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Smart Processing Of Agro-Waste Into Textile Bast Fibers

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Abstract
The aim to lessen environmental effects and support circular economics is causing a radical change in the global textile sector towards sustainable methods. Making textile grade bast fiber from agriculture waste is one creative strategy that is gaining popularity. Banana Stem, Okra stalk, Flax shives, hemp hurd and sugarcane bagasse are example of lignocellulosic leftovers that are used in this process but are usually thrown away after harvest, creating disposal issues and causing environmental damage. These cellulose and hemicellulose rich agro residues have a lot potential as sustainable raw materials for the production of bast fiber. The feasibility of using agriculture waste as a source of bast fibers for textile applications is investigated in this study. By contrasting them with conventional bast fibers like jute and flax, the mechanical, physical, and chemical characteristics of fiber made from different agro wastes are highlighted.
The result show that some agriculture waste offer better biodegradability and cheaper cultivation inputs while performing on par with or even better than conventional fibers. By valuing agricultural by products, the incorporation of these fibers into textile value chain may boost rural economics and lessen reliance on virgin raw resources. This study emphasizes the increasing potential of agricultural waste in the production of bast fibers, offering a viable route to more environmental friendly textiles and encouraging advancements in the materials engineering, fiber science, and agronomy. To confirm the economic and environmental benefits of these substitute fibers, further studies should concentrate on lifespan evaluations, composite fiber mixing and industrial scale processing techniques.
Keywords: *Agricultural waste, bast fibers, Sustainable textiles, Lignocellulosic fiber*

INTRODUCTION

Despite being essential to both economic growth and day-to-day living, the global textile sector is also one of the biggest causes of environmental deterioration. There is an urgent need to shift to more environmental friendly activities due to growing awareness of pollution, climate change, and unsustainable resource usage. Using agricultural waste to produce bast fibers is one viable alternative; this is a circular and sustainable method that is consistent with the ideas of green manufacturing. (Atchison, 1976).
High tensile strength, durability, and biodegradability are attributes of bast fibers, which are usually obtained from the phloem or "inner bark" of the plants including flax, jute hemp, and Kenaf. These fibers have historically been grown for industrial and textile uses. However, new opportunities for obtaining bast like fiber from agricultural residues farming byproducts that are frequently wasted or underutilized have been made possible by recent developments in material science and fiber processing. Once regarded as garbage, agro-waste resources including banana pseudostems, okra stalks, sugarcane bagasse, and flax straw have demonstrated significant promise as raw materials for the production of bast fiber.
This innovation reduces the industry's reliance on synthetic or water intensive natural fiber like cotton by addressing the problem of agriculture waste disposal, which increases greenhouse gas emission and land pollution. At the same time, it offers a substitute source of renewable textile fibers. Additionally, turning these leftovers into useful fibers opens up new business prospects, particularly in rural and agricultural areas.
The viability, methods, and uses of turning agricultural waste into textile grade bast fibers are examined in this research. It examines the extracted fibers mechanical and structural characteristics, assesses their environmental advantages from a life cycle standpoint, and contrasts their performance with that of traditional bast fibers. The textile industry may transition to a more robust, sustainable, and circular future by utilizing agricultural waste in this matter.

A Source of Bast Fibers from Agriculture Waste

A large, untapped resources with substantial promise for the manufacture of sustainable materials is agricultural waste. Every year, enormous amounts of biomass are produced worldwide as agriculture cultivation byproducts; a large portion of the biomass is either burned or allowed to degrade in the field, which pollutes the environment. The extraction of bast fibers long, robust, and cellulose rich fibers found in the phloem tissue of some plants is one of the waste's most promising applications.

Pearl millet, Sugarcane, bananas, flax, hemp, okra, and flax are common crop that produce a lot of stem or stalk residue after harvest. Because of their naturally lignocellulosic content a compound of cellulose, hemicellulose, and lignin, these wastes are structurally appropriate for being turned into fibers of textile quality. In order to seprate and purify the fibrous material, these fibers are usually extracted via mechanical decoration, alkaline chemical treatment, or retting (the biological or chemical breakdown of pectin).

