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MESTA FIBER (HIBISCUS SABDARIFFA): A REVIEW OF ITS PROPERTIES, APPLICATIONS, AND ROLE IN PROMOTING SUSTAINABILITY

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Abstract
The increasing world demand for eco-friendly natural fibers and products is gaining interest in sustainable fibers as alternatives to man-made fibers. Bast fibers such as linen, banana, jute, bamboo, sisal, kenaf, and Mesta have been used for a long time. Bast fibers are the raw materials of the present and the future, not just for textiles but also for modern eco-friendly composite materials, medicine, cosmetics, food, biopolymers, agro-fine chemicals, and energy. The retting is the biggest problem with extracting the fibers. Dew retting as well as stagnant water and running water retting are the conventional methods to separate the long bast fibers. Due to higher tensile property, mechanical performance, environmental benefits, and economic viability, Mesta has shown significant promise compared to synthetics. They can be grown in numerous climates, and, under the right conditions, they don't hurt the ecology too much or at all. The study looks into the important physical and mechanical properties and benefits of Mesta fibers, as well as their possible uses. It focuses on how they might help promote sustainable consumption and green industrial practices. The review talks on Mesta's environmental, technical, and social-economic importance, showing that they are still crucial for accomplishing ecologically sustainable development goals and coming up with novel bio-based materials.

Keywords: *Mesta fiber, Hibiscus sabdariffa, Natural fibers, Eco-friendly textiles, Fiber characterization, Sustainable consumption, Biodegradable materials*

Introduction

Sustainable Natural Fibers

Figure 1: Sustainable Natural Fibers

Growing concerns about climate change, environmental degradation, and the depletion of nonrenewable resources have prompted a global shift toward sustainable materials in all industries, including textiles and composites. There is growing recognition of the environmental advantages of natural fibers derived from plants, animals, or minerals, including their biodegradability, renewability, low carbon footprint, and lower processing energy consumption (11, 12).

Sustainable natural fibers, particularly those derived from plants like cotton, flax, hemp, jute, kenaf, coir, bamboo, and lesser-known bast fibers like ramie, banana, and Mesta (Hibiscus spp.), provide a competitive alternative to synthetic fibers in a variety of applications. The main constituents of these fibers-cellulose, hemicellulose, lignin, and pectin-retain their mechanical properties and are compatible with biodegradable polymers (2, 14). Their potential for the development of a bio-based economy is demonstrated by the use of these fibers in the manufacturing of textiles, packaging materials, auto parts, and bio composites (6, 7).

