species. The research examined various properties of banana pseudo-stem fibers, including their physical properties (like density, hygroscopicity, and linear density), chemical properties (hemicellulose, cellulose, and lignin content), and mechanical properties (such as breaking elongation, peak load, and tenacity). Results indicated that after treatment, the moisture content of the banana fibers ranged between 5.15% and 9.15%, with notable alterations in physiochemical properties resulting from the different treatments. Also, Begum (2021) focused on the water absorption behavior of raw and alkali-treated natural fibers, including cotton, areca, pineapple leaf, and banana. While untreated areca fiber exhibited the highest capacity for water absorption, alkali-treated cotton surpassed the others under modified conditions. In contrast, banana fibers demonstrated relatively low water absorption, ranking just above pineapple fibers in this regard.

This current paper outlines extraction of fibre from pseudo stem of banana and also discusses its suitability for textile applications by evaluating its chemical composition and physical properties including moisture regain and moisture content, while comparing its water absorption and vertical wicking with cotton and wool.

Materials and Methods

Materials

Materials used includes banana pseudostem, sodium hyroxide, sodium silicate, soap, calgon PT, hydrogen peroxide, acetic acid, hair conditioner, and water. The banana psuedostems were collected from waste fills in Awka, Anambra State, Nigeria. The other materials were purchased from various vendors in Awka, Anambra State, Nigeria. The various stages of production are extraction, pretreatment, softening, and spinning/knitting. Cotton fibres were collected from villages near Awka and conditioned in stan-dard atmospheric conditions for 24 hours. Scouring operation was then performed on the cotton fibres using chemical reagents such as sequestering agents (Optavon Mex Liq) to remove the hardness of water, Acetic acid for neutralization, wetting agent (Imerol PCLF), and detergent(Hasulyn NOF) to lower the surface tension of water, NaOH for scouring, and distilled water for dilution.

The Extraction

The extraction was carried out using the manual decortation process. The extraction process involves preparation of pseudo-stem, followed by cutting and tuxying, decortation and drying. The pseudo-stem was prepared by unwrapping and cutting lengthwise into ribbons not exceeding 3 inches in width. Then the ribbons were tuxied until the fiber strands became visible to the eyes to make them fit readily into the manual decorticator and for easier decortication process. After this, the extracted fibers are dried in the sun to have finer and more lustrous fibres.

The Pretreatment

The fibres are then pretreated by boiling the fibres for two hours and thirty minutes in alkaline solution in order to remove the insoluble non-fibrous parts. Reagents used includes caustic soda which is the main ingredient, sodium silicate is used for stabilizing hydrogen peroxide, detergent (premier^{tm}) is used as the wetting and anti-reposition agent, calgon (dry powder) is used as the dispersing agent, hydrogen peroxide is the mild bleaching agent. The material to liquour ratio used was 1:20. 500g of the extracted fibre was weighed using a mechanical scale followed by the correct amount of the individual reagent to compressed the liquour. 10kg of water was poured in a stainless steel pot, and allowed to boil. Caustic soda was added gradually and in minute quatities while stirring. Calgon powder was then added, followed by sodium silicate (known locally as water glass), the detergent and lastly, hydrogen peroxide. The cooking time used is 2hrs 30mins at 90^{o}C. Next, the fibers, being knotted and rolled into two bundles, were dipped into the liquor with the aid of a spatula for washing.

The Softening Stage

The next stage is the softening stage which includes chemical preparation and measurement, soaking and washing and drying.The softening solution used in this process contained Acetic acid, fiber softener and water. In order to obtain the optimum result, the fiber softener employed was made sure to contain dehyquart A, which is a cosmetic chemical that improves softness and compatibility of fibers. The fibres were chemically treated with reagents to improve softness and compatibility of fibres. After this, the fibres were soaked overnight in a softening solution for 15hrs, 30 mins with a soaking temperature of 25^{o}C using a MLR of 1:30. After soaking, the fibers were washed about six times and dried in open air under the sun.

