Extraction and Characterization of Sri Lankan Water Hyacinth Fibers

U.K.O.I. Rathnapriya
Textile and Apparel Engineering
University of Moratuwa
Moratuwa, Sri Lanka
rathnapriyaukoi.19@uom.lk

E.A.T. Silva
Textile and Apparel Engineering
University of Moratuwa
Moratuwa, Sri Lanka
silvaeat.19@uom.lk

U.S.W. Gunasekara
Textile and Apparel Engineering
University of Moratuwa
Moratuwa, Sri Lanka
ujithe@uom.lk

Keywords—water hyacinth fibers, mechanical extraction, chemical extraction, tensile properties, crystallinity

I. INTRODUCTION

Historically, natural fibers like hemp, flax, cotton, and silk were the cornerstones of textile production. However, the Industrial Revolution marked the advent of synthetic fibers such as nylon and polyester, which reshaped the industry. As the global population grew, so did the demand for textiles, but this surge in synthetic fiber production has led to significant environmental issues, including pollution and the depletion of fossil fuels. While synthetic fibers offer durability, natural fibers are increasingly favored for their sustainability and biodegradability.

This study focuses on an unconventional natural fiber source, water hyacinth *(Eichhornia Crassipes)*, an invasive aquatic plant. Native to the Amazon Basin and now widespread in tropical and subtropical regions, water hyacinth is notorious for its rapid growth, forming dense mats that disrupt ecosystems, hinder navigation, and clog waterways. Various control methods have been tried, but a more sustainable and economically viable approach involves harnessing the plant's fibrous content for industrial use. By extracting fibers from water hyacinth, this research aims to transform it from an environmental nuisance into a valuable resource. Through detailed characterization of these fibers extracted from different method, the study aims to assess their properties and potential applications, contributing to more sustainable textile production and offering solutions to both ecological and industrial challenges.

II. LITERATURE REVIEW

The increasing exploration of natural fibers, such as banana, pineapple, and areca fibers, highlights the environmental benefits of biodegradable materials over synthetic ones [1]. These natural fibers are valued for their lightweight nature, high strength-to-weight ratio, and rapid replenishment, making them ideal for a variety of applications [3]. Water hyacinth fibers offer significant environmental benefits over synthetic fibers due to their renewable and biodegradable nature [2]. Unlike petrochemical-based fibers, which contribute to long-term pollution, water hyacinth fibers provide a sustainable alternative with high absorbency and biodegradability, making them suitable for eco-friendly textile applications [2]. Numerous studies have explored the industrial potential of water hyacinth fibers, particularly in composites [5]. These fibers have been shown to significantly improve the tensile strength and reduce the bulk density of concrete, making them a sustainable reinforcement option [5]. They also show promise as eco-friendly thermal insulation materials when combined with natural rubber latex [4].

While the mechanical properties of water hyacinth fibers are comparable to other natural fibers like flax [7] and hemp [6] its invasive nature in tropical and subtropical regions ensures its rapid availability, providing a sustainable solution for large-scale harvesting with minimal environmental impact. Although research has explored various industrial uses for water hyacinth fibers, there is a gap in the literature regarding the extraction and characterization of fibers from the Sri Lankan variant. Given potential geographical differences in fiber properties, this study addresses this gap by analyzing and comparing the properties of Sri Lankan water hyacinth fibers from different extraction methods through a characterization. This approach aims to contribute to the development of eco-friendly products tailored for the local market.

III. MATERIALS AND METHODS

A. Harvesting

The water hyacinth plants used for fiber extraction were harvested from the Bolgoda river in Rathmalana, Sri Lanka, with mature, healthy stems selected. After collection, the plants were cleaned, sorted, and the stems were naturally air-dried at room temperature in a shaded area to prevent damage. Once dried, the stems were stored indoors to maintain fiber quality, after which they underwent further processing for fiber extraction and characterization.

B. Extraction Techniques

1. Mechanical Extraction

Mechanical extraction was performed using a decorticator machine, where the stems of the water hyacinth were first cleaned and then processed to separate the fibrous material. The extracted fibers were air-dried and manually combed to remove non-fibrous residues. This method is straightforward but requires careful handling to ensure the uniformity and quality of the fibers.

2. Chemical Extraction

For the chemical retting process, water hyacinth stems were immersed in a 10% NaOH solution for 96 hours, followed by manual separation of fibers. The outer fleshy parts were peeled, and the remaining stem was combed to extract individual fibers. The fibers were washed, neutralized with acetic acid, and air-dried for 24 hours. A revised method involved boiling the stems in NaOH solutions of varying concentrations (2%, 5%, 10%, 15%, and 20%) at 100°C for one hour to improve fiber extraction efficiency.