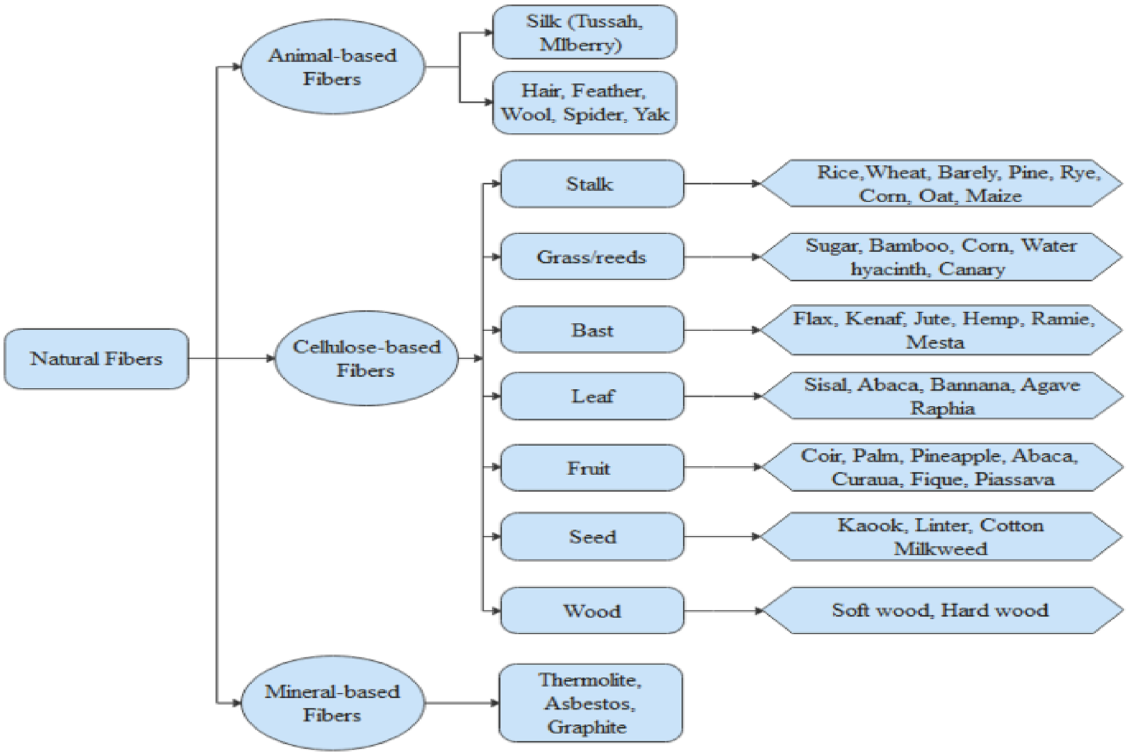

Figure 2: Types of Natural Fibers

People are interested in sustainable natural fibers since they don't hurt the environment too much over their whole life cycle. Natural fibers don't need as much energy to develop and manufacture as synthetic fibers generated from oil. Often, they cultivate crops with minimal input or agricultural waste, even in poor soil conditions (8). Life cycle assessments (LCA) of natural fiber composites have shown that they are better for the environment because they produce fewer greenhouse gases, use less energy, and are easier to get rid of when they are no longer useful, especially when they are combined with biodegradable matrices (17). Natural fibers also benefit rural economies by producing jobs and contributing value to agro industrial chains. Fibers cultivated, gathered, and processed utilizing labor-intensive, low-cost technologies provide significant socioeconomic benefits, especially in poor nations (16). Natural fiber production's decentralized structure also aligns well with the Sustainable Development Goals (SDGs), particularly those focusing on equitable economic growth, climate action, and responsible consumption (20).

Recent improvements in fiber processing, chemical and enzymatic treatments and hybrid material design have made sustainable fibers more useful and competitive with synthetic alternatives. Researchers have also looked at using regenerated cellulose fibers such as viscose, Lyocell, and modal manufactured from sustainable forestry resources. These fibers are biodegradable like natural fibers, but they are also more consistent and easier to work with (18).

Despite their potential, there are still challenges in ensuring the consistent quality, scalability, and moisture resistance of natural fibers. However, innovation and investment in this field are still driven by the convergence of technological advancements, market demand, and environmental urgency (5). Sustainable natural fibers can therefore hasten the transition to greener materials and circular manufacturing.

Mesta (Hibiscus sabdariffa)

Natural fibers have gained increasing attention due to their biodegradability, renewability, low cost, and reduced environmental impact. Among various bast fibers, *Mesta*, derived from *Hibiscus sabdariffa* and *Hibiscus cannabinus* (commonly referred to as Roselle and kenaf, respectively), is an important source of lingo cellulosic fiber cultivated extensively in India, Bangladesh, and parts of Southeast Asia (14). Mesta encompasses both species, though *H. sabdariffa* is particularly recognized for its dual-purpose utility in fiber and food applications (4).

Figure 3: Mesta Natural Fibers

Hibiscus sabdariffa is an annual or biennial shrub from the Malvaceae family. It is mainly cultivated for its bast fibers, which come from the stem's outer bark. Fibers are conventionally removed using water or dew retting, followed by physical stripping. Mesta fiber is well-known for its significant moisture absorption, moderate strength, light weight, and potential use as a reinforcing ingredient in textiles and bio composites (15, 16). Compared to jute and flax, mesta/rosella is better suited for frontier areas due to its shorter cultivation cycle and increased adaptability to various agricultural climates (7). Numerous studies have assessed the physicochemical characteristics of Mesta fiber.