The Spinning and Knitting Stage

The spinning operation was then carried out to get the fibres into yarns for knitting operations. The drop spindle was used to spin for producing yarns. After producing the yarns they were placed in hot water for 15 minutes. The wet yarns were towel dried and spread to dried. This was done to make the fibers settle into their new yarn form. Knitting was finally carried out to manipulate the twisted fiber yarn and turning it into fabric. This was done by hand, using knitting needles to create consecutive rows of connected loops that intermesh with one another, creating a pattern.

Tests

Chemical composition and physical properties tests were carried out on the fiber bundles; The following tests was carried out to determine the chemical composition of the fibers. ;

Cellulose content: 0.3g of sample was weighed into 50ml glass centrifuge tubes containing 50ml of watér, centrifuged at 1500rpm for. 10mins, and the supernatant decanted. The sample was resuspended in 12.5ml glacial acetic and 2.5ml of concentrated nitric acid and digested in a boiling water bath for 20min and the supernatant collected. The supernatant was transferred to a Gooch crucible (w_1), washed successfully with hot alcohol, 10ml of 90% benzene, and 60% of ether, dried and weighed, (w_3) finally ashed (w_2) and reweighed.

$$\text{Percentage Cellulose} = \frac{(W_3 - W_2)}{W_1} \times 100 \qquad (1)$$

Hemicellulose content: A 1 gram sample was accurately weighed and placed into a 20 x 150 mm test tube, with the initial weight noted as W_1. To this, 15 ml of 72% sulfuric acid was added, and the mixture was stirred for one minute to ensure complete wetting of the sample. The contents were then transferred into a 1000 ml Erlenmeyer flask, and the volume was brought up to 500 ml using deionized water. The flask was positioned on a heating manifold and connected to a reflux condenser. The mixture was gently boiled and maintained under reflux for four hours. After the reflux period, the condenser was rinsed with a small amount of deionized water prior to dismantling the setup. The hydrolyzed solution was filtered using crucibles, and the filtrate was collected and weighed. The crucible and its contents were dried in an oven at 105 ± 3°C for two hours, cooled in a desiccator, and weighed again, with this weight recorded as W_2. The crucible was then placed in a muffle furnace and ignited at 575°C for at least three hours or until complete combustion of carbon content was achieved. After cooling in a desiccator, the final weight was recorded as W_3.

$$\text{Percentage Hemicellulose} = \frac{(W_2 - W_3)}{W_1 - \frac{\text{total solid}}{100}} \times 100 \qquad (2)$$

Lignin content: A 0.3 g portion of the prepared sample was weighed and placed into a 16 x 100 mm test tube. This initial weight was recorded as W_1. Each sample was prepared in duplicate, at minimum, to ensure reliability. To prevent inaccuracies in calculations due to moisture exchange with the atmosphere, the sample for total solids determination was weighed simultaneously with the sample intended for acid-insoluble lignin analysis, as ground biomass is highly susceptible to moisture gain or loss when exposed to air. The average total solids value was documented as T_{final}. Sulfuric acid (H_2SO_4) was then added to the test tube, and the contents were thoroughly mixed using a glass stirring rod for one minute to ensure complete wetting of the sample. The test tube was placed in a water bath maintained at 30°C and allowed to hydrolyze for two hours. After hydrolysis, the sample was cooled in a desiccator. The combined weight of the crucible, acid-insoluble lignin, and acid-insoluble ash was then measured to the nearest 0.1 mg and recorded as W_2.

$$\text{Percentage Lignin} = \frac{(W_2 - W_3)}{W_1 \times \frac{T_{final}}{100}} \times 100 \qquad (3)$$

Pectin content: 2 grams of the sample were first rinsed with 80% neutral ethanol and then dried at a temperature range of 50–55 °C. Pectin extraction was carried out using a boiling solution composed of 0.25% oxalic acid and 0.25% ammonium oxalate. The extract obtained was filtered and subsequently centrifuged at 750 rpm for 15 minutes. The resulting pellet was resuspended in a 0.5% sodium hydroxide (NaOH) solution. The suspension was then digested with thermostable α-amylase at pH 5.0 for 30 minutes at 100 °C and allowed to cool afterward. The pH was adjusted to 7.5, and the mixture was incubated with protease VIII for another 30 minutes at 60 °C. Following this, the sample was cooled, the pH adjusted to 4.5, and incubated with amyloglucosidase at 60 °C for 30 minutes. Finally, the absorbance of the resulting solution was measured at 620 nm.

