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Preparation And Characterization Of Eco-Friendly Handmade Paper From Banana Fibers

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Abstract
This study explores an eco-friendly approach to handmade paper production using banana fiber extracted from agricultural waste, specifically banana pseudostems. As a sustainable alternative to conventional wood-based paper, this method addresses key environmental concerns, including deforestation and solid waste accumulation.The process begins with the collection of banana pseudostems, which are sun-dried and thoroughly washed to eliminate dust and impurities. The cleaned fibres are then treated with a 10% caustic soda solution and cooked under pressure to break down the lignocellulosic structure, facilitating pulp formation. Once softened, the fibres are mechanically blended into a uniform pulp and cast into sheets for handmade paper production. To evaluate the quality of the resulting paper, several physicochemical parameters were analysed, including grammage (GSM), pH, thickness, bulk, and moisture content. Results indicate that the paper is lightweight, biodegradable, and free from synthetic additives or harsh chemicals. Its smooth texture and satisfactory mechanical strength render it suitable for lightweight paper applications such as tissue paper, wipes, and tracing paper. This environmentally responsible method reduces the reliance on chemical bleaching and promotes the efficient conversion of agricultural residues into value-added materials. The process is cost-effective, simple, and scalable, presenting opportunities for rural employment and micro-enterprise development. By transforming agrowaste into functional products, this initiative aligns with circular economy principles and supports sustainable development goals. The findings highlight the commercial potential of banana fibre-based handmade paper and its promising role in fostering a greener, more sustainable paper industry.

Keywords: Banana Fiber, Handmade Paper, Agricultural Waste, Lignocellulosic Fiber, Biodegradable Paper, Eco-friendly Process, Sustainable Paper Production

1. Introduction

In recent years, the global push for sustainable development has intensified the search for environmentally responsible alternatives across multiple industries, particularly the paper manufacturing sector [1]. Traditional wood-based paper production is a major contributor to deforestation and environmental degradation due to its heavy reliance on timber resources and chemical processing [2]. In this context, the use of agricultural waste—specifically banana fibre—for handmade paper production emerges as a promising, eco-friendly alternative [3].

Banana fibre, extracted from the pseudostems of banana plants, is biodegradable, renewable, and abundantly available in regions where banana cultivation is widespread [4]. This makes it an ideal raw material for sustainable paper production, especially in tropical and subtropical countries. Typically discarded as agricultural waste after fruit harvesting, banana pseudostems can be transformed into a value-added resource, reducing both environmental burden and waste accumulation [5].

The papermaking process using banana fibre is simple, low-cost, and energy-efficient [6]. It involves sun-drying the pseudostems, washing to remove impurities, followed by alkaline treatment with a 10% caustic soda solution to break down the lignocellulosic structure. The softened fibres are then mechanically pulped and cast into sheets. Unlike conventional processes that require extensive chemical bleaching and industrial infrastructure, this method can be implemented using basic tools, making it particularly suitable for rural and cottage-scale industries [7].

2. Materials and Methods

2.1 Materials

Banana fibre was sourced from the pseudostems of banana plants, an abundant agricultural residue collected post-harvest from local farms [8]. The chemicals used included sodium hydroxide (NaOH) for fiber softening, bleaching agents such as hydrogen peroxide or sodium hypochlorite for pulp whitening [9], and fillers like calcium carbonate ($CaCO_3$) and titanium dioxide (TiO_2) to enhance paper properties [10]. Distilled water was used throughout to ensure purity and prevent contamination.

2.2 Preparation of Banana Fiber and Pulp

The banana pseudostems were initially sun-dried for 3–5 days to reduce moisture content, followed by thorough washing with tap water to remove dust and impurities [11]. Cleaned fibres were air-dried before chemical treatment. The dried fibres were boiled in a 10% NaOH solution for 30 minutes to break down lignin and hemicellulose, facilitating fibre softening and cellulose liberation [12]. The alkali-treated fibres were then washed multiple times with hot distilled water and ambient tap water to remove residual chemicals and cool the fibres.

Next, a portion of the softened fibres was blended mechanically with water for approximately 5 minutes to produce a homogeneous pulp slurry. This pulp was filtered through cotton cloth to eliminate excess water, yielding a manageable fibrous mass [13]. The pulp underwent bleaching to reduce residual lignin and lighten the color, improving brightness and printability [9].

