Global Research journal of Natural Science and Technology (Grjnst)
Volume: 03 - Issue 1 (2025)
p.ISSN: 2790-7643 e.ISSN: 2790-7651
www.grjnst.com

Valorization of Banana Pseudostem Biomass for Sustainable Paper Production under Climate Change

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Abstract

Paper is an essential commodity in daily life and is widely used around the world. Traditionally, it is produced from wood pulp, contributing significantly to deforestation. In response to environmental concerns, alternative lignocellulosic sources, such as agricultural waste biomass, are gaining attention. Sindh, a major banana-growing region, generates large quantities of banana plant residues, including pseudostems and leaves. These are typically discarded or burned, releasing CO_2 and contributing to environmental pollution. Therefore, the proper disposal and valorization of banana pseudostem waste offer a sustainable alternative to wood-based pulp. In this study, banana pseudostems were processed for fiber extraction and utilized for paper production and other value-added bioproducts. The extracted banana fiber exhibited promising properties, including fiber length (1.75 mm), diameter (29.3 µm), and coarseness (0.13 mg/m), fineness (19%), ash content (8.4%), and moisture retention capacity (11.72%). The pulping process was optimized by varying the cooking time (45, 60, and 75 minutes) and sodium hydroxide (NaOH) concentrations (10g, 15g, and 20g). The highest pulp yield was obtained under the conditions of 10% NaOH, at 130 °C, with a cooking time of 63 minutes. Paper sheets produced from the banana pseudostem fiber demonstrated excellent mechanical and physical properties: tensile strength (81.66 ± 3.88 N), bursting strength (31.63 ± 5.51 kPa), moisture retention (8.3 ± 1.00%), and brightness (69.63 ± 2.52%). This study concludes that the recycling of banana pseudostem waste can significantly reduce biomass burning and associated CO_2 emissions. Banana pseudostem pulp presents a viable and sustainable alternative to wood pulp for paper manufacturing. The process is economically feasible, cost-effective, energy-efficient, and environmentally friendly. Furthermore, this valorization approach can benefit local banana growers and entrepreneurs, particularly women, by enabling the production of handmade paper, handicrafts, and other bioproducts. These initiatives could promote rural livelihoods and foster the development of a circular bioeconomy, supporting climate change mitigation efforts and reducing reliance on synthetic paper materials in the pulp and paper industry.

Key words: Banana psuedostem, papers sheets, byproducts, circular bio-economy, climate change

1. INTRODUCTION

. Waste management is an ecologically sustainable and financially feasible challenge in the modern world due to global warming and deforestation. Raw materials of papers are wood pulp derived from forests tree loggings. Deforestation a global issue that triggers climate change and is caused by many factors; one of them is tree logging due to paper industry. Therefore, a need to harness the non-woody alternatives for paper pulp like lignocelluloses wastes with low cost, less energy, and chemical utilization. However, banana pseudo stem is a best raw material for paper pulp and processing. In order to tackle the climatic change, shift away from non-renewable, non-degradable manufacture products into biodegradable resources. Comparatively least attention has been given on the efficient utilization of fresh biomass generate during the production of bananas and many other types of crop (Jirukkakul, 2020). The plant parts including fruits, leaves, flower buds, trunk, and pseudostem can be utilized in a variety of ways. According to Abro et al., (2023), it is possible for a decorticator machine to remove the fibers from banana pseudostem must next undergo retting and degumming (Mohapatra et al., 2010; Bello et al., 2018). Sindh is the major banana producing province of Pakistan, contributing 93% in national banana acreage (35000 ha) and produces 154300 tons banana, which accumulates 83% of total banana production for Pakistan (Agricultural Statistics of Pakistan, 2020-21). After fruit harvesting, a huge quantity of leftovers like banana stalks, pseudostems, and leaves are dispose of by dumping into soil, landfills, and incinerating the garbage on routinely basis (Banana brochure, 2018). Despite the facts that these residues contain maximum organic carbon and nutrients during fruit harvesting, these methods are not friendly for the environment. This results in the loss of important resources, emission of disagreeable odors, and a lack of cleanliness.

