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Banana Cellulosic Fiber: A Natural Innovative and Sustainable Bio-Resource for Eco-Friendly Industrial Applications

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ABSTRACT

Growing concern about changing climate triggered by global warming, agro-waste disposal and synthetic non-renewable products are major challenges. World is moving from non-degradable and no-renewable, bio-degradable recyclable sustainable substitutions. Thus, there is increasing demand for natural fibers to substitute altered fiber with organic plant fibers like banana tree. After fruit cutting huge banana biomass is leftover in the field with mean biomass generated by a single pseudostem is around1.44 (±0.6) kg on dry weight basis and half ton of banana waste emitted about 0.5-ton CO_2 and burring caused global warming. This also badly affects the air quality index AQI (to measure the air pollution levels) by spreading fume mist affecting human and livestock health. A lignocellulose bio-fiber is extracted through raspador machine mechanically. The extracted fiber was processed with 1M NaOH at 80°C for 90 minutes for decontamination. We produced innovative green textile industrial & cottage cellulosic organic banana pseudo-stem fiber. It has good spin able quality, durable, antibacterial attributes, and low weightage, absorption of moisture quality morphological and thermal characteristics. Its physico-chemical dynamics ie; fineness tex 3-7 strength bundle tex 20-30 level of moisture 10-11 and density 1.35 (g/cm3) staple Length 10-50 (cm) L/D ratio 150. Strength of tensile (MPa) 600-800. Elongation at break 3-9 (%). The banana fiber is best for potential materials for textile paper food and cottage, medical usage and eco and environment friendly wrapping industry. A novel eco-green technique could boost livelihood of the rural marginalized farmers with value added bio-products by value chain creating system to enhance circular economic wellbeing.

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INTRODUCTION

The rising concern of changing climate and global warming, agro-waste disposal, and non-renewable chemically altered materials are major challenges for a growing economy. This demands replacement of natural non-degradable with biodegradable sustainable materials. Cotton is conventional crop and is expensive that requires large quantity of irrigation water, fertilizer of chemicals and indiscriminate pesticides sprays. With global increasing need for natural, eco-loving bio-fibers as substitute to synthetic fiber, there is high need to inquire various potent areas of sustainable fiber like banana. Banana is Pakistan's biggest fruit crop, and it grows on 37,000 hectares and produces 154,800 tons. The crop thrives in Sindh province due to suitable soil and climatic conditions. Sindh province alone accounts for 87% of its cultivation. Thatta, Hyderabad, Badin, Mirpurkhas, Tando Allahyar, Matiari, Tando Muhammad Khan, Sangar, Naushero Feroz, and Nawabshah are some of Sindh's major banana-producing districts. Furthermore, its cultivation has spread to northern portions of Sindh, particularly district Khairpur. Banana crop after fruit harvest every ton produces around 3 tons' debris as trunk residues trashes waste 150 tons (Ahmad and Danish 2018; Abro *et al*., 2023). One ton of fruit generates round 3 tons of waste. Most of residue is left over in the field and biomass mean generated by stem of one plant is 1.44 (±0.6) k. Ea Each ton of crop waste of banana left over emits, a half-ton of CO_2 per year CH_4 gas too (Mostafa and Uddin, 2015**;** Abro *et al*., 2019). This also badly affects the air quality index AQI negatively affecting human and livestock health. Its millions of tons of waste every season after banana crop harvest and disposal of such huge waste is problem. Banana growers incur 7000-8000/acre as additional cost to dispose of the gigantic waste. Moreover, bio-waste burnt having adverse environmental effect, contributing increase in global warming. Thus, the potential to bio-converting residue into potential ecofriendly techniques of textile grade fibers need to explore, if not will produce a huge disposal management problem (Aminudin *et al*., 2017). Further this could be cheap, eco-friendly domestic, cottage, fabric sustainable fashion and industrial utilizations. Agro-based bio-fibers are suitable for composite, textile, pulp and paper manufacture as these have structure, properties and composition required. These bio-fibers can be utilized for fuel, enzymes, chemicals and bio-food items. Recently the utilization of natural fibers was thought to be "environment and eco-friendly" sources pf organic fiber and world is eager for use of bio-fibers (Sumesh *et al*., 2022). Bio-plant fibers as Banana fibers are better than processed fibers, including local availability, density, cost effective, insulation thermally, good endurance, best resistance to electrical, acoustic property and specific high strength (Khan *et al*., 2014). Further banana fiber is biodegradable, broken down in CO_2 by microbes in water and soil. In Sindh banana fibers are locally available in huge quantity, but not yet exploited fully. Presently limited utilization of banana fiber, like fabrics mats and ropes, (Vigneswaran *et al*. 2015). But it can be utilized in a wide range of industries strategies and by value added composite eco-friendly techniques (Figure 1). The potential exploitation of banana fiber links and enhancing efficiency of fiber production process will play a key role in upcoming circular green economy. Banana fibers has low in health risks, environmentally and economically safe and biodegradable. Further these plant fibers are non-carcinogenic recyclable suitable for sustainable fashion and low cost-effective and user friendly (Libog *et al*., 2023). That is why research work was proposed for objectives; below a) to collect wasted banana pseudo-stem pseudo-stem for the fiber production of textile grade fiber as green technology b) manufacturing value added by-products from discarded banana pseudo-stem pseudo-stem to enhance soil health and circular economy at rural level.