$$\text{Pectin concentration (mg/g)} = \frac{\text{Absorbance} \times \text{Conc. of standard}}{\text{Absorbance of standard}} \qquad (4)$$

Moisture regain/content test:

This test was carried out to determine the ability of the oven-dry fiber to absorb moisture. It was measured according to CS11-41 standard. 1g of the sample was accurately weighed to net weight, w1 and dried completely in an oven. This dry weight was measured as w_2 and the moisture regain and content calculated.

$$\text{Moisture regain} = \frac{(W_1 - W_2)}{W_2} \times 100 \qquad (5)$$

The following tests were carried out on the produced fabric and also on two similar fabrics one knitted with a yarn of cotton and the other, wool;

Water absorption capacity:

This test was carried out to determine how much water the fabric can absorb when fully immersed. It was conducted according to ISO 20158:2018 standard. A container with reasonable diameter was filled with water. The fabric specimen was weighed to the nearest 0.01g and recorded as w_1,after which it was positioned horizontally, a few millimetres above the water surface, then gently dropped onto the water surface. The specimen was carefully remove from the water from on corner after 2 minutes and hung vertically to drain for 60s. The specimen was once again weighed to the nearest 0.01g, and the water absorption capacity calculated.

$$\text{Water absorption capacity} = \frac{(W_2 - W_1)}{W_1} \times 100 \qquad (6)$$

For cotton and wool, scoured cotton and wool samples were individually placed in containers containing distilled water and allowed to soak at room temperature for intervals of 10 minutes over a total period of one hour. At the end of each 10-minute interval, the samples were removed and placed between layers of filter paper and circular discs, each weighing 15 grams. The pressure exerted by the discs facilitated the absorption of surface moisture by the filter paper. The samples were then weighed using a digital balance to determine their water absorption percentages.

$$Water\ Absorption\ (\%) = \frac{Weight\ after\ Immersion - Weight\ before\ Immersion}{Weight\ before\ Immersion}\ x\ 100\%$$

Vertical wicking:

It was carried out according to AATCC TM197-2011E2(2018)E specification. The premarked test fibre specimens were suspended vertically with its lower end immersed in a container of water and the mark aligned with the water surface. The height of water reached in the fibre specimens against gravity was visually observed and recorded after 30 minutes

Results and Discussion

Chemical analysis

Table 1: Chemical Composition of Banana Fibre Specimen

Constituent	**Cellulose**	**Hemicellulose**	**Lignin**	**Pectin**	**Others**
Composition (%)	43.889	19.494	28.789	0.820	7.008

Cellulose is the primary structural component of plant cell walls and a significant constituent of banana fiber as observed in the table. At 43.889%, the result shows the fibre sample has significant strength and rigidity this is because cellulose provides the fiber with strength and rigidity. Cellulose is a polysaccharide made up of β-D-glucose units linked by β-1,4-glycosidic bonds, forming long chains that are capable of hydrogen bonding, contributing to the high tensile strength of the fiber (Xu et al., 2021). The Hemicelluse components accounts for 19.494% of the banana fiber sample. Unlike cellulose, hemicellulose has a branched, amorphous structure and consists of various monosaccharides, including xylose, mannose, and arabinose. Hemicellulose acts as a matrix substance that surrounds cellulose fibers and contributes to the flexibility and processability of the fiber Guo and Wang (2022). The percentage of composition of lignin (28.789%) suggests it has substantial mechanical strength and durability, making it suitable for applications requiring robust materials Pandey et al., (2023). Lignin, a complex aromatic polymer is essential for providing rigidity and resistance to microbial degradation in plants. Pectin is present at 0.820% in the banana fiber sample and this suggest that good overall binding of cells and integrity of the fibre structure (Ahmed et al., 2021). Pectin is known to have gelling properties owing to the polysacharide constituents. This polysaccharide primarily consists of galacturonic acid units and is known for its gelling properties.
The "Others" category, constituting 7.008% of the sample, which likely includes proteins, waxes, and inorganic compounds. These components can influence the fiber's properties, such as water absorbency, thermal stability, and biodegradability (Aworinde et al., 2021).

