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From Waste to Wealth: Unlocking the Potential of Bangladesh's Okra Fiber for Economic Prosperity

Bashir Ahmed[1], Md. Ahshan Habib[2*], Md. Shamsul Alam[1], Kamrul Hasan Bhuiyan[2], Md. Golam Rabbani[2], Md. Tajbir Husain[1]

[1]Department of Apparel Manufacture & Technology (AMT), Sonargaon University, Dhaka, Bangladesh
[2]Department of Fashion Design & Technology (FDT), Sonargaon University, Dhaka, Bangladesh
Email: *habib.fdt@su.edu.bd

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Abstract

Bangladesh's thriving okra cultivation sector annually yields substantial harvests, yet a significant portion of the plant remains underutilized after harvesting, posing as agricultural waste. This oversight neglects the economic potential of okra fiber, which is versatile and valuable across various industries. This paper explores this untapped potential by investigating the physico-mechanical properties, chemical treatments, and fabrication techniques of okra fiber, drawing from a wealth of research. Comparative analyses with established natural fibers like jute and sisal shed light on okra fiber's transformative role in Bangladesh's economic landscape. Along with the applications in the fashion world, meticulous investigation into its mechanical, thermal, and morphological characteristics uncovers inherent strengths and integration pathways into industrial applications. Strategies for optimizing yield and quality, including novel approaches like photo-grafting and protein extraction, are explored. Considerations for cytotoxicity and environmental sustainability ensure its viability as a green resource. This research aims to unlock okra fiber's full potential, positioning Bangladesh for sustainable economic development and innovation.

Keywords

Okra Fiber, Agricultural Waste, Industrial Applications, Fabrication Techniques, Environmental Sustainability, Biomass Utilization

1. Introduction

Around the world, there is a growing shift toward sustainable resources as we search for alternatives to synthetic materials that harm our environment. Natural fibers like jute, sisal, and flax have gained widespread attention for their environmental benefits. However, another potential resource, okra fiber, remains almost untouched. This oversight is particularly relevant for Bangladesh, where okra farming is extensive, and a significant portion of each harvest primarily the stalks goes to waste. By tapping into this underutilized resource, Bangladesh could not only reduce agricultural waste but also create new economic opportunities for rural communities.

This study explores two important questions that could reshape how we view okra fiber in both industrial and environmental contexts:

- How does okra fiber perform when compared to established fibers like jute and sisal in terms of strength, flexibility, and durability?
- What are the potential environmental and economic benefits of integrating okra fiber into Bangladesh's industries, especially for sustainable product development?

Previous research has shed light on the remarkable qualities of natural fibers like jute and sisal, which have become key players in sustainable industries. Yet, despite its high cellulose content and impressive physical properties, okra fiber hasn't received the same level of attention. Only a handful of studies have explored its potential, and few have examined it in depth within Bangladesh, where we are one of the world's top producers of this vegetable plant.

This study stands apart by offering a comprehensive look at okra fiber's properties, comparing them with those of well-established natural fibers and considering how these fibers could benefit Bangladesh's push for sustainability. By examining new chemical treatments and fabrication methods, this research aims to make okra fiber a serious contender in the world of sustainable materials. Ultimately, our goal is to turn an overlooked agricultural byproduct into a valuable resource that supports both economic growth and environmental well-being in Bangladesh.

2. Objectives of the Study

- ✓ Examine the unrealized potential of Bangladesh's okra fiber.
- ✓ Examine the morphological, mechanical, thermal, and physical characteristics.
- ✓ Compare the fiber from okra to well-known natural fibers like sisal and jute.
- ✓ Examine textile, composite, and other industrial uses.
- ✓ Research spin ability both on its own and in combination with other fibers.
- ✓ Think about sustainability—both in terms of the environment and the economy.
- ✓ Draw attention to okra fiber as a useful and sustainable resource.
- ✓ Convert agricultural waste into a thriving economy.

3. Literature Review

According to data from FAOSTAT, Bangladesh's okra production surged to

85,233 metric tons in 2022, marking a significant increase of 21.8% compared to the preceding year. This represents the highest production level on record for the country, with the lowest recorded output standing at 54,183 metric tons in 2019. Bangladesh ranks 8th among the 46 countries monitored in terms of okra production [1]. **Figure 1** displays the chart where you can check the top 10 okra producing countries and Bangladesh is in the 8th position in global production according to FAOSTAT.