Banana fiber obtain from the banana plant utilize in the production of a wide range of textiles. According to Environmental Protection Agency (2008), the amount of banana waste is nearly two tons for every ton of fruit that is produced. One hectare of banana harvesting may produce 50-60 tons/ha new pseudostems. Fibers of the finest quality that are accessible after the fruit collection (Ferdous et al., 2021). The fibres and other stem components are removed and used to manufacture a broad variety of high-value commodities. The maximum level of cellulose is necessary for making paper and pulp. The banana stem contains a significant amount of cellulose, making it a potential candidate for usage as an alternative source of raw material (Kumar et al., 2013). Banana tree stems are a great source of raw materials for making tissue paper because of largest amount of cellulose (Khan et al., 2014). This method produces deep, rich brown pulp that can be utilized to make premium tissue paper since it turns white when run through a bleaching machine. Banana tree stems are a great source of raw materials for making tissue paper because they contain the largest amount of cellulose of any plant material (Khan et al., 2014; Abro et al., (2024). On the other hand, the apparatus/equipment and machinery that is required to process the pseudostem into paper already exists. This method produces pulp that is rich and deep brown can be used to manufacture the white pulp by running it through a bleaching machine. (Taleat et al., 2023; Vu et al., 2018). According to Subagyo and Chafidz (2018), the extracted and processed pulp has been used to make the sheets for biodegradable papers. Khristova et al. (2021) used the banana stems to make a wide variety of goods like grease proof paper, fiber, board, writing paper, and tissue paper, etc. Banana pseudostem pulp has the potential to be utilized as a raw material, this investigation was carried out to evaluate its utility in cost-effective way to process the production of organic biodegradable by-products According to the findings of this research, and paper production from banana pseudostems pulp is an environmental friendlier and responsible decision. This is one of the most recent and new invention in paper industries for production of paper by pseudostems as a wonderful raw material in manufacturing of tissue papers with outstanding strength. This study is therefore designed for objectives as to utilize economically important banana pseudostem waste generated in banana fields for production of biodegrdble paper sheets s value added bio-products to boost circular economy.

2. Materials and Methods

2.1. Banana fiber extraction unit

The research was carried out at banana fiber extraction unit and recycling experimental area of dept. of Soil Science, Sindh Agriculture University, Tandojam, Sindh. The banana plants are abundantly grown in Sindh. After the banana fruit harvest, the banana plant was cut down as it didn’t bear fruit again. The enormous banana pseudostems were used as a raw material for this experiment (Fig. 1A). The pseudostem of bananas plant biomass were collected and purchased from local farmer's field near Tandojam, Hyderabad. An electric driven solar powered raspador machine was installed in Banana Extraction Unit for banana pseudostem decortication (Fig. 2A). The raspador machine extracted 8 to 10 kg of banana raw fiber in a day.

2.2. Processing of Banana Pseudostem

Sheaths of different sizes were prepared from collected pseudostems of banana plant biomass. The banana plant sheaths were cut down and then extracted banana fibers were cut into tiny pieces (2–3 inches). These pieces were fed into the raspador machine to separate it from the sliced sheaths. After sun drying, the banana pseudostem was measured and ready for cooking.

Figure 1. Banana pseudostem (A), Banana fiber extracting machine (B), Banana psuedostem fiber (C), Chopping of banana fiber (D), Cooking of the fiber for paper pulp (E), Banana pulp blender (F), Sieve (G),

2.3. Processing of paper and pulp

A representative chemical makeup for samples included sodium hydroxide, which was employed for pulp-making process (Figs. 1C, D). Following several applications of NaOH, this procedure eliminated the lignin and hemicelluloses. The kappa number was used to calculate the pulp's lignin probability. However, we utilized this to prepare the sheets of paper and Kleenex. Similar characteristics of paper and paper pulp were noted, e.g., brightness, moisture retention, tensile strength, and tensile burst.

2.4. Cooking

Each banana fiber slot, 150 g of dried fiber was weighed and put into glass beakers. For cooking, liquid (NaOH) was added in 1:5 ratio before being coked. The digester's cooking liquor volume was kept constant by adding hot water. Tap water was used to rinse the digested fiber (pulp) until the combination was neutral. After being oven-dried, the pulp yield was measured by gravimetric analysis (Fig. 1E).