For example, pearl millet (*Pennisetum Glaucum)* plant's stems, which are frequently thrown away after milled is harvested, have between 4 to 5% of their weight in useable fiber. These fibers are well known for being compatible with natural colors, biodegradable, having a moderate tensile strength. In a similar vein, the stalks of okra (Abelmoschus esculentus), a commonly disregarded agriculture waste, produce bast fiber that are as fine and have tensile properties as commercial fiber like flax and jute.

In addition to reducing the environmental costs of disposing of agro-waste, using such agricultural leftovers for fiber extraction promotes resource efficiency and the ideas of the circular economy. Decentralized and environmentally friendly fiber manufacturing is also promoted by turning waste into value added products, which open up new revenue streams for farmers and rural processing facilities.

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METHODS OF FIBER EXTRACTION

One of the most important processes in turning lignocellulosic biomass into useful textile materials is the extraction of bast fibers from agricultural waste. Fibers are separated from non-fibrous plant materials including lignin, pectin and hemicellulose in this process. The quality, yield, and environmental sustainability of the final fibers are all greatly impacted by the choice of extraction technique. The method may be broadly divided into four categories: mechanical, chemical, biological, and thermomechanical.

1. Mechanical Decortication

A popular first step in fiber recovery is mechanical decortication, which works especially well for large stemmed plant like hemp and bananas. In order to separate the fiber bundle frim the woody core, the outer layers of the stem are crushed or scraped using rollers, blades, or hammer mills. Although this process is quick and economical, it frequently produces coarse fibers that need to be further refined to increase their softness and spinnability.

2. Water or Enzymatic Retting

Water retting is a biological process that breaks down the pectins that hold the fiber bundles to the surrounding tissues by using natural microbial activity. Enzymatic retting, on the other hand, speeds up the procedure under carefully monitored circumstances by using commercially available enzymes, such as cellulases and pectinases. Because it uses less water and chemicals and yields consistent, high quality fibers, enzymatic retting is regarded as ecologically friendly. It may more expensive than conventional retting methods.

3. Chemical Retting (Alkaline or Acid treatment)

Soaking agricultural waste in solution of hydrogen peroxide, Oxalic acid, or sodium hydroxide (NaOH) is known as chemical retting. These substance liberate the bast fiber by dissolving the lignin and hemicellulose matrix. Chemical retting offers higher yield and cleaner fibers, but it also has serious negative environmental effects, such as chemical runoff and excessive water use, which calls appropriate waste water treatment systems.

4. Steam Explosion and Microwave-Assisted Extraction

These thermomechanical methods are becoming more and more well liked because of their effectiveness and capacity to process biomass with high moisture content. Steam explosion breaks down cell walls promotes fiber separation by exposing plant materials to high pressure steam and then abruptly decompressing them. In a similar vein, microwaves assisted processing breaks chemical bonds in lignocellulosic materials using electromagnetic radiation. Both approaches needs specialized equipment yet are quick, energy-efficient, and generate little chemical waste

Characterization of Extracted Fibers

To determine if bast fibers taken from agricultural waste are suitable foe textile application, it is crucial to characterize them. These descriptions shed light on the mechanical, structural, thermal, and surface characteristics of the fibers, which affect how well they spin, dye, and create fabrics.

The following are the most often evaluated parameters:

1. Tensile Strength and Elongation

The fiber's resistance to breaking under tension is determined by its tensile strength, whereas its elongation signifies its flexibility. Under controlled circumstances, Universal Testing Machines (UTMs) are used to assess these mechanical attributes. Banana fiber, for instance, has a tensile strength between 400 and 600 MPa, which puts it in the same class as more conventional bast fibers like hemp and jute. Despite being less well known, okra fibers are very fine and flexible, which makes them appropriate for spinning operations where they may be blended with cotton or rayon.

2. Moisture Regain Capacity

This charaterstics, which is essential for comfort and processability, gauges the fiber's capacity to absorb moisture from the air. The breathability of bast fibers in fabric application is attributed to their normal moisture regain rates of 10-13%. The fibers of banana and okra absorb moisture well, which improves dye absorption and mixing characteristics.