C. *Characterization Techniques*

Various methods can be employed to characterize water hyacinth fiber. Common characterization techniques include morphological, chemical, physical and moisture absorbency.

1. *Morphological Characterization*

The morphological properties of the extracted water hyacinth fibers were analyzed using Scanning Electron Microscopy (SEM). This technique provided detailed observations of the fibers' surface texture, diameter, length, and cross-sectional morphology. The fiber diameters were measured using image analysis software applied to the SEM images, while the fiber lengths were determined either manually or through a fiber meter. Prior to SEM analysis, the fibers were coated with a thin gold layer using a sputter coater operating at 30 kV. The SEM was set to an accelerating voltage of 10 kV and operated in a vacuum environment (1×10^{-3} Pa) utilizing a thermionic emission gun, ensuring high-resolution imaging.

2. *Chemical Characterization*

X-ray diffraction (XRD) was employed to investigate the crystallographic structure and chemical composition of the water hyacinth fibers. The fibers were scanned across a 2θ angle range of 10° to 50°, and the resulting diffraction patterns revealed both the amorphous and crystalline regions of the fibers. The Crystallinity Index (CI) was calculated to quantify the degree of crystallinity, which is critical for understanding the fibers' structural integrity and potential applications.

$$CI = \frac{Ae - Aa}{Ae} \quad (1)$$

Ae: Area under the experimental powder pattern
Aa: Area under the amorphous theoretical curve

3. *Mechanical Characterization*

The mechanical properties of the water hyacinth fibers, including tenacity (cN/tex), mean breaking strength (gf), mean breaking elongation (%), and density (g/cm³), were valuated using an Instron tensile testing machine. The tests were conducted at a gauge length of 25 mm and a speed of 3 mm/min, with a 50 kN load cell. The data collected from 50 fiber samples provided average values that reflect the overall mechanical performance of both treated and untreated fibers.

4. *Moisture Regain Analysis*

Moisture regain properties of the fibers were assessed to determine their moisture absorption capacity of Water Hyacinth fibers. Dry, mechanically and chemically extracted fibers were initially weighed, then placed in a controlled humidity chamber set at 83% RH and 28°C for 100 hours. The fibers were periodically weighed to measure the moisture absorbed over time, which provided insights into their behavior in humid environments.

IV. RESULTS AND DISCUSSION

A. *Extraction Results*

1. *Mechanical Extraction*

Mechanical extraction provided faster processing but required manual intervention to fully separate fibers, as the decorticator machine left some fibers attached to the stem. Combining mechanical and manual techniques yielded better results, although machine processing risked damaging the fibers.

Figure 1 Mechanically Extracted WHFs

2. *Chemical Extraction*

In chemical retting, the initial room temperature method was slow and required manual separation. However, the boiling method using NaOH significantly improved efficiency, reducing extraction time to one hour. Among the tested NaOH concentrations, the 10% solution was optimal, effectively breaking down stem tissues and facilitating easy fiber extraction with minimal manual effort. Higher concentrations (15% and 20%) caused fiber degradation, making them unsuitable for further use.

Figure 2 Chemically Extracted WHFs 10% (W/V) NaOH

B. *Characterization Results*

TABLE I. CHARACTERIZATION RESULTS

Technique	Comparison of the Extracted Fibers	
	Mechanical Extracted WHFs	***Chemically Extracted WHFs***
SEM	Rough and more non-fibrous materials	Smooth and less non-fibrous materials
Tensile Test (MPa)	111.27	217.39
Elongation (%)	2.31	3.25
Moisture Regain (%)	14.32	15.81
Young's Modulus (GPa)	4.67	6.64
Crystaline Index (%)	49.55%	57.24%

The results demonstrate clear differences between water hyacinth fibers extracted mechanically and chemically, as analyzed through SEM, moisture regain, X-ray diffraction, and tensile tests.

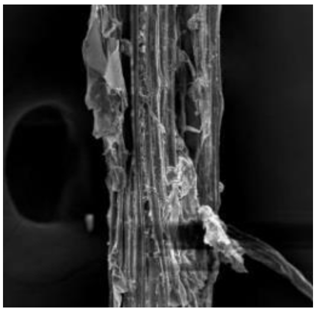

Figure 3 SEM analysis of Mechanically Extracted WHFs

Figure 4 SEM analysis of Chemically Extracted WHFs

SEM Analysis reveals that mechanically extracted fibers have a rough and uneven texture, with non-fibrous residues and structural irregularities, necessitating further processing. In contrast, chemically extracted fibers show a smoother surface, greater uniformity, and more consistent thickness as the most non-cellulosic components are removed, making them suitable for high-quality applications.