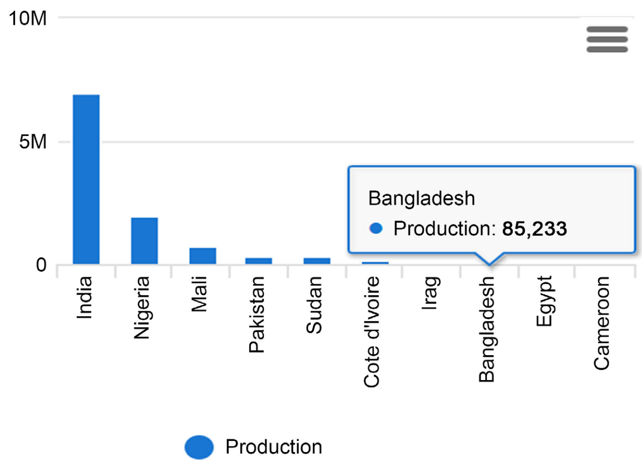

Figure 1. FAOSTAT—okra production statistics and ranking of Bangladesh [1].

Though we are using okra as a vegetable, now the question is, what about the plants after harvesting okra? The answer is that it's being burned for cooking as fuel only and, in some cases, fed to animals. An investigation of the use of inedible plant parts after harvest was carried out in Konneripatti (Mettur) village, Edappadi, Salem, Tamil Nadu, India. The findings showed that the respondents' uses for these inedible parts were diverse. In particular, 37% of farmers used the inedible parts of food crops as fuel, while 58% of farmers used them as animal feed. Furthermore, 2% and 3% of respondents used these parts to make shelter and rope, respectively. Unfortunately, a large quantity of stems from okra plants are thrown away in the field each year without being properly used [2].

In order to investigate the important fibre characteristics, such as chemical composition, weight loss, burning behavior, and moisture content, the okra fibers were removed from the stalk of the plant after it had been treated with alkali and acid. To evaluate the morphological changes in the fibers throughout processing, Scanning Electron Microscopy (SEM) research was also conducted. To determine the presence of chemical groups in the fibers both before and after treatments, a Fourier transform infrared spectroscopy (FTIR) test was also performed. The work has shed information on how to better utilize okra fibers in textile production [2]. The results of SEM investigation show that non-cellulosic chemicals have overlapped and cemented the technical fibers. The test findings exhibit a high degree of resemblance to the physical, mechanical, and microstructural (cross-sectional and longitudinal view) features of other bast fibres [3]. **Figure 2** illustrates scanning electron microscopy (SEM) appearance cross section of okra fibres fiber morphology.

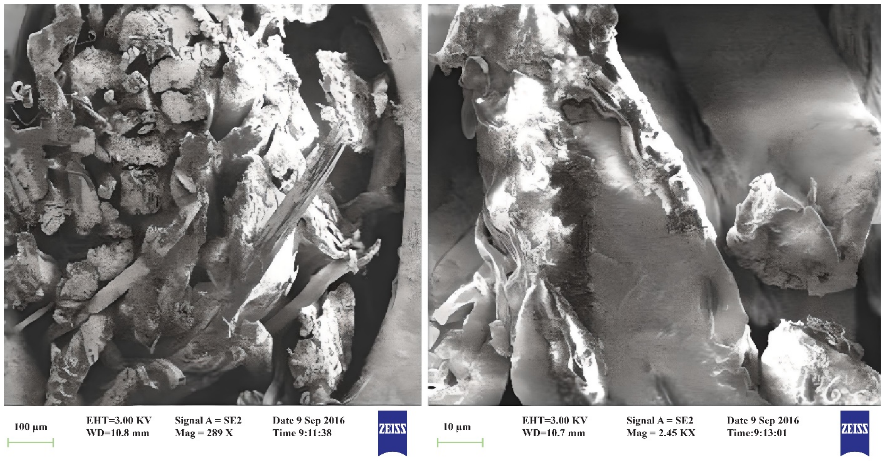

Figure 2. Scanning electron microscopy (SEM) appearance cross section of okra fibres fiber morphology [2].

Okra fibre derives from the Malvaceae family and is composed of roughly 60–70% cellulose and has good thermal characteristics, strength, and modulus [4]. Near the stem, on the outside of the plant's center, is where the fiber is located. Similar to the bark fibers of jute, kenaf, flax, and hemp, the bast fiber of okra is bright, strong, and lustrous. It may also be spun into yarn. Clusters are formed when the pectin in the plant cell wall combines with the okra fibers [5].