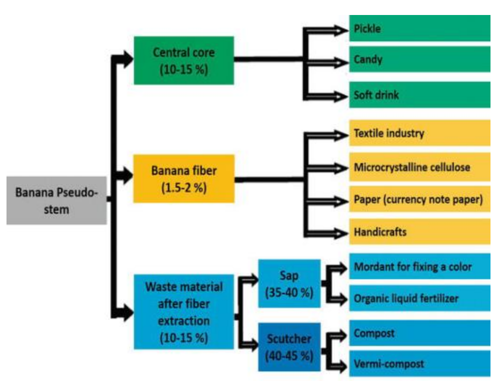

Figure 1. Banana psuedostem industrial utilization.

MATERIALS AND METHODS

Experimental Design and Site

The study was carried out in the Banana fiber extraction unit, Department of Soil Science, which is located in the Faculty of Crop Production at Sindh Agriculture University Tandojam (2°48'16.1" N, 101°30'10.99" E), Sindh.

Banana Fiber Extraction Unit

A well-furnished banana pseudo-stempseudo-stem fiber processing unit is established (2019) at Sindh Agriculture University Tandojam, Sindh.

Collection of Material

Wasted, ripe, and unproductive banana pseudo-stem were carefully transported to a banana fiber facility. We used fresh water to wash the trunks. The decayed, diseased banana stem was discarded in order to disinfect the pseudo-stem's unclean surface.

Raspador Machine

Raspador is a unique machine that produces fiber from banana trunks that is made locally. The model is a copy of a decorticator machine used in Bengal, which produces fiber from leftover banana trunks. After unfolding the stems, they were cut into two halves and thoroughly cleaned twice with fresh water. Banana fiber extractor (Agri Equip Pvt Ltd, 1 HP electric driven) in action (Figure 2).

Processing of the Banana Pseudo-stem

After processing, the pseudo-stem was split into layers of two to three feet. Sheets were then put into the machine.

Figure 2. Raspador (banana fiber extracting) machine.

Extraction of Banana Fibers

The processed banana pseudo-stempseudo-stem sheaths (Figure 3) were brought to the processing units. Each fully developed banana pseudo-stem contains around 14-18 flesh sheaths encoded in three different separate layers. The fiber extracted from banana stem resembled to ramie and bamboo fibers morphologically. Pseudo-stemPseudo-stem sheaths are (a) coarse one (outermost 2-3 sheaths) and easily breakable, (b) lustrous and soft (middle sheaths), and (c) very soft (with some inner & middle sheaths). For improving the quality of the banana extracted, were treated for hot water degumming.

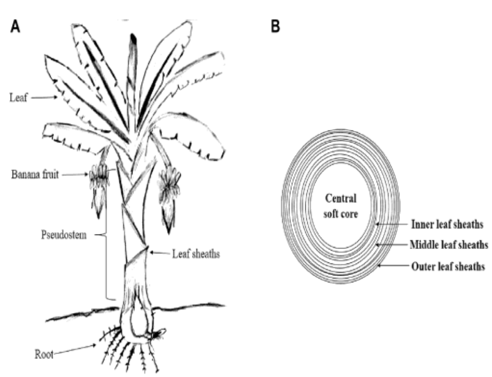

Figure 3. Various banana psudostem layered sheaths.

Chemical Degumming

Initially in degumming process the fibers were washed with water for neutralization secondly, bleaching with hypochlorite third & fourth with a hydrocarbons. The extracted banana fibers were boiled in an aqueous solution a few times in alkaline environment. Afterwards, a mixture of NaOH & water is added to remove any contamination for degumming of banana fiber (Bezazi *et al.*, 2014). Conventional degumming processes include using alkali scouring agent such as sodium hydroxide (NaOH). Impurities in banana fibers were removed using 1M NaOH at 90°C for 90 minutes, resulting in a satisfactory consistency between breaking tenacity and breaking extension.

Sun Drying

For fiber analysis, dried at sun light and then leftover control condition 6 days. The fifer is further processed to produce bio products and handicrafts.