Furthermore, the moisture regains for chemically extracted fibers is higher, at 15.81%, compared to 14.32% for mechanically extracted fibers. This increase is attributed to the removal of non-cellulosic components during chemical treatment, which enhances the fiber's hydrophilic properties and increases its surface area and porosity. The structural modifications from chemical treatment, such as greater porosity and the introduction of hydrophilic groups, contribute to the higher moisture absorption.

X-ray Diffraction analysis indicates that chemically extracted fibers have a higher crystallinity index 57.24% compared to mechanically extracted fibers 49.55%, implying a more organized structure. The higher CI in chemically extracted fibers indicates a more ordered and crystalline structure, achieved by removing amorphous regions and non-cellulosic components. This enhanced crystallinity improves structural strength, while mechanically extracted fibers, with a lower CI, offer better moisture absorption and swelling properties.

The fibers obtained via chemical extraction demonstrate significantly higher tensile strength, registering at 217.39 MPa compared to 111.27 MPa for mechanically extracted fibers. This indicates that chemically extracted fibers are substantially stronger and produce purer fibers with more consistent properties. Additionally, these fibers exhibit greater elongation at break, with a value of 3.25%, as opposed to 2.31% for their mechanically extracted counterparts, suggesting that chemically extracted fibers can withstand more deformation before breaking. The Young's Modulus of chemically extracted fibers is also higher, at 6.64 GPa compared to 4.67 GPa for mechanically extracted fibers, indicating that the former are stiffer and more resistant to deformation.

V. CONCLUSION

The study demonstrates that fibers extracted from the Sri Lankan water hyacinth plant, particularly through chemical methods, exhibit superior properties for disposable textile applications. Chemically extracted fibers offer higher tensile strength, greater elongation at break, and improved moisture regain, making them more durable and suitable for applications requiring flexibility and absorbency. Despite challenges associated with chemical extraction, such as environmental concerns and handling, this method consistently produces higher-quality fibers with smoother surfaces and fewer non-fibrous residues compared to mechanical extraction. Thus, the Sri Lankan water hyacinth plant presents a viable and sustainable source for eco-friendly fibers, with significant potential for the Sri Lankan textile industry.

REFERENCES

[1] S. R. Djafari Petroudy, "Physical and mechanical properties of natural fibers," in Advanced High Strength Natural Fibre Composites in Construction, Elsevier, 2017, pp. 59–83. doi: 10.1016/B978-0-08-100411-1.00003-0.

[2] T. R. Téllez, E. López, G. Granado, E. Pérez, R. López, and J. Guzmán, "The Water Hyacinth, Eichhornia crassipes: an invasive plant in the Guadiana River Basin (Spain)," Aquat. Invasions, vol. 3, no. 1, pp. 42–53, Mar. 2008, doi: 10.3391/ai.2008.3.1.8.

[3] S. Chokshi, V. Parmar, P. Gohil, and V. Chaudhary, "Chemical Composition and Mechanical Properties of Natural Fibers," J. Nat. Fibers, vol. 19, no. 10, pp. 3942–3953, Oct. 2022, doi: 10.1080/15440478.2020.1848738

[4] Y. Liu, D. Thibodeaux, and J. Rodgers, "Preliminary Study of Linear Density, Tenacity, and Crystallinity of Cotton Fibers," Fibers, vol. 2, no. 3, pp. 211–220, Jul. 2014, doi: 10.3390/fib2030211.

[5] R. Vijay, A. Vinod, D. Lenin Singaravelu, M. R. Sanjay, and S. Siengchin, "Characterization of chemical treated and untreated natural fibers from Pennisetum orientale grass- A potential reinforcement for lightweight polymeric applications," Int. J. Lightweight Mater. Manuf., vol. 4, no. 1, pp. 43–49, Mar. 2021, doi: 10.1016/j.ijlmm.2020.06.008.

[6] A. Bismarck et al., "Surface characterization of flax, hemp and cellulose fibers; Surface properties and the water uptake behavior," Polymer Composites, vol. 23, no. 5, pp. 872–894, Oct. 2002, doi: 10.1002/pc.10485. [39] W. H. Morrison Iii, D. D. Arch

[7] W. H. Morrison Iii, D. D. Archibald, H. S. S. Sharma, and D. E. Akin, "Chemical and physical characterization of water- and dew-retted flax fibers," Industrial Crops and Products, vol. 12, no. 1, pp. 39–46, Jun. 2000, doi: 10.1016/S0926-6690(99)00044-8.