Below is a comparative table including come common properties of okra fiber alongside other natural fibers such as cotton, jute, hemp, and flax [6] [7].

Table 1. Common properties of okra fiber alongside other natural fibers [6] [7].

Property	Okra Fiber	Cotton	Jute	Hemp	Flax
Density (g/cm^3)	1.50	1.54	1.46	1.48	1.54
Tensile Strength (MPa)	250 - 400	287 - 597	393 - 800	310 - 700	345 - 1500
Elongation at Break (%)	4.5 - 10	7 - 8	1.7	1.6	2.7
Young's Modulus (GPa)	10 - 20	8 - 12	10 - 30	30 - 60	27 - 80
Fineness (µm)	40.50 (4 mo.), 56.12 (6 mo.)	10 - 20	17 - 20	16 - 50	12 - 18
Moisture Absorption (%)	7 - 12	7 - 8.5	10 - 16	6 - 12	8 - 12
Thermal Stability (˚C)	250 - 320	280	240	200 - 250	230 - 260
Microfibrillar Angle (˚)	10 - 20	18 - 22	8 - 10	6 - 10	5 - 10
Cellulose Content (%)	60 - 70	88 - 96	61 - 71	70 - 77	64 - 71
Lignin Content (%)	7 - 9	0 - 1	12 - 13	8 - 10	2 - 3
Whiteness (%)	48.4 (4 mo.), 43.56 (6 mo.)	80 - 85	Golden/Brown	Light Brown	White/Beige

Table 1 highlights essential characteristics such as density, tensile strength, elongation at break, moisture absorption, thermal stability, and cellulose content.

This comparison provides valuable insights into the performance and suitability of each fiber for various applications, including textiles and eco-friendly materials, helping researchers and manufacturers make informed choices based on material strength, flexibility, and sustainability. The following discussion focuses on key properties and their implications for various applications found during the preparation of the table:

- ✓ **Density:** Okra fiber has a density comparable to other bast fibers like Jute and Hemp but is slightly higher than Cotton. This indicates that Okra fiber could be suitable for lightweight applications where strength is also a priority, such as composites and lightweight textiles.
- ✓ **Tensile Strength:** Okra fiber demonstrates tensile strength within the range of many bast fibers, though slightly lower than Jute and Hemp. This suggests that while Okra fiber may not be ideal for applications requiring extreme tensile performance, it is still strong enough for moderate strength uses, such as ropes and eco-friendly packaging.
- ✓ **Elongation at Break:** The elongation at break of Okra fiber is relatively low compared to Cotton, indicating less flexibility. However, its stiffness makes it favorable for structural applications, such as reinforcement in composites.
- ✓ **Young's Modulus:** The stiffness of Okra fiber, reflected in its Young's modulus, aligns with bast fibers like Jute and Flax, making it suitable for applications that require rigidity, such as construction materials.
- ✓ **Moisture Absorption:** The moisture absorption capacity of Okra fiber is on par with Cotton but higher than other bast fibers. This property makes it ideal for hygroscopic applications, such as absorbent materials, but may also present challenges in humid environments if dimensional stability is critical.
- ✓ **Thermal Stability:** Okra fiber's thermal stability, comparable to Jute and Flax, makes it a viable option for applications exposed to moderate heat. However, its lower stability than synthetic fibers limits its use in high-temperature environments.
- ✓ **Cellulose and Lignin Content:** Okra fiber contains a significant amount of cellulose, which enhances its strength and biodegradability. The moderate lignin content suggests that it is relatively easier to process compared to fibers with higher lignin content, like Hemp, while still retaining structural integrity.
- ✓ **Microfibrillar Angle:** The microfibrillar angle of Okra fiber influences its mechanical properties. A low angle corresponds to higher tensile strength and stiffness, aligning Okra fiber with bast fibers used for reinforcement purposes.

Okra fiber has been used in very few studies. In the past, okra fiber was employed as a reinforcing filler to create composites using urea formaldehyde resin, biodegradable maize starch, poly lactic acid, and polyvinyl alcohol [8].

Researchers found that 100% okra fiber by itself cannot be spun into yarn because of its reduced elasticity after examining the spin ability of staple okra to create spun yarn. The greatest alternative technology is therefore combining with different fibers. Okra-cotton blended yarns were made and examined in a ring spinning technique by S. Vanishree [9].