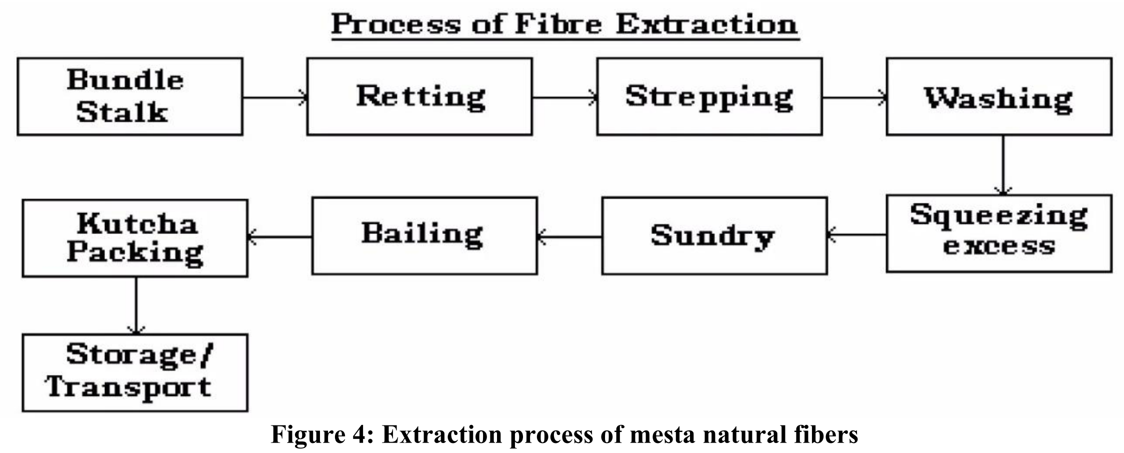

Figure 4: Extraction process of mesta natural fibers

Most Mesta fiber is grown in eastern states like West Bengal, Bihar, Assam, and Odisha, making India one of the world's top producers. (9) According to the Ministry of Textiles, Government of India (2020), the Mesta is essential to small and marginal farmers' livelihoods, especially in regions where jute cultivation is not feasible. Apart from its fiber yield, H. sabdariffa yields valuable by-products like leaves used in traditional medicine, seeds for oil, and calyces used in food and beverages (1). Numerous studies have assessed the physicochemical characteristics of Mesta fiber.

It consists mainly of cellulose (~55–70%), hemicellulose (~15–25%), and lignin (~10–20%), which gives it sufficient strength and stiffness for use in composites (2, 10). Recent research has also focused on enhancing the performance of Mesta fibers through chemical, enzymatic, and mechanical treatments to make them more suitable for high-value textile and industrial applications (5). With growing interest in sustainable materials, Mesta fiber is being increasingly considered in the development of eco-friendly textiles, reinforced composites, insulation panels, and packaging materials. Its potential to replace synthetic fibers in a range of applications aligns with global efforts toward circular economy and sustainable development (12).

Characteristics and Properties of Natural Fibers and Mesta Fiber

1. Overview of Natural Fiber Properties

The plant-extracted fibers are popularizing day by day because of the properties they have, such as being biodegradable, renewable, and having environmental benefits. The impact of the physical, thermal, and chemical properties of plant fibers will be predicted based on the source of the plant, environmental conditions, and harvesting and extraction parameters (10,16). These fibers are mostly made up of cellulose, hemicellulose, lignin, and small quantities of waxes and pectin. Cellulose is the major component that gives them strength and rigidity. Natural fibers have the following properties: low density and high specific strength; effective thermal insulation; they can break down and be used again; they have moderate mechanical strength; they can absorb moisture in different amounts and stay stable in size; they have a rough surface; and they affect how well composites bond at their interfaces. However, natural fibers do have certain issues, including their hydrophilic nature, inconsistent quality, and sensitivity to environmental conditions. These problems require surface treatments to make them work better in textiles and composites (5).

2. Mechanical and Physical Properties of Common Natural Fibers

The mechanical behavior of natural fibers varies depending on the botanical source. The below table summarizes key mechanical and physical properties of commonly studied fibers:

Table 1: Mechanical and physical properties of natural fibers

Fiber	Density (g/cm³)	Tensile Strength (MPa)	Young's Modulus (GPa)	Elongation at Break (%)	Reference
Cotton	1.50	287–597	5.5–12.6	3–10	14
Flax	1.50	345–1500	27.6	2.7	2
Jute	1.46	393–800	10–30	1.8	10
Hemp	1.48	550–900	30–70	1.6	16
Ramie	1.50	400–938	20–128	1.2–3.8	14
PALF	1.50–1.55	170–1627	82–106	1.6–3.0	3

Natural fibers are appropriate for lightweight composite applications as they have a higher specific stiffness-to-weight ratio as well as a lower tensile strength than synthetic fibers.

3. Characteristics and Properties of Mesta Fiber (Hibiscus sabdariffa):

Mesta is a bast fiber that is moderately strong, biodegradable, and cheap. It is usually manufactured from the stem bark of the Hibiscus sabdariffa plant. Mesta hasn't been studied as much as its cousin kenaf (Hibiscus cannabinus), although it has similar or slightly worse mechanical performance. It also has added benefits, such as shorter growth cycles and the opportunity to employ different plant components (1).