2.3 Sheet Formation and Drying

The prepared pulp was spread evenly on a wooden frame mold to form thin sheets of uniform thickness [14]. Excess water was pressed out using a wooden block, and the sheets were sandwiched between absorbent cotton layers for further moisture removal and surface smoothing. Finally, the sheets were dried under sunlight or at room temperature, producing durable, biodegradable handmade paper [8]

2.4 Diagrammatic Representation of Paper Preparation from Banana Fibers:

Figures 1 to 5 illustrate the stepwise process involved in the preparation of handmade paper using banana fibres. Fig. 1 shows the raw banana fibres, Fig. 2 displays the processed banana pulp, Fig.3 depicts the blending of banana fibres, Fig. 4 represents the bleaching of the banana pulp, and Fig. 5 shows the final handmade paper product. This sequence visually demonstrates the transformation of raw banana waste into eco-friendly paper through mechanical and chemical processes.

Fig. 1 Raw Banana Fibre

Fig.2 Processed Banana Pulp

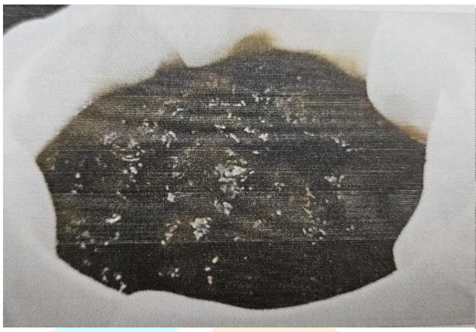

Fig.3 Blending of Pulp

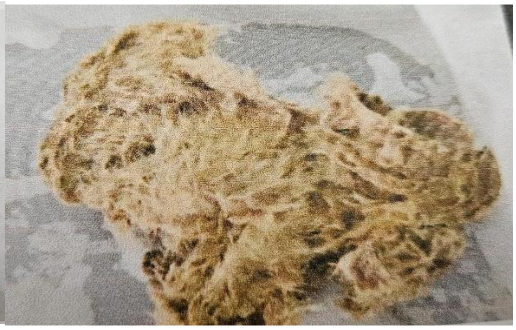

Fig. 4 Bleaching of Banana Pulp

Fig.5 Final handmade paper product

2.5 Characterization of Handmade Paper

The paper's physical and mechanical properties were systematically evaluated:

- Grammage (GSM) was measured by weighing paper samples and calculating weight per unit area (g/m²) [15].
- pH was determined by forming a pulp suspension in distilled water and measuring with a digital pH meter [10].
- Thickness was recorded using a micrometre screw gauge at multiple points, averaging the values [15].
- Bulk, indicative of paper volume relative to mass, was calculated as GSM divided by thickness [16].
- Moisture Content was assessed by oven-drying pre-weighed samples at 110°C for 60 minutes and calculating the percentage weight loss [16].

2.6 Role of Chemicals

Sodium hydroxide softened fibres by breaking down lignin and hemicellulose during pulping [12]. Bleaching agents enhanced pulp whiteness and reduced natural pigments [9]. Fillers such as $CaCO_3$ and TiO_2 improved opacity, brightness, and printability, while starch added strength and improved surface quality, ensuring the paper remained eco-friendly yet functional [10, 17].

3.0 Results and Observations

The quality of the handmade paper produced from banana fibre was assessed by determining its key physical and mechanical properties using standardized testing methods. The results for each parameter are summarized below:

1. Grammage (GSM – Grams per Square Meter)
   The grammage, indicating the weight of the paper per unit area, was calculated using the formula:
   GSM = (Weight of paper (g) / Area of paper (cm^2)) × 10,000
   For the sample, the measured weight was 1.565 g and the area was 900 cm^2, resulting in a GSM of:
   GSM = (1.565 / 900) × 10,000 = 17.39 g/m^2
   This value reflects the paper's density and mechanical strength.
2. pH Value
   The pH of the paper, measured from a pulp suspension, was recorded as 6.2, indicating a slightly acidic nature. This acidity level is important in evaluating the paper's long-term durability and resistance to degradation.
3. Thickness
   Thickness measurements taken at four locations yielded values of 0.04 mm, 0.03 mm, 0.03 mm, and 0.04 mm, with an average thickness of:
   Average Thickness = (0.04 + 0.03 + 0.03 + 0.04) / 4 = 0.035 mm
   This uniform thickness supports consistent quality in paper formation.
4. Bulk
   The bulk, representing the paper's volume per unit mass, was calculated by dividing GSM by thickness (converted to meters):
   Thickness = 0.035 mm = 0.000035 m
   Bulk = 17.39 / 0.000035 = 496,857.14 g/m^3
   This high bulk value indicates a lightweight yet voluminous paper structure.
5. Moisture Content
   Moisture content was determined by oven-drying the paper sample. The initial weight was 1.565 g, and the weight after drying was 0.123 g (derived from moisture loss of 1.442 g). The moisture content percentage was calculated as:
   Moisture Content = ((1.565 – 0.123) / 1.565) × 100 = 92.14 %
   This significant moisture retention highlights the paper's hydrophilic nature, which may affect mechanical strength and shelf life.