On the other hand, researchers came to the conclusion that when bast fibers are blended, a lack of blend homogeneity and cohesion among fibers prevents the proportion of bast fibers in blended yarns from increasing [10] [11]. In order to satisfy the real demand in the textile weaving sectors, okra blended woven fabric can be regarded as a sustainable woven fabric because its performance fell within reasonable bounds considering the weight, thickness, air permeability, tensile strength, tear strength, abrasion, pilling, and fuzzing of the fabric. Furthermore, optical microscopic images were used to study the morphological characteristics of the fiber alignment in the structure of the woven fabric [12]. **Figure 3** shows optical microscopic images of 80% polyester 20% okra blend woven fabric.

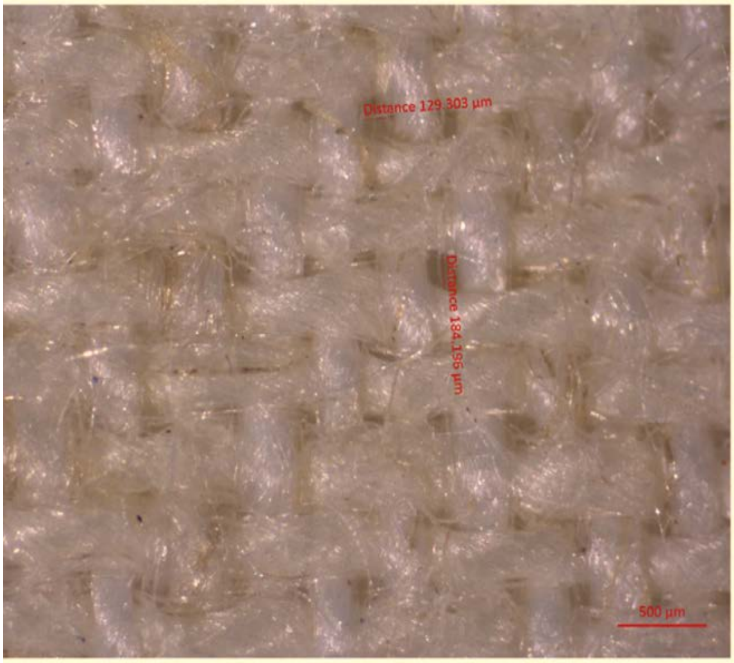

Figure 3. Optical microscopic images of 80% polyester 20% okra blend woven fabric [12].

The idea of blending states that a fabric created from blended yarns typically has better properties than a fabric created from a single fiber [13]. A combination of woven fabric made of polyester and okra had a range of acceptable qualities. Owing to its affordability and the accessibility of okra fiber, PO blended fabrics show great promise and may be able to fill the real need for blended fabrics in the textile weaving sectors [12].

A different study concentrated on producing composites made of Okra fiber (OF) with different fiber contents and polypropylene (PP) as the matrix material. Tensile, impact, and bending qualities were among the mechanical characteristics of both untreated and mercerized fibers that were methodically examined. Compared to untreated fiber composites, mechanized fiber composites showed better mechanical properties, with maximum tensile and bending strengths. With 45% fiber content, mercerized fiber composites showed optimal hardness and impact strength. Mechanical characteristics improved with exposure to different radiation. Water absorption, degradation, and interfacial characteristics were also investigated; fiber resulted in increased interfacial bonding between the matrix and fiber [14].

Potentially used as reinforcement in composite materials, okra fiber can provide special mechanical qualities when incorporated into a matrix. Okra fiber can be harvested and processed appropriately to make composites with improved tensile and flexural strengths, comparable to those made with sisal and jute fibers [15]. **Figure 4** illustrates the hybrid fiber composite (Jute, Okra, and Sisal) specimens subjected to tensile testing. Research done by using okra fiber for creating okra fiber reinforced polyester composites revealed superior tensile strength and modulus compared to pure polyester specimens [16].

Figure 4. Hybrid fiber composite specimens subjected to tensile testing [15].

In another study, researchers explored the potential of okra fiber by developing a unique woven fabric used in creating PLA bio-composites. This study found that a composite with 20% okra woven fabric exhibited the best mechanical and thermal properties, demonstrating strong fiber-matrix bonding, making okra fiber a promising green material for automotive and packaging applications [17]. Another study highlights a sustainable fabric made from 100% okra fiber, comparing it with jute fabric. Okra fabric had slightly lower tensile strength but better elongation, tear strength, stiffness, and abrasion resistance, with less shrinkage. Both fabrics, after enzyme treatment, showed improved dyeing and color fastness. This research emphasizes the potential of okra fiber as a sustainable alternative for commercial applications [18].