Physical Properties

Moisture regain/content

A moisture regain of 0.75% for banana fibre indicates that it can absorb a small amount of moisture from the environment. This property is essential for applications where the fibre's behaviour in humid conditions is a concern. Low moisture regain suggests that banana fibre is relatively hydrophobic, which can be advantageous in applications requiring low water uptake and stability under varying humidity conditions (Reddy and Yang, 2022). With a moisture content of 0.7%, banana fibre has a low inherent water content. This low moisture content is beneficial for storage and processing, as it reduces the risk of microbial growth and degradation. Additionally, fibres with low moisture content tend to exhibit better mechanical properties, such as tensile strength and stiffness, making them suitable for reinforcement in composite materials (Renay et al., 2023).

The low moisture regains and moisture content contributes to the dimensional stability of banana fibre. Fibers that do not absorb much moisture from the air are less likely to swell or shrink with changes in humidity, maintaining consistent dimensions in end-use applications (Jabbar et al., 2022). Also, low moisture uptake can enhance the mechanical properties of banana fibre. Water can act as a plasticizer, reducing fibre stiffness and strength. Therefore, the low moisture regain and content help maintain the structural integrity and durability of banana fiber (Elanchezhian et al., 2018). Furthermore, banana fibre's low moisture content also has implications for its biodegradability. While the fibre remains stable and strong during its useful life, it is also biodegradable at the end of its lifecycle, making it an eco-friendly material (Bonifacio et al., 2023).

Water Absorption Capacity

Figure 1: Water absorption capacity of banana fibre, cotton fibre, and wool fibre

Figure 1 shows the analysis of water absorption capacity of banana, cotton, and wool fibre highlights the significant differences in their hydrophilic properties. These differences stem from their distinct structural and chemical compositions, which influence their suitability for various applications in textiles and beyond. Banana fiber has a moderate water absorption capacity compared to cotton and wool. The ability of banana fiber to absorb water is influenced by its cellulose content, which allows water molecules to penetrate the fiber structure (Reddy and Yang, 2022).This property makes banana fiber suitable for applications where moderate water absorption is beneficial, such as in composites and certain textile products where quick drying is advantageous (Singh et al., 2021). Cotton exhibits the highest water absorption capacity among the three materials. This is due to its high cellulose content and the presence of hydroxyl groups that form hydrogen bonds with water molecules, allowing it to absorb a significant amount of moisture (Pecunia et al., 2023). High water absorption makes cotton ideal for applications requiring high moisture retention, such as towels, medical textiles, and clothing, particularly in hot climates (Hosseini et al., 2023). Wool has the lowest water absorption capacity among the three materials. Its structure includes a significant amount of keratin, a protein that repels water to some extent, reducing its overall absorption capacity (Muthu, 2022). Wool's low water absorption capacity is advantageous in cold and wet environments as it retains warmth even when damp. This property makes wool suitable for outerwear, insulation, and other applications where moisture resistance and thermal insulation are critical (Jabbar et al., 2022).

Vertical wicking

After the observation of the three fabric samples, the total height climbed by the water through the fabrics against gravity are given as;