3.1 Physical and Mechanical Properties

The physical properties of Mesta fibers make them suitable for applications in textiles, composites, paper, and insulation. Reported average values are:

Table 2: Physical and Mechanical Properties of Mesta fiber.

Property	Value	Reference
Density	1.40–1.50 g/cm³	14
Fiber Length (after retting)	1.0–2.5 meters	1
Diameter	20–30 µm	13
Tensile Strength	400–600 MPa	16
Young's Modulus	10–20 GPa	19
Elongation at Break	1.5–2.5%	5
Moisture Regain	12–14%	14

3.2 Surface Morphology and Microstructure

According to SEM images, Mesta fibers have an uneven, rough surface with longitudinal grooves and micro fibrillar bundles. Unless surface treatment or blending is done, these inherent surface flaws may make textile spinning more difficult to handle, but they also improve mechanical interlocking in composites (5). Usually oval or polygonal in shape, the cross-section has a hollow lumen that helps reduce density and improve thermal insulation.

3.3 Thermal and Acoustic Properties

The first indications of thermal degradation in Mesta fibers occur between 230 and 250°C, indicating their intermediate thermal stability. This is believed to be due to the breakdown of hemicellulose. Cellulose typically begins to break down at 300°C and peaks between 350°C and 360°C.These thermal characteristics are satisfactory enough for making thermoplastic composites and some nonwoven products (13). Mesta's hollow microstructure also makes it a strong sound absorber and insulator.

3.4 Chemical Composition

The chemical makeup of Mesta influences its mechanical strength, biodegradability, and response to chemical treatments. Typical chemical composition is as follows:

Table 3: Chemical composition of Mesta Fiber.

Component	Mesta (%)	Reference
Cellulose	55–70	14
Hemicellulose	15–25	16
Lignin	10–20	1
Pectin, Wax	2–3	5

The cellulose gives it strength, while the hemicellulose and lignin make it flexible and resistant to breaking down by microbes. But too much lignin can make fabrics and composites more brittle and yellow.

3.5 Limitations

Despite the advantages of Mesta fiber, it is not identical as it is compared to other industrially optimized stem fibers such as linen. Because of Mesta fiber variability, it requires optimum selection of the retting, scouring, processing, and spinning processes. In addition, application of proper enzymes and chemical treatments is essential to enhance the hydrophilicity property of the fiber (7).

Role of Mesta Fibers in Sustainable Consumption

Fast-growing annual bast fiber crops, kenaf (Hibiscus cannabinus) and mesta (Hibiscus sabdariffa), are indigenous to tropical and subtropical areas, including Southeast Asia and India. Due to their high biomass yield, minimal environmental impact, and broad range of applications in the paper, textile, and composites sectors, these plants are becoming increasingly acknowledged as sustainable substitutes for synthetic and resource-intensive natural fibers (1, 14).

Mesta is annual bast fiber crops that grow mostly in tropical and subtropical climates. In India, people call both Hibiscus cannabinus and Hibiscus sabdariffa "Mesta." People like these fibers since they don't hurt the environment much, are strong and light, and can be used again and again (10, 14). Mesta fibers are lingo cellulosic and fully biodegradable in the natural environment, unlike synthetic fibers. This means that things made from them do not add to the problem of micro plastic pollution (7). Because of this trait, they can be utilized in one-time and throwaway items like packaging and geotextiles, where being able to break down naturally is important for reducing environmental impact. Kenaf and Mesta have been moved up the list of good alternatives to synthetic fibers and natural fibers that aren't good for the environment, like cotton and jute, because more people want products that break down naturally and are good for the environment (1).

Renewable and Rapidly Grown Resource

Mesta is renewable, annual crop that need fewer pesticides, fertilizers and lower maintenance to grow compared traditional fiber crops like cotton (10). Because they develop quickly (harvestable in 4–5 months), you can plant them numerous times a year in favorable conditions. This way it enhances the better usage of farming land and achieves sustainable farming (16).

Biodegradability and End-of-Life Benefits

Mesta fibers are lingo cellulosic and fully biodegradable under natural conditions, which means the products made from these fibers do not contribute to persistent micro plastic pollution, unlike synthetic fibers (7). This property makes them suitable for single-use and disposable applications (e.g., packaging, geotextiles) where biodegradability is crucial for environmental impact reduction.

Carbon Sequestration and Low CO_2 Emissions

Mesta grows and absorbs carbon quickly, taking in more CO_2 than many other crops. This is why they are advantageous carbon sinks in life cycle assessments (LCAs) of bio-based products (13). Using mesta-based composites in the automotive, construction, or packaging industries also means that fewer resources come from fossil fuels, which helps minimize the overall carbon footprint (5).