Researchers have focused on the potential of okra fiber as a sustainable alternative to synthetic fibers. It also reviews okra fiber's extraction process, properties, and comparison with jute fiber, emphasizing its viability for various textile applications and advocating for its cultivation to boost farmers' income while reducing greenhouse gas emissions from burning plant waste [19]. Researchers have found okra fibre as a potential material for green bio-composites [8]. Okra fibers, derived from the stem waste of okra plants, are biodegradable and exhibit high cellulose content, making them strong and suitable for polymer matrix composites. These fibers offer a sustainable alternative to synthetic materials, with good mechanical properties and color fastness, and can be further enhanced through eco-friendly chemical modifications [20]. Study's findings indicate that the most promising industries for the okra industry are primarily those that use biodegradable matrices in their short-lived goods [21]. Focusing on the scenario, it can be easily measured that how okra fibre can be used in different fields and how we are wasting a valuable natural fibre as it can be used as fuel after the extraction of the fibre from the stem of the plant and the green parts of the plant can be used as animal feed.

4. Materials and Methodology

We gathered okra plants from a farm close to Narayanganj. As per our observation, typically, the plant's stem reaches a height of between 90 and 200 cm. The harvested plants were gathered while still green, and then the extraction technique was used. Fibers were extracted using the retting process with stagnant water.

The retting procedure eliminated the hemicelluloses, sticky pectin, and waxy epidermal tissue that held the fiber bundles together. Bundled okra plants were submerged in soft water for 10 days in a concrete tank. The soft pulp was then removed from the stalks by tapping them with a wooden hammer and scraping them with a knife. The fibers were re-immersed for five more days, then washed, combed, and sun-dried for two days. **Figure 5** shows the collected okra plants. **Figure 6** shows debarking of fibre from stem. **Figure 7** shows macro view of the bark.

Figure 5. Collected okra plants subjected to extract fibre.

Figure 6. Debarking of fibre from stem.

Figure 7. Macro view of the bark.

Fiber yield was calculated as 4% of the green plant's weight using Chakma's formula. The fibers were processed by scouring, bleaching, and dyeing. Scouring used a mixture of water, sodium hydroxide, wetting agents, and detergents, maintained at pH 10.5. Bleaching involved hydrogen peroxide, soda ash, and sodium silicate, processed at 70˚C - 80˚C for 8 hours [2]. Then, Fibre was tested for several properties that proved that it is one of the best alternatives of Jute, Kenaf, and Sisal and so on. As the fibre is primarily stiff, to soften and eliminate lignin, the stiff fiber was treated with NaOH, Na_2CO_3, and H_2O_2.

In order to create yarn, treated fiber was chopped and mixed with polyester in various proportions; however, 75/25 PO yarn broke. Yarns made of polyester and flax were also ready for comparison. Using ASTM standards, characteristics of the yarn and fabric were described, including linear density, strength, mass variation, and thread density.

Under carefully monitored circumstances, the fabric's cover factor, weight, thickness, abrasion, pilling, air permeability, tensile strength, and tear strength were evaluated. All experiments were conducted under controlled conditions, and the results were tabulated for analysis [12].

It is possible to create cellulose-based films from okra fibers, offering a sustainable alternative to conventional plastics. The process begins with the extraction of cellulose from okra stems and leaves, which involves de-waxing and delignification using alkali treatments to remove non-cellulosic components. The extracted fibers are then bleached with agents like hydrogen peroxide to obtain pure cellulose, followed by thorough washing and neutralization. The purified cellulose is dissolved in a suitable solvent system, such as an ionic liquid or an alkali-stabilizer solution, or converted into cellulose acetate through acetylation with acetic acid and acetic anhydride. The resulting solution is cast onto a smooth surface to form a thin film, which is then dried to remove residual solvent or moisture. Post-processing steps may include cutting, shaping, and applying additional coatings to enhance specific properties. These okra fiber-based films can be used in various applications, including biodegradable packaging, agricultural films, medical materials, and consumer products. While the biodegradability and renewable nature of okra make it an attractive resource, challenges such as extraction efficiency, mechanical properties, and cost-effectiveness need to be addressed through further research and optimization. Advances in chemical processing and material science could help overcome these challenges, making okra fiber films a viable eco-friendly alternative to traditional plastics [22] (**Figure 8**).