Physical Characterization

In banana fiber processing unit temperatures at 27 °C and 65% humidity was for 24 h for banana bio-fiber. The bundles of fiber were crushed and selected at random in order to determine fiber. Further the crushed banana fibers were placed onto slides, & test for optical on microscopy.

$$Slenderness\ Ratio\ = \frac{Lf}{Df}$$

Where Lf represents length of fiber & Df represents diameter of fiber

$$Flexibility\ Coefficient = \frac{LDf}{Df} \times 100$$

The lumen fiber dia is represented as LDf and Df represents fiber diameter (μm)

Chemical Characterization

As whole the lignin, hemicellulose and cellulose content of the extracted banana-fibers were analyzed Chemico-physically by using developed techniques. For each bio-assay, 1g of finely powdered fiber was used.

$$Cellulose\ Total\ (dry\ basis) = \frac{Residue}{Dry\ matter\ weight} \times 100$$

$$HemiCellulose\ Total = \frac{Acid\ detergent\ Fiber - Neutral\ detergent\ fiber}{initial\ (Total) weight} \times 100$$

$$Lignin\ \%\ \frac{Lignin\ Residue}{Dry\ matter\ weight} \times 100$$

Mechanical Characterization

The characteristics tensile of three different layered banana extracted fibers were analyzed (50 mm L gauge-Tinius Olsen H50KS UTM) for operating at 0.5 mm/minute speed crosshead. For obtaining a significant statistical data, three banana fibers were evaluated. Every experiment was taken at 25°C & 40–42% humidity relatively. For examining the mechanically strength o of fiber chosen, strength tensile & elongation break determined. The strength of tensile-was computed by formulas examining. The breaking load, strain stress, area cross-sectional utilizing, test data were computed.

$$Strength\ of\ Tensile\ \left(\frac{N}{mm2}\right) = \frac{Load\ Breaking}{Area\ Cross\ Section}$$

RESULTS

Extraction of Banana Fiber

It was inferred from results that from mechanically banana extracted fiber was of textile grade quality. Further the result depicted that second and the third layers of the pseudo-stem are the finest of all fibers extracted. Banana fiber has a little longer yet a good strength. From the inner to outer layers, the thickness of fiber's decreases and goes up 0.06 to 0.26 mm. The banana lingo-cellulosic fibers from bananas stem were strong, with best fineness/length ratio, and were industrial textile quality.

Figure 4. Banana fiber extracted by raspdor.

Physical Characteristics

The physical attribute values are given in table 1. below. It was observed that length of banana fiber, dia resembled to hemp fax, jute fibers. The fiber is durable and sustainable in all means and physical parameters.

Chemico-Mechanical Composition

From analysis it was depicted that fiber had chemical composition of different species, locations of geographical, conditions of agroclimatic zones, nutrients soil, plant age, extraction conditions. Further fiber linear density was used to test and evaluate fineness of treated banana fiber (Table 2).

Table 1. Physical characteristics of banana fibers observed during analysis.

Parameters	Values
average length	382.0 µm
Dia of fiber	25.00 µm
Lumen fiber dia	3.90 µm
Thickness (cell wall)	10.77 µm
Slenderness	31.53
flexibility coefficient	58.97
Runkel Ratio	0.73 ratio

*Means ± standard deviations, average of 3 replicates.

Table No 2. Morphological and Mechanical Physicochemical characteristics of banana fiber.

Parameters	Values
Banana fibre Tenacity	30.97 gm/denier
Fibre fitness	17.1 denier
Fibre moisture retention	6.53 %
B Elongation of fibre	81.7%
Percent of cellulose (Total)	61.6 %
Percent cellulose Alpha	41.9 %
Percent of Gum Residual	13 %
Percent Lignin of fibre	14%

*Means ± standard deviations, average of 3 replicates.

The mechanical characteristics of banana fiber has influiunce on extraction process of sheaths. The fineness and length of fiber are described as variety of crop, the sheath length, and technique of banana fiber extracted. The diference in that may be result of mean length used. The schematic SEM diagram of layer (middle) of banana stem for green textile is presented in Figure 5.

The use of banana fiber in various environmentally friendly industrial processes generates creative concepts for two possible future commercialization. The fundamental concerns of adopting banana fiber for certain purposes are its strength and content.

Figure 5. Schematic SEM diagram of layer (middle) of banana stem for green textile.