2.5. Paper and pulp characterization

1. **Percentage pulp yield**

An analytical balance was used to measure the weight of various wet pulps. The W1, weight of crucible and W2 the weight of crucible with pulp. The sample was dried for 1 h at 60°C in an oven, allowed to cool at room temperature in a desiccator, and then weighed again. After 30 min of cooling and weighing, the crucible was put back in an oven, and the process was repeated until the weight (W3) remained constant.

This following formula was used to determine the pulp yield:

$$\text{Pulp yield} = \frac{W2-W3}{W2-W1} \times 100$$

2. **Green Paper sheet production**

After that, 120 g of chopped pieces fiber were added into 1 L boiled water for 30 min and 25 mL sodium hydroxide added into the mixture. After boiling, the pieces were filtered and cleaned with purified water, then the pieces mixed in 500 mL water in a Kenwood blender (1.5 liters, 8 blades, operating at 18,000 rev/min @ 2000 watts) for 5 to 10 min to make the pulp (Fig. 1E). The pulp was then poured into a tiny pulp-containing tank or bucket to produce a sheet over a mould (Figs. 1F, G). After that, the sheets of molded pulp were allowed to dry in sun. To ensure smoothness, the dry sheets were rolled between two rollers before cutting into appropriate size and dried sheets of dry banana paper piled together. Several varieties of paper were made from the pulp of banana fiber (Fig. 1H).

2.6. Specific tests paper testation

The following criterion were used to examine the mechanical and optical characteristics of conditioned papers.

1. **Measurement of moisture content**

Within an hour at room temperature, samples of paper sheets derived from banana fiber were submerged for 10 min at a time in containers filled with distilled water. Each sample size for this procedure was 5 g. Paper sheet samples were removed from the container at predetermined intervals and stored between two filter sheets and two circular disks (each weight 15 g). Filter paper thus collected surface moisture under the pressure of a single 15 g circular disk. A precise digital balance was used to weigh the samples in order to determine the percentages of water absorption.

$$\textbf{Moisture retention (\%)} = \frac{(\text{weight after immersion}) - (\text{weight before immersion})}{\text{weight before immersion}} \times 100$$

2. **Tensile properties**

Tensile strength of paper sheets is crucial for handling and using of the final goods. The initial gauge separation and crosshead speed were set at 10 mm/min, and the papers were made in 1×15 cm^3. The samples were examined at 25°C and 50% relative humidity in a standard atmosphere. Numerous load and elongation measurements were made to check the sample stretch until it broken down.

3. **Bursting strength**

The bursting strength tester (UEC 1020B, UMS® India) was used and TAPPI T-403 method used to assess the bursting strength.

Statistical analysis

All the results given in the table are mean ± standard deviations (n = 3). The data were subjected to one-way analysis of variance (ANOVA) for the determination of significant differences in the treatments, using the SAS 9.3 statistical software.

Results

1. **Quality parameters of banana fiber byproducts**

Extensively grown banana generate huge amount of psuedostem wastes, if managed properly could be the best alternative for wood pulp to retard the deforestation, which ultimately change the climate. The banana psuedostem was collected from the field chopped and processed in the raspador machine for the extraction of the fine quality banana fibers of 1.63 mm in length from banana pseudo-stem. The analysis of the fiber showed that there was high a cellulose percentage available from the banana psudostem. This was a best alternative of wood pulp for the production of biodegradable tissue papers and paper sheets (Figs. 2A to F), (Table 1). The lignin was comparatively low and good to detach lignin from the cellulose. The ash content was 8.2% that can be used for the industrial process. The moisture regain level of the fiber was 11.3% that was highly important for manufacturing of tissue papers and paper sheets. The data revealed that fiber length was appropriate for the spin ability. The fineness showed the suitability of the fiber for paper pulp making and final finished handmade and industrial products.

Table 1. Banana fibers Characteristics

Banana Pseudostem Fiber Morphology

Length of Fiber	Width of Fiber	Coarseness	Fineness	Ash	Moisture
1.62 mm	28.2μm	0.13 mg/m	18%	8.65%	10.3%

2. Pulping of banana fiber for paper making

The observed banana fibers for paper pulp yielded 46.7-66.8% for extracted banana fiber respectively as shown in table 2.