Figure 8. Visual representation of okra based plastic (generated using copilot).

The transformation of okra fiber into PET (polyethylene terephthalate) bottles involves several key processes. Initially, okra fibers are extracted through a water retting process, followed by drying and mechanical processing to isolate and purify the cellulose content. This cellulose is then chemically treated and dissolved using a solvent such as acetic acid, converting it into a viscous solution. Through a series of chemical reactions, the cellulose solution is polymerized into bio-based plastic resin, forming the base material for PET production. This bio-resin undergoes further processing, including polymerization and extrusion, to create PET pellets. The PET pellets are then melted and molded into preforms, which are subsequently blow-molded into the final PET bottle shape using high-pressure air. This innovative process not only utilizes renewable okra fibers but also contributes to sustainable plastic production, reducing reliance on petroleum-based raw materials and decreasing environmental impact. Figure 9. Illustrating the transformation of okra fibre into PET bottles that will degrade or decompose within 3 months.

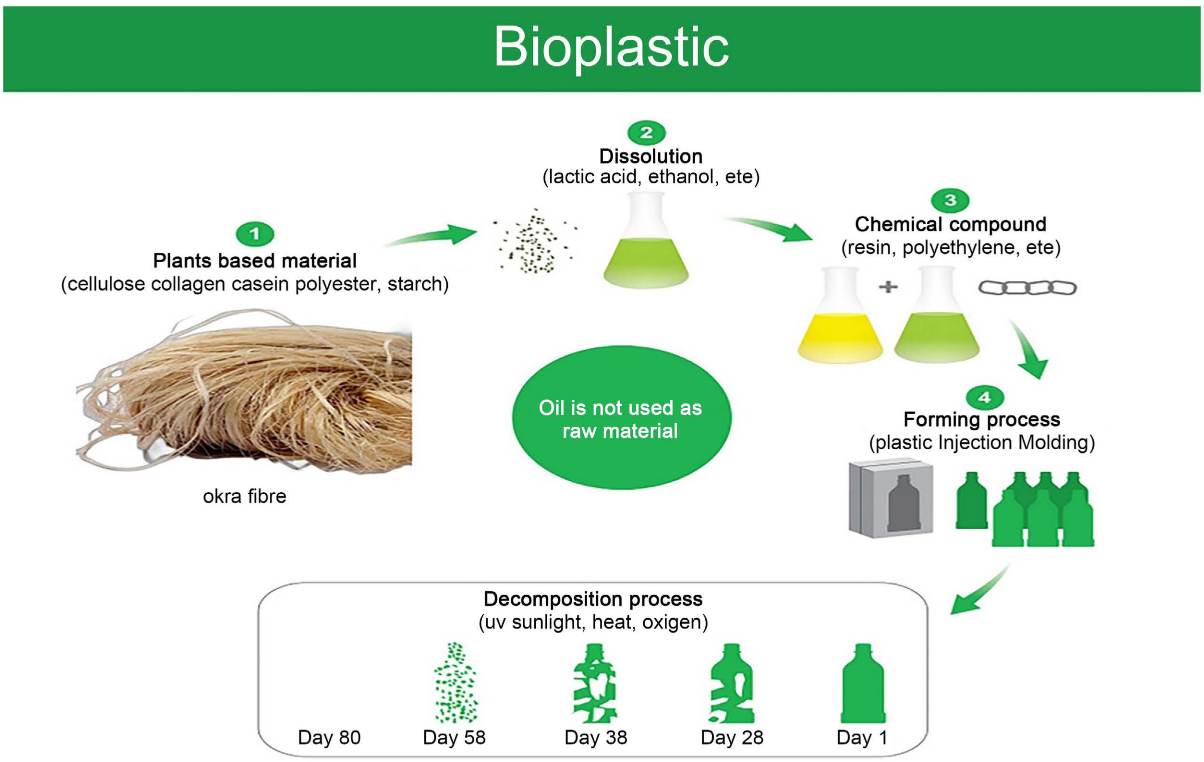

Figure 9. Visual representation of transforming okra fibre into pet bottle which will be degrade or decompose within 3 months.