DISCUSSION

Globally, the most accepted technique of fiber extraction is retting in water. Discarding cementations compartments as hemicellulose lignin, pectin, wax, facilitates fiber production. However mechanical attributes of fiber banana are greatly influenced by extraction technique. The length of the strip stem sheath, plant species, and generation technique all influence the fineness and fiber length. As pseudo-stem fiber is not a well-developed natural fiber for clothing and fabrics appropriate equipment not developed, yet. Although there had been many attempts for decorticator type but not up to mark (Paramasivam *et al*., 2020). However, this technique is laborious and yields meagre banana fiber. Resultantly large scaling up cannot further utilize it. As the mechanical fiber production can affect fibers due to high-pressure and speed pounding, however manual fiber extraction yields good quality. A very high plant cellulose content and less micro fibril fiber angle are major issues contributing to mechanical characteristics of manually produced fibers, altering not during the whole method (Jagadeesh *et al*., 2021). Due to agroclimatic variable conditions in agriculture, chemical properties of banana stem sheaths differ in same plant cultivars. (Jayaprabha *et al*., 2011). Achieving fibers individual through raspador or is to be alarming, few chemicals may be applied fiber production and the procedure of decontamination. It was observed that lignin, lipids hemicellulose and waxes are of acidic nature, degumming is accomplished typically by heating the material some time under a moderate alkali, such as NaOH (Pandey *et al*., 2021). Lignin, hemicellulose and other impurities on the surface of fiber have removed by chemicals such as magnesium carbonate, $NaHCO_3$ (Siva *et al*., 2020). Owing to its good tensile and flexible strengths and stiffness, banana mechanical fiber's attributes made it a best option for a variety of ecofriendly utilization. Tensile strength of banana fiber is higher than that of coir, bamboo, sisal, fiber (Ramesh *et al*. 2017). Due to its strength, banana stem fiber is a good fit for the reinforced materials composite, pulp and paper sheet industry. Banana stem fiber cells have unique thick walls of cell form whereas its lumen is larger and highly small (Ramesh *et al*., 2017).

As banana pseudo-stem contains huge quantity of cellulose that could be utilized as a substitute raw materials source Banana fibers are an alternative to synthetic fibers for reducing pollution of environmental and owing to their excellent characteristics, which include effective cost, light weight, and biodegradable (Kumar *et al*., 2019). The banana fibers can be extensively used for industrial reinforcement materials. The commercialization and industrialization of the fibers extracted from pseudo-stem produces an important potential for monetary gains in cottage textile and paper industries to boost circular bio-economy (Jirukkakul *et al*., 2020). Consequently, scientists are experiencing for its potential utilization in manufacturing of textiles cottage carpet and papers ecofriendly applications. Initiating their waste enterprises in banana fields as women driven handicrafts, rope manufacture, fiber and fabric manufacturing and many others can assist it young girls and women in rural Sindh for improving their current economic conditions a better livelihood. The elevated contents of cellulose which are present in ramie bamboo, hardwood, jute, softwood, and other plant materials allow them to all be used in the production of biodegradable tissue paper in industry. As of elevated cellulose contents plant material, the pseudo-stem of banana plants is a best raw material for biodegradable tissue paper production (Khan *et al*., 2014).

Major morphological banana fiber properties make it blend easily with various other fibers or materials. From textile point of view, sustainable fiber relates to utilization of ecofriendly technologies for production of fabric that entails proposed green circular bio-economy (Ramachandran *et al*., 2022). It will benefit growers by applying and have additional income by extracting and selling banana pseudo-stem (Balda *et al*., 2021). Consequently, by fibers of banana, many kinds of fabric, such as household textiles technical, can be made. Ease in procumbent and abundance local in nature made them potential applications. Banana fiber has enormous potential as basement structure of various green composite requirements, as plastic is pollutant. It is mainly due to banana fiber has best absorption and strengthen capacities. Therefore, for sustainable cost-effective and ecofriendly substitute beneficial for synthetic natural fibers. Major bottlenecks to the commercial utilization of banana fiber are the climate suitable production necessary for responsible extraction of high-quality fiber from the pseudo-stem. Major utilizations are eco-friendly, plastic-free pollution masks N95, Personal Protections kits; eco carry handbags; eco-friendly fabrics and clothing, down carpets, and green mattresses; and use in the production of artisans and crafts technology. Future utilizations for fiber of banana could determine properly in days to come (Sangamithirai and Vasugi 2020).

CONCLUSION

New technologies and composites based on natural and sustainable fibers have been developed as a result of concerns about the world's changing climate and the growing need for creative solutions. The main component of the fiber that is removed from bananas is cellulose, which is made up of pectin, hemicellulose, and lignin. The morphological and structural characteristics of banana fiber is similar to those of bamboo and jute. Compared to many technologies, fiber extraction and technical methods using a raspador machine are preferred. Degumming is mainly optional when it comes to fiber quality, and the natural fibers that are utilized most successfully come from resources like naturally must have important attributes.

CONFLICT OF INTEREST

The authors have not declared any conflict of interests.

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