Table 2. Amount of water NaOH, banana fiber blending and boiling time utilized for the making pulp for paper sheets production

	120 g banana fiber			
	Parameters			
Trials	**Amount of water (lit.)**	**Time in boiling banana fiber (min)**	**Time of blending banana fiber (min)**	**Amount of NaOH (g)**
1	1.5	55	7	12
2	1	45	5	15
3	1	35	5	20
1	1	60	5	10
2	1.5	55	7	15
3	2	60	5	20
1	1	60	5	10
2	1	55	10	15
3	1	55	20	15

3. Specific properties of banana paper

3.1. Tensile strength of green paper sheets

Table 3 indicated that tensile strength (160 Nm) was increasing with grinding degree. From this we inferred that tensile strength increased with increasing grinding degree and after that tensile strength of the pulp diminishing gradually. This is due to minimum fiber size with high grinding degree. The reason of maximum strength was the rearrangement of fiber and with minimum fiber size made the stronger fiber to fiber bond. The same value for the paper sheets were observed (31.68 Nm). The fiber strength decreased after crossing the optimum limit. This was due to maximum fineness cause to lower the strength.

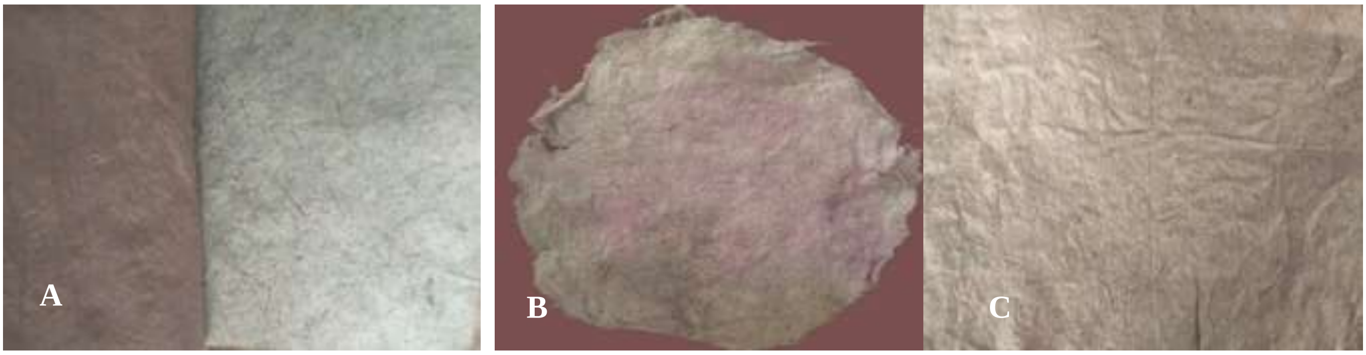

Figure 1. Biodegradable paper sheets **A, B, C**) from banana fiber pulp

3.2. Brightness of green paper sheets

The brightness (77.32%) of tissue paper was observed, when the brightness increased, the strength decreases due to high bleaching by using NaOH. The brightness value of paper sheet made from the banana fiber was 69.33% (Table 2). The low value for the paper sheet may be due to thickness and amount of bleaching soda used for pulping. Maximum bleaching of the pulp reduced the ability and strength of pulp broken the fiber-to-fiber bond. The brightness of both papers sheets depend upon the amount of the NaOH used to bleach the banana psuedostem fiber used for the production of pulp.

3.3. Bursting strength of green paper sheets

If the paper sheets can resist the maximum pressure applied perpendicularly to the plane of the test piece without breaking, the bursting strength values were 81.66 KPa (Table 3). Bursting strength indicated the ability of packaging material to retain its contents; hence, a paper with low value will tear easily. The bursting strength is an important characteristic mainly depend upon the amount of fibers used for the production of paper products.

Table 3. The morphological characteristics of quality papers sheets made of banana fiber

Parameter	values
Burst strength (KPa)	81.66 ± 3.88
Tensile strength (Nm)	31.63 ± 5.51
Brightness (%)	69.63 ± 2.52
Moisture retention (%)	8.3 ± 1.00

Means of triplicates ± standard deviation. Means are significantly different from all determined by LSD posttest ($p < 0.05$).

3.4. Moisture content of green paper sheets

Moisture content of the papers was observed (8.3%), which was quite appropriate for paper industry. This was observed in both cases that wet papers sheet retained higher value than the dry ones, because of thickness, the paper sheets had lower absorbance.