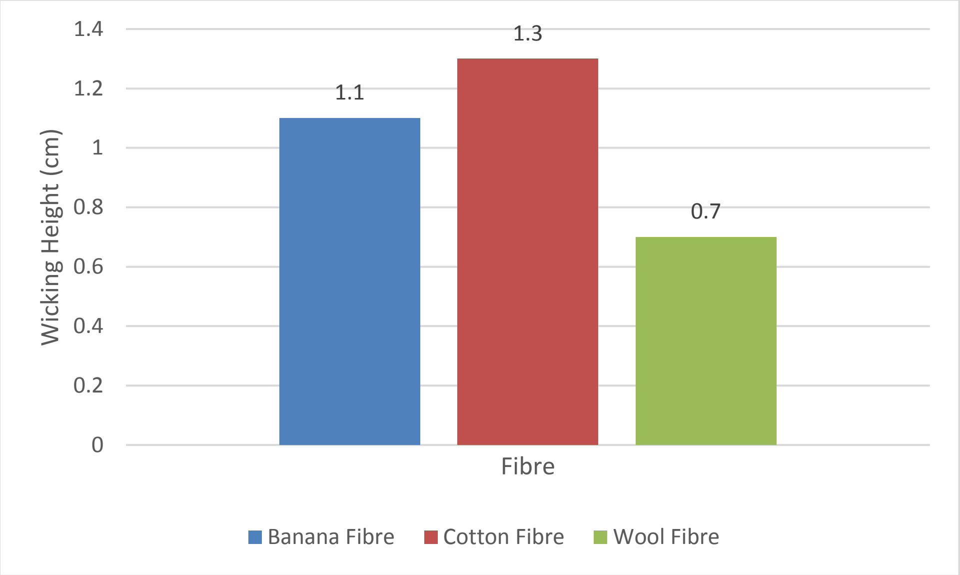

Figure 2: Vertical wicking of banana fibre, cotton fibre and wool fibre

The analysis of vertical wicking heights among banana fiber, cotton, and wool highlights significant differences in their moisture transport capabilities. As observed in Figure 2, banana fiber exhibits moderate vertical wicking. The wicking ability of banana fiber is influenced by its cellulose content and the presence of microfibrils that can facilitate capillary action (Reddy and Yang, 2022). Moderate wicking height makes banana fiber suitable for applications where balanced moisture management is needed, such as in certain sportswear and industrial textiles where both absorption and drying are important (Singh et al., 2021). Cotton shows the highest vertical wicking height among the three materials. Its high cellulose content, along with a highly porous and hydrophilic structure, enhances its ability to transport moisture effectively through capillary action Hosseini et al., (2023). The superior wicking ability of cotton makes it ideal for performance and athletic wear, where efficient moisture transport and quick drying are essential to maintain comfort (Muthu, 2022).

Wool has the lowest vertical wicking height. The lower wicking performance is due to the presence of hydrophobic keratin and the crimped structure of wool fibers, which impede moisture movement (Gupta and Shrivastava, 2022). Wool's lower wicking height is beneficial in applications where moisture transport is less critical, and thermal insulation is more important. This includes cold weather garments and blankets, where the material's ability to retain warmth even when slightly damp is a key advantage (Jabbar et al., 2022).

Cotton demonstrates the highest efficiency in vertical wicking (1.3 cm), followed by banana fiber (1.1 cm) and wool (0.7 cm). This ranking correlates with the inherent hydrophilicity and structural characteristics of each fiber. The porous and hydrophilic nature of cotton allows it to wick moisture more effectively. This was consistent with the report of Chude et al. (2021) that the functional properties of fermented Bambara groundnut flour were strongly influenced by water absorption and composition; the presence of hydrophilic materials promote liquid transport. Similarly, Okpalanma et al. (2024) reported that starches had different physicochemical properties, depending on their composition, which is consistent with the superior porous and hydrophilic properties of cotton. In addition, banana fiber's moderate wicking height indicates that natural cellulose-based fibers can offer moderate wicking properties. This observation agrees with Aniemena et al. (2024), who reported that mixing materials with moderate moisture holding capacities resulted in good product quality and balance. Conversely, the lowest wicking height of wool is due to the constraint imposed by keratin structure and wool crimp. This finding agrees with Nwagbo et al. (2020), who underlined that, in some applications, structural resistance to oxidation and moisture absorption is important for protection. Also, the good properties of cotton for sportswear and banana fiber for multi-purpose applications align with Chinenye et al. (2025), who also noted the importance of functional natural materials for different applications. Thus, cotton is the preferred choice for fast wicking, banana fiber for moderate performance and wool for thermal insulation and low-moisture applications..

Conclusion

The integration of banana fiber into textile applications presents a viable and sustainable opportunity. This study adds to the growing body of knowledge on the chemical and physical properties of banana fibre. By examining its cellulose, hemicelluose, lignin, and pectin composition, the suitability of banana fibre for textile application is established. Also, by comparing the physical properties of banana fibre with more popular textile materials, cotton and wool, it is observed that banana fibre has moderate properties that can make it a feasible material for textile applications. With its chemical composition and physical properties, banana fibre can address some of the critical challenges facing the industry. Further studies can be carried out to investigate modification and treatments such that the chemical and physical properties can be enhanced.

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