3. Crystallinity Index (via XDR)

The crystallinity index (CI), which influences the stiffness and thermal characteristics of fibers, is found via X-ray diffraction (XDR). More organized cellulose structures, which are usually present in bast fibers, are indicated by high CI. The semi-crystalline nature and mechanical toughness of banana and flax bast fibers are demonstrated by CI values, which range from 50% to 65%.

4. Thermal Stability (via TGA/DSC)

Differential Scanning Calorimetry (DSC) and Termogravimetric Analysis (TGA) shed light on the stability and degradation of fibers in hot environments. Because they break down between 220°C and 350°C, the majority of lignocellulosic bast fibers are stable enough for routine textile processing. The fiber of hemp and bananas exhibit multistage heat breakdown because of their intricate cell wall components.

5. Surface Morphology (via SEM)

SEM, or Scanning electron microscopy, aids in the analysis of the fiber surface uniformity, diameter, and topography. Better spinnability and fabric feel are provided by fiber with tiny diameters and smooth, consistent surfaces. In contrast to mechanically processed banana fibers, which could still include impurities or lignin residues, SEM pictures of chemically retting banana fibers frequently show a more polished and clean surface.

Comparison with Traditional Bast fibers

It is crucial to compare the qualities of agriculture waste-derived bast fibers to those of well-known commercial bast fibers like jute flax in order to assess their feasibility for use in textile applications. Tensile strength, elongation, moisture recovery, biodegradability, and source sustainability are among the important mechanical and functional characteristics that are compared in the table below:

Property	JUTE	FLAX	BANANA	OKRA
Tensile strength (MPa)	400-500	500-900	400-600	450-750
Elongation (%)	1.5-1.8	2.5-3.5	1.8-2.1	2.2-2.8
Moisture Regain (%)	12.5	12.0	11.0	13.0

Biodegradability	High	High	Very High	Very High
Source Sustainability	Cultivated	Cultivated	Waste-drived	Waste-derived

The results show that the mechanical properties of okra and banana bast fibers are similar to those of flax and jute. Okra fibers in particular exhibit exceptional elongation and tensile strength, which makes them very versatile for usage in woven technical fabrics or mixed yarns. In a comparable manner, banana fiber show sufficient strength and reduced moisture recaptures while being significantly coarser, which may be useful in textile applications that are sensitive to moisture.

Agro-waste fibers have clear benefits from an environmental standpoint. Banana and okra fibers are derived from post harvested agriculture waste, which makes intrinsically more sustainable and cost effective than jute and flax, which need specialized land, water and agrochemical inputs. Additionally they have equally high or better biodegradability ratings, which increases their attractiveness in the nonwoven, packaging and sustainable clothing industries.

The potential for agricultural bast fibers to function as sustainable alternatives or supplements to conventional bast fibers is highlighted by this comparative analysis. They might play a major role in the shift to a circular and bio based textile industry with the right processing technology and supply chain integration.

CONCLUSION

In the textile business, turning agriculture waste into bast fibers offers a creative and sustainable substitute for traditional fiber sources. According to this study, agro-residue like okra stalk and banana pseudostems have potential mechanical and structural properties that are on par with or better than those of conventional bast fibers like jute and flax. High quality fibers may be removed with little impact on the environment by using techniques including mechanical decortication, retting and sophisticated thermomechanical treatments.

Agro waste fibers have the necessary tensile strength, flexibility, moisture absorption, and biodegradability, according to fiber characterization, which makes them appropriate for a variety of uses, including industrial textiles and clothing. Utilizing waste products also lessens the burden of agricultural disposal, supports the circular economy, and opens up new business options for rural areas. Future studies should concentrate on establishing pilot scale decentralized fiber extraction systems, standardizing quality control for fibers blends, and refining enzymatic and low energy processing methods. Agricultural bast fibers have the potential to significantly alter the sustainability profile of the textile industry if they are successfully scaled.

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