Minimal Water and Chemical Use Compared to Cotton

Growing cotton demands huge amount of water and sometimes relies on chemical fertilizers and pesticides. Mesta, on the other hand, usually grows better with less water and fewer chemicals, which makes it an excellent choice for areas where water is scarce or the environment is sensitive (14, 1). Their compatibility with organic farming practices is another way they help sustainable agriculture.

Waste Valorization and Circular Economy

Mesta farming is more than just fibers, also with core biomass and leaves can be utilized for bioenergy, animal feed, as well as compost. This zero-waste potential fits with the ideas of a circular economy and makes their sustainability value chain stronger (10, 11).

Social and Economic Sustainability

Growing demand of Mesta fibers increases opportunities in Mesta farming, fiber retting, fiber extraction, and fiber processing. Promoting these crops helps smallholder farmers, gender-inclusive labor practices, and regional bio economies. These are all important parts of SDG 12 (UN Sustainable Development Goals) for sustainable consumption and production patterns (20).

Application in Eco-Friendly Products

Researchers are investigating the potential applications of mesta fibers in various environmentally friendly products, including natural fiber-based biocomposites, packaging that decomposes naturally, insulation that retains sound and heat, and textiles made of cotton or other natural fibers (19). When products function well but have less environmental impact, the transition to greener materials becomes simpler.

Figure 5: Applications of Natural Fibers in various sectors

Economic Potential

a. Market Viability and Value Addition

Mesta has minimal production costs and a high potential return on investment because they may be used in so many ways (13). Kenaf industries have been marketed around the world with the support of government programs in countries like China, Malaysia, and Thailand. The Central Research Institute for Jute and Allied Fibres (CRIJAF) and the National Jute Board in India want mesta to flourish as a jute alternative and for other fiber uses.(9)

b. Employment and Rural Development

Mesta cultivation and processing support rural employment, especially for smallholder farmers, women, and cottage industries. Value-added activities such as retting, spinning, weaving, and composite manufacturing provide income generation opportunities and stimulate local economies (1).

c. Export and Industrial Integration

For the paper pulp and fiber-based composites industries, kenaf and Mesta are becoming commodities worth exporting. Their application in biodegradable packaging, automotive components (such as dashboards and insulation), and green building materials complies with international environmental standards and opens up new markets (5, 7).

Future Prospects

a. Blended Textile Innovation
Blending of Mesta with natural fibers like cotton or regenerated fibers such as voscose, modal can improve the handle, thermal, mechanical and comfort properties of fabrics and makes them suitable to utilize in sustainable technical textiles clothes. (19).

b. Bio-composite Development
Biodegradable composites, strengthened by PLA, PHB, and recycled polymers, incorporate Mesta. The goal of these bio-based composite materials is to be utilized in Automobile interiors, furniture and packaging industries (10, 11, 2).

c. Policy and Investment Opportunities
The UN's Sustainable Development Goals (SDGs) have led to a greater focus on natural fibers for climate resilience, a circular economy, and green industrialization. Mesta can attain their full economic potential in both the domestic and international markets if they make smart investments in fiber research, value chains, and marketing (20).

Conclusion
Mesta (Hibiscus sabdariffa and Hibiscus cannabinus) are two eco-friendly fibers that are essential for the environment, economy, and industry. Their rapid growth, high yield, low water and chemical consumption, and biodegradability are the key resources for scaling and promoting sustainable products. As Mesta is an eco-friendly alternative to conventional fibers like jute, cotton, and synthetics, it offers moderate to high mechanical properties suitable for a wide range of applications from textiles and packaging to automotive composites and green geotextile materials. These bast fibers are very important for rural development and sustainable consumption. Growing them on marginal lands increases agricultural production without competing with food crops. Extracting and processing of Mesta fibers offers jobs in many rural places and supports small scale farmers and rural craftsmanship of village people to generate revenue. Moreover Mesta exits multifunctional potential it can provide not only fiber for textile applications but also tasty calyces, medicinal leaves, and oil-rich seeds. Recent improvements in fiber extraction, post extraction fiber treatments, and composite technologies have made Mesta even more useful in high-performance applications. Because of echo - friendly production, sustainability certification, regulatory support and rising consumer demand for sustainable products Mesta stands in good position and it is playing a vital role in world. In short, Mesta is not just alternative to traditional fibers; they are essential to the future of sustainable industry since they can help the environment while also boosting the economy and society.

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