5. Result & Discussion

Okra fiber extraction and processing have shown to have enormous promise in a number of home and industrial industries. Okra plants that underwent retting produced fibers with a 4% yield of fiber based on the weight of the green plant. The fiber's qualities were enhanced by the scouring, bleaching, and dyeing processes, which allowed it to compete with more conventional fibers like sisal, kenaf, and jute. Okra fiber's potential for textile applications was confirmed by the remarkable linear density, strength, mass variation, and thread density found in the fibers, yarn, and fabric characterization carried out in accordance with ASTM (American Society for Testing and Materials) standards, specifically D2256, D1907, D5034, D737, D570, D1424, D3884 Test result was notable.

Additional testing revealed that okra fibers might be used to make cellulose-based films. These films can be used in consumer goods, medical materials, agricultural films, biodegradable packaging, and other uses where traditional polymers are not as sustainable. De-waxing, delignification, bleaching, and solvent casting were all steps in the transformation process that produced films that took advantage of okra's renewable and biodegradable qualities.

The possibility of turning okra fibers into PET (polyethylene terephthalate) bottles was also investigated by the study. Okra cellulose underwent a series of chemical processing and polymerization steps to become a bio-based plastic resin. PET pellets were created by further processing this resin, which was then molded into preforms and blow-molded into bottles. When compared to conventional petroleum-based plastics, these PET bottles made of okra show a notable decrease in environmental effect since they degrade in three months.

Okra fiber's adaptability encompasses a wide range of commercial and residential applications. Its use in packaging materials, bio-plastics, and textiles demonstrates how revolutionary it can be in a number of industries. The ability to turn okra fibers into sustainable and biodegradable products not only solves environmental issues but also offers a greener substitute for traditional materials. Subsequent investigations centered on refining mechanical characteristics, increasing extraction efficiency, and boosting economic viability may further establish okra fiber's standing as a marketable, sustainable resource.

6. Potential of Okra Fibre

In our opinion, Bangladesh has a great chance to capitalize on the economic potential of okra fiber because of its burgeoning okra farming industry. Okra fiber, which is extracted from the plant's stems, is a resource that is underutilized but has the potential to be important in a variety of sectors. The following are Bangladesh's main okra fiber potentials:

6.1. Textile Industry

- **Sustainable garments:** Jute and sisal are two classic fibers that can be rivaled by eco-friendly garments made from okra fiber. These textiles can meet the increasing demand on the international market for sustainable textiles.
- **Spin ability and Blending:** To create textiles with desired qualities, okra fiber can be combined with other natural and synthetic fibers. Okra-cotton mixed yarns have been found to have promising properties, including increased strength and durability. Tensile strength, rip strength, and air permeability are

among the acceptable properties that blended textiles, such polyester-okra mixes, have demonstrated for textile applications.

- **Employment Creation:** The production, processing, and industrial use of okra fiber can lead to the creation of a large number of jobs in the manufacturing, agricultural, and research sectors, thereby promoting rural development and lowering poverty.

6.2. Bio-Plastics and Packaging

- **Cellulose-Based Films:** Okra fiber may be converted into films made of cellulose, which offers a sustainable substitute for traditional plastics. By using these biodegradable films for consumer items, packaging, and agricultural films, plastic waste and its negative effects on the environment can be reduced.
- **Bio-based PET Bottles:** Another creative use is the conversion of okra fiber into PET bottles. These bio-based bottles provide the packaging industry with a greener option because they break down far more quickly than conventional petroleum-based plastics.

6.3. Composite Materials

- **Reinforcement in Polymer Composites:** Okra fiber can be used as reinforcement in polymer composites to improve their tensile, bending, and impact strength, among other mechanical qualities. Okra fiber composites can be used in a variety of applications, such as packaging, construction materials, and automobile parts.
- **Hybrid Composites:** Okra fiber's potential use in high-performance applications can be increased by combining it with other natural fibers like jute and sisal to create hybrid composites with higher mechanical qualities.

6.4. Environmental and Economic Sustainability

- **Waste Utilization:** By making use of okra stems, which are often regarded as agricultural waste, farmers may create an extra source of revenue while also greatly reducing environmental pollution. In addition to solving waste management problems, turning okra waste into useful fiber advances the circular economy.
- **Green Economy:** Encouraging the use of okra fiber is consistent with the objectives of global sustainability. Compared to synthetic fibers, it has a smaller environmental impact during production and cultivation, which makes it a good choice for environmentally friendly product development. This might establish Bangladesh as a pioneer in the manufacture of sustainable fibers, drawing in foreign capital and consumers.