4. Discussion

2.1. Composition and Morphological characteristics of banana fiber

Banana psuedsotem fiber is the best raw material for the paper production to replace the wood pulp to avoid deforestation and climatic changes. The results of this new invention indicated the morphology and chemical makeup of the banana pseudostem fibers. The amount of ash for annual plants are the subject of observation. For industrial processing, the production of ash is higher. The second observation is that, in comparison to other annual plants, there was a relatively small quantity of lignin. This raw material is worthy for pulping despite of having maximum ash concentration because of low lignin level (Pavithra and Dhurai, 2022). The results are in accordance with Melesee et al. (2023). Tables displayed the morphological characteristics and composition of banana fiber determined by the fiber extraction procedure indicated the higher percentage of cellulose extracted from banana pseudostem (Gomes et al., 2024). The shorter fiber of grasses and hardwoods are necessary for pulping extraction because of printability, stiffness, and opacity, whereas longer fibers of wood or non-wood increase the formation of a matrix in the paper sheet with good tensile strength (Jhansi et al., 2024). Accordingly Kumari et al. (2022), the pseudo banana stem has excellent slenderness ratio favorable for pulping and papermaking. The flexibility ratio of the fiber components can be used to describe the paper during drying and beating process. The detected moisture content of the banana fiber found in this study is consistent with the findings of Jirukful et al. (2019).

4.2. Pulping of banana fiber for paper making

In this work, banana pseudostem fibers were the effective substitute for papermaking. Before being turned into pulp, the collected fibers were soaked into water, following the NaOH treatment, cleaned from impurities (bacteria), and then beaten to turn it into pulp (Mote et al., 2023). As in our earlier work, the ideal pulping parameters were determined when maximum fibers were cooked by using kraft process with varying chemical charges and a broad range of time and temperature likely Melesse et al. (2023). The low alkali charges maximize the yield (48.61%). The pulp was oxygenated for delignification (high kappa was 19.9) prior to bleaching. Brightness was 6.56% after boiling, and three-stage sequential bleaching was used to achieve the brightness after delignification. The pulp was repeatedly cleaned with distilled water, the pH was maintained within the specified range, (adjusting through buffers) and the process involved a high charge of bleaching chemical. Banana fiber can be an alternative raw material of paper industries like writing paper, anti-grease paper, cheque as well as in hard board industries (Khan et al., 2013; Mote et al., 2023). Pulp is processed through a number of procedures to manufacture the final paper. Shopping bags, folders, greeting cards, invitation covers, scribing pads, envelops, art paper, and printing papers all are making by this material (Teleat et al., 2023). Additionally, by substituting banana fiber pulp against bamboo or wooden pulp, writing paper can also make from banana fiber using the standard industrial technique. A high kappa value is the result of insufficient lignin removal caused by the lower temperature (Khan et al., 2014; Ferdous et al., 2023). Higher temperature degraded the cellulose and reduce the pulp production, so, it is clear that the high cooking temperature, the pulp output marginally increases from 31% to 33% because of large banana pseudostem. The kappa number decrease sometime when the cooking temperature change from 110°C to 130°C (Lakhan et al., 2013; Melesse et al., 2023). This indicates that if the lignin level low, the delignification of banana pseudostem seems a big challenge similarly the results of Yiga et al. (2023).

4.4. Physical and mechanical properties of paper sheets

4.4.1. Moisture content (%)

The paper without lamination had a lower moisture content (MC) than laminated paper due to its thickness and usage of lamination techniques. According to Jirukful et al. (2019), the wet laminated paper retained higher MC (12.29–12.80%) than dried laminated paper, while the standard limit is <10%. The MC of laminated paper can be increased by using flour solution used as adhesive to adhere the paper and film. Drying can lower the higher MC of the paper and also control the final MC. On the other hand, poor quality paper with a rough surface look was due to excessive dryness at higher temperatures. The results are in complete agreement with the findings of Deshmukh et al. (2023).

4.4.2. Bursting strength

Bursting strength is the highest pressure that can be applied perpendicular to the test pieces plane. Low-value paper torn quickly, so, bursting strength is a measure of a packing material capacity to hold its contents. In this study, bursting strength increased tandemly with the degree of refining. This is because fibers combination always affect the tensile index and burst strength of the papers (Jhansi et al., 2024). The ability of the fibers improved as the fining degree increases because more and more hydroxyl groups fractionate the fiber surface. In both instances, it was discovered that bursting strength increases as coating concentration increased. There were notable differences between the factors (Yiga et al., 2023).