Summary of Paper Quality Parameters

Parameter	Value	Unit
Grammage (GSM)	17.39	g/m^2
pH	6.2	—
Thickness	0.035	mm
Bulk	496,857.14	g/m^3
Moisture Content	92.14	%

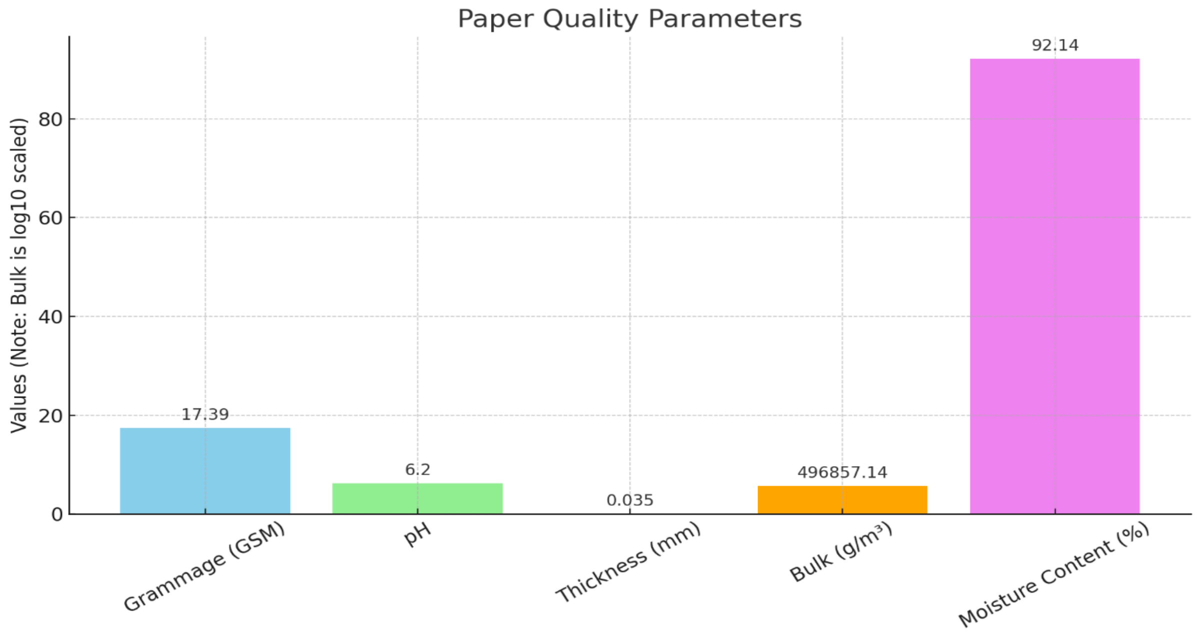

Fig. 6 Graphical presentation of key quality parameters of handmade paper produced from banana fibres. The graph compares grammage (17.39 GSM), pH (6.2), thickness (0.035 mm), bulk (496,857.14 g/m^3, log-scaled), and moisture content (92.14%). These parameters reflect the structural, chemical, and physical properties of the paper, indicating that the sheet is lightweight, slightly acidic, moderately thick, and retains a high percentage of moisture—important factors for evaluating usability and storage stability.

These results confirm that the handmade banana fibre paper possesses desirable characteristics such as moderate density, slight acidity, uniform thickness, high bulk, and significant moisture content, which collectively influence its potential applications and handling.