6.5. Innovation in Processing Techniques

- **Chemical Treatments and Surface Modifications:** Okra fiber's strength and absorbency can be improved by applying sophisticated chemical treatments.

The features of the fiber can be further optimized for certain industrial applications through innovations like photo-grafting and protein extraction.

- **Fabrication Techniques:** Developing efficient fabrication techniques for processing okra fiber into various forms (e.g., yarns, fabrics, and composites) can enhance its commercial viability. Improved retting processes and mechanical extraction methods can increase yield and quality.

❖ **Other Potentials of Okra fibre:**

It has been examined that Okra fiber offers several other potential applications in the following fields. These are:

- **Agricultural Applications:** Okra fiber offers sustainable farming and gardening options when it comes to mulching materials, erosion control mats, and biodegradable plant pots.
- **Medical Textiles:** Because of their biocompatibility and antimicrobial qualities, textiles based on okra fibers can be utilized in medical applications such as surgical gowns, wound dressings, and medical implants.
- **Environmental Treatment:** Okra fiber can be utilized to reduce environmental contamination in environmental remediation applications like oil spill cleaning, soil erosion control, and water filtration systems.
- **Insulation Materials:** Okra fiber can be utilized in construction as an insulating material to help with thermal and acoustic comfort, as well as energy efficiency.
- **Paper and Pulp Industry:** By adding okra fiber to paper and pulp products, papermakers can use a more sustainable alternative to wood pulp and lessen their need for it.
- **Art & Crafts:** Okra fiber can be used in crafts to make handmade paper, ornaments, and sculptures. It also gives artistic products a distinctive, organic look.
- **Filters and Filtration Media:** To remove pollutants and impurities from fluids and gases, air purification systems, water treatment facilities, and industrial filtration operations can all employ natural fiber-based filters and filtration media.
- **Automotive Interiors:** Okra fiber offers automakers a sustainable and environmentally friendly alternative for upholstery, carpeting, and interior trim components.
- **Sports Equipment:** Okra fiber can be utilized to make lightweight, strong materials for athletes and outdoor lovers. Examples of this equipment include tennis rackets, hockey sticks, and bicycle frames.
- **Green Building Materials:** Okra fiber-based building materials can be utilized to create ecologically friendly and energy-efficient structures by providing sustainable wall panels, flooring, and ornamental finishes.
- **Animal Bedding:** Okra fiber makes a cozy and environmentally friendly bedding alternative that is simple to compost after usage for both dogs and livestock.
- **Geotextiles:** Geotextiles made of okra fibers have applications in civil engi-

neering, including soil structure strengthening, slope stabilization, and erosion prevention.

- **Cosmetic Sponges:** Okra fiber provides a sustainable and natural substitute for synthetic sponges by being turned into applicators for beauty and skincare products.
- **Aquaculture:** Okra fiber can be utilized to support sustainable aquaculture methods by providing a substrate for the growth of algae, bio-filters for the purification of water, and nesting material for aquatic animals.
- Green roofing: Okra fiber can be used to make environmentally friendly roofing materials, like eco-friendly roof tiles or shingles, which insulate buildings and improve their environmental sustainability.
- **Erosion Control:** Okra fiber-based erosion control blankets or mats can be used in landscaping and environmental restoration projects to prevent soil erosion on slopes, riverbanks, and construction sites.

7. Conclusions

As a key component of the movement towards sustainable economic development, this study emphasizes the revolutionary potential of okra fiber in Bangladesh. This research highlights the versatility and usability of okra fiber across a range of sectors by closely analyzing its physico-mechanical properties, chemical treatments, and production procedures. Said to be agricultural waste, okra fiber was once neglected but is now valued for its qualities, which are on par with those of typical natural fibers like sisal and jute.

The study highlights how crucial it is to improve extraction and processing methods in order to maximize fiber production and quality. The commercial feasibility of okra fiber can be further enhanced by innovations in chemical treatments and production techniques, positioning it as a competitive substitute for synthetic materials. To fully realize the promise of okra fiber, future research should concentrate on solving issues with mechanical characteristics and cost-effectiveness.

In conclusion, Bangladesh stands to gain a great deal economically and environmentally from realizing the potential of okra fiber. This research opens the door for sustainable development, job creation, and environmental preservation by turning agricultural waste into useful industrial resources. Okra fiber is a viable route to both global sustainability and economic prosperity, and it is expected to become a fundamental component of Bangladesh's green economy.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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