4.4.3. Tensile strength

The tensile index of both coated and uncoated pulp-with-fineness paper was higher than that of pulp-based paper. Melesee et al. (2023) have published similar findings, showing that an increase in pulp fineness is accompanied with an increase in the tensile index. This work indicated that tissue papers possessed a higher tensile index than paper sheets. Thick paper sheets may have a higher tensile index because of absorption on the fibers, which increased the surface charge density and suggested the formation of linking qualities (Teleat et al., 2022). The swelling of cellulose fiber caused by solvent penetration is a primary cause to minimize the tensile strength of paper sheets.

4.4.4. Brightness

This study indicated the brightness value (77.32%) for the paper sheets used to make the tissue paper. It was found that as the amount of bleaching with NaOH increased, the paper's brightness also increased but its strength decreased. This is because severe bleaching of the pulp cause breakage of fiber-fiber link, which minimize the pulp strength, while boost the pulp bleaching ability (Mote et al., 2023; Lakhan et al., 2013), similarly the results of this study.

4.4.5. Green papers sheets

As an alternative raw material, banana fiber can be used in hard board, writing, anti-grease, cheque paper, and different paper based industries (Jhansi et al., 2024; Mote et al., 2023; Mohyuddin et al., 2014). Banana plants initially harvest to make basic paper components, and then fibers are harvested. Before being turned into pulp, the gathered fibers are soaked in water (Aiyedun et al., 2023). It is attempted to delay the ability to moisten and penetrate during the size stage. Porosity is decreased by sizing, which lowers the absorption capacity. Pulp is processed through a number of stages to create finished paper (Taleat et al., 2021). Shopping bags, folders, greeting cards, invitation covers, scribing pads, envelops, art paper, printing paper, and many more are making by this material (Deshmukh et al., 2023; Yiga et al., 2023). Additionally, by substituting banana fiber pulp for bamboo or wooden pulp, writing paper is also made from banana fiber using the standard industrial technique (Mohapatra et al., 2010; Melesee et al., 2022). Banana fibers combine with scutcher, cotton rags, waste paper, and straw in different amounts to make handmade paper sheets (Jhansi et al., 2024; Aiyedun et al., 2023). There are various applications for this kind of paper in place of the current board that is on the market (Sakare et al., 2020).

Conclusion

This study concluded that banana agro-wastes including banana pseudostems are excellent alternative of wood pulp from with less amount of chemical for fabrication of organic sustainable paper sheets. It is suggested that farmers should not burn the banana pusedostem rather recycle for the extraction of fiber & production of sustainable biodegradable sustainable green papers sheets for waste management, improve income through circular economy under ever changing climate.

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REFERENCES

Abro, S. A, et al. (2024). Integrated Influence of Banana Pseudostem Scuture Waste Compost and Mineral Fertilizer on Growth and Yield of Chia *Plant health* 3 (1) 57-66

Abro, S. A, et al. (2023). Banana Cellulosic Fiber*:* A Natural Innovative and Sustainable Bio-Resource for Eco-Friendly Industrial Applications. *Plant health,* 2-2 57-64.

Ahmad, T & Danish, M. (2018) Prospects of banana waste utilization in wastewater treatment: A review. Journal of Environmental Management. ;206: 330-348

Alavudeen, A., et al. (2015). Mechanical properties of banana/kenaf fiber-reinforced hybrid polyester composites: Effect of woven fabric an random orientation, Materials & Design.;66: 246-257.

Aiyedun, P. O., et al. (2023). Development of pulp and paper using stem and fruit stem of Musa Species. J Amasya University Institute of Sciences Technology 4 (1), 20-32

Alwani, M. S., et al. (2013). An approach to using agricultural waste fibers in bio composites application: Thermogravimetric analysis and activation energy study. Bio-Resources. 9:218-230

Arafat, K. M. Y., et al. (2018). Handmade paper from waste banana fibre. *Bangladesh J Science and Industrial Research*.53 (2): 83-88.