4.0 Discussion

The present study highlights the potential of banana fibre, an agro-waste byproduct, as a viable and sustainable raw material for handmade paper production. Extracted from the pseudostem of the banana plant, these fibres possess desirable characteristics such as high moisture absorbency, soft texture, natural sheen, and complete biodegradability. Their breathable and hypoallergenic nature further enhances their suitability for eco-friendly applications, especially in packaging, stationery, and hygiene-related products (18, 19).

The initial assessment of handmade paper made solely from banana fibre revealed a slightly acidic pH of 6.2, typical of untreated lignocellulosic materials. While such acidity may compromise long-term durability, the introduction of calcium carbonate ($CaCO_3$) into the pulp effectively increased the pH, thereby improving chemical stability and archival properties (20). Additionally, starch served as a functional additive, promoting fibre bonding and improving the smoothness and uniformity of the sheet (21).

Measured values for grammage (GSM) and thickness were initially low, consistent with the lightweight nature of unmodified banana fibre sheets. Upon incorporation of $CaCO_3$ and starch, both GSM and thickness increased, indicating improved mechanical strength and enhanced structural integrity. These enhancements are attributed to the fillers' ability to occupy inter-fibre voids and reinforce the matrix through better adhesion (22).

A particularly high moisture content (92.14%) was observed in the untreated paper, a consequence of the fibres' natural hygroscopic properties. While high moisture retention can negatively impact strength and storage performance, the addition of $CaCO_3$ and starch significantly mitigated this issue. Their combined effect likely reduced water uptake through partial hydrophobicity and the formation of a tighter, less porous structure (23).

Bulk density was found to be lowest in the untreated samples, suggesting a compact yet lightweight sheet. While this compactness may benefit certain uses, the value can be optimized through further modifications in sheet formation and layering techniques.

Beyond technical performance, handmade paper offers several broader advantages. It is generally acid-free, durable, and biodegradable, aligning with environmental and sustainability goals. Its unique surface texture and artisanal finish provide aesthetic value, making it a preferred choice for premium packaging, artistic endeavours, and archival documents (24).

In conclusion, the modification of banana fibre pulp with $CaCO_3$ and starch significantly enhances key physical and chemical attributes, including pH stability, grammage, thickness, moisture resistance, and overall usability. These findings support the development of banana fibre-based handmade paper as a high-quality, eco-conscious alternative to conventional paper, contributing to both waste valorisation and sustainable material innovation.

5.0 Conclusion

The development of handmade paper from banana fibre offers a compelling example of sustainable innovation, leveraging agricultural waste for value-added, eco-friendly applications. Derived from the pseudostem of the banana plant, these fibres exhibit excellent biodegradability, natural lustre, softness, and moisture-absorbing properties, making them highly suitable for environmental and commercial applications.

The physicochemical evaluation of the handmade paper confirmed that banana fibre-based sheets, while naturally lightweight and slightly acidic, could be significantly improved through the incorporation of calcium carbonate and starch. These additives enhanced the paper's pH balance, thickness, grammage (GSM), and resistance to moisture, thereby increasing its structural integrity and usability. Such enhancements are vital for practical deployment in packaging, printing, or specialty stationery.

The use of Clorox during fibre preparation effectively bleached and clarified the pulp, contributing to the mechanical strength and aesthetic quality of the final product. The resulting paper showed adequate tensile strength, maintaining its integrity even under superficial filtration conditions. Notably, although coconut peel failed to form usable paper sheets, its fibrous byproduct showed potential in water filtration applications, opening avenues for alternate uses of agro-waste.

Limitations

Despite these promising results, the study faced certain limitations. The most notable was the high moisture content (92.14%) in untreated banana fibre paper, which can affect long-term durability and storage stability. Additionally, while the use of additives improved mechanical properties, further optimization is needed to achieve consistent uniformity and industrial-grade performance.

Future Scope

Future research should focus on refining the pulping, drying, and additive incorporation processes to reduce moisture content and enhance mechanical strength. Investigations into combining banana fibre with other plant residues or synthetic binders could result in hybrid composites with superior properties. Additionally, exploring the suitability of other agricultural wastes—such as coconut peel, sugarcane bagasse, or rice husk—for papermaking or filtration applications may broaden the scope of sustainable materials in both domestic and industrial contexts.

In essence, this study demonstrates that with appropriate modifications, banana fibre-based handmade paper can serve as a strong, biodegradable, and environmentally responsible alternative to conventional paper, aligning with the goals of circular economy and green technology.

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