Basak, S., et al. (2016). Banana pseudostem sap: A waste plant resource for making thermally stable cellulosic substrate. *Journal of Industrial Textiles*. 46:1003-1023.

Bello, K., et al. (2018). A study on adsorption behavior of newly synthesized banana pseudostem derived superabsorbent hydrogels for cationic and anionic dye removal from effluents. *Carbohydrate Polymers*.181:605-615

Deshmukh, G.M., et al. (2019). Banana Pseudostem: An alternative raw material for paper making. *International J Engineering Applied Sciences and Technology*, 4 (4), 68-73.

Ferdous, T., et al. (2023). Pulping bleaching potential of banana pseudo stem, banana leaf and banana peduncle. *Biomass Conversion and Biorefinery*, 1-12.

Gomes, C.V., et al. (2024). Improving textile circular economy through banana fibers from the leaves central rib: effect of different extraction methods *Food Bioproducts Processing* 146 (2024) 195–204

Jirukkakul, N., et al. (2020). Production of Packaging Molded from Banana Sheath. Pertanika *J Science & Technology*, 28(3).

Khan, M.Z.H., et al. (2014). Paper Making from Banana Pseudostem: Characterization and Comparison. *Journal of Natural Fibers*, 11:199–211.

Khristova, P., et al. (2021). Use of banana pseudostem pulp for biodegradable paper sheets production. *Waste Biomass Valor*. https://doi.org/10.1007/s12649-021-01444-6

Khan, M. Z. H., et al. (2013). Fiber morphology and pulping study of banana pseudo-stem. *International Journal of Fiber and Textile Research* 3(1): 31–35).

Lakhan S. and Tarun K.B. (2013) Handmade paper from banana stem. *International Journal of Scientific and Engineering Research*,; 4(7)

Lilian, C., et al. (2015). Evaluation for paper ability to pseudo stem of banana tree. *Procedia Materials Science* 8, 814–823.

Mohapatra, D., et al. (2010) Banana and its by-product utilization: An overview. *Journal of Scientific & Industrial Research.* 69:323-329

Mohiyuddin, A.K.M., (2014). Usefulness of banana (Musa paradisiaca) wastes in manufacturing of bio-products*: a review The Agriculturists, 12(1), pp.148-158.*

Mote, A., et al. (2023) Handmade Paper from MUSA Accuminata (Banana) Stem. *National J of Adv. Research in Science, Commun.Technology* 3, 1 428-438

Patil, R. G. and Kolambe, B. N. (2011). Development of value added products from banana pseudostem. An Overview of Progress. *National Agricultural Innovation Project (Component* 2), 1-23 pp.

Pavithra and Dhurai (2022) The Various Properties And Uses Of Banana Fibre In Home Textile International Research *Journal of Engineering and Technology* 2-5 615-617

amdhonee, A. and Jeetah, P.(2017).Production of wrapping paper from banana fibers. Journal of Environmental Chemical Engineering, 5(5), pp.4298-4306.

Sango, T., et al. (2018) Step-wise multi-scale deconstruction of banana pseudostem (Musa acuminata) biomass and morpho–mechanical characterization of extracted long fibres for sustainable applications. *Industrial Crops and Products*.;122:657-668 .

Subagyo, A., and Chafidz, A. (2018). Banana Pseudostem Fiber: Preparation, Characteristics, and Applications. Banana Nutrition - Function and Processing Kinetics. Web of Science,

Subramanya, R., (2017) Evaluation of structural, tensile and thermal properties of banana fibers. *Journal of Natural Fibers*.;14: 485-497

Taleat, A.A.T., et al. (2021). Pulp Extraction and paper production from banana pseudostem and its characterization. International Conference of Sciences, *Engineering & Environmental Technology (ICONSEt*, 6 (18): 129 – 134.

Vigneswaran, C., et al. (2015). Banana fiber: Scope and value added product development. *J Textile and Apparel, Technology and Management*.;9:1-7

Vijaya, k., et al. (2017). A review paper on design and fabrication of banana fiber extraction machine and evaluation of banana fiber properties. *Int. J Adv. Res. in Electrical, Electronics and Instru. Engineering*. 6 (3): 1513-1518.

Vu, H. T., (2018) Phenolic compounds within banana peel and their potential uses: A review. *Journal of Functional Foods*. ; 40:238-248 jhnjym