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Extraction and Characterization of Furcraea Fiber for Textile Applications – An exploratory Investigation

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Abstract: **The aim of this paper is to study the use of Furcraea plant leaves as a potential source of lignocellulose fibers with an emphasis on textile applications. The plant leaves are retted in water, squeezed and beaten to collect the fibers. According to National Standard 08-1113-1989, the length of the fibers measures in the range of 60 to 100 cm. Bundle strength, color, fineness, root content, defects and bulk density are measured to be 19.0 g tex^{-1}, 36%, 34.44 tex, 1.52%, 16.75% and 0.37 g cc^{-1} respectively. The extracted fiber grade has also been estimated in accordance with commercial natural fiber standard IS 271 (2003). The findings revealed that these fibers are viable substitutes for jute fibers of TD-4 grade to produce packaging bags of food grains.**

Index Terms: **Furcraea, Composite, Leaf fiber, Extraction, Fiber properties, Textile.**

I. Introduction

Over the last few years, researchers have been exploring new natural fibers that can be used as raw materials for various applications. The main factors encouraging the investigation of these environmentally friendly materials are the rapidly expanding environmental consciousness, restrictions on the use of petroleum based Man-made materials, and high processing costs [1].

While natural fibers can be used in a wide range of applications, including textiles and composites, there is currently more research being conducted on the use of natural fibers in composites compared to textiles. Sreenivasan et al [2], characterized s. cylindrica fibers but primary textile parameters i.e., bundle strength, bulk density and defects were not evaluated [3]. Shinoj S R et al [4] collated information on the aptness of oil palm fruit for bio composite formation in various polymer matrices but did not explore its suitability for textile applications. Similarly, many researchers reported characterization of novel plant based fibers with primary objective of investigating the degree of suitability for composite application [5-7]. On the other hand, recent research has increasingly focused on exploring new natural fibers specifically for textile applications. Bauhinia Vahlii bark fiber has been characterized and found suitable for yarn production through blending with existing cellulosic fibers [8]. Recent investigations on Furcraea foetida plant leaf fibers have revealed their potential as an alternative material for existing textile fibers, specifically yarns [9]. The fiber extracted from the stalk portion of the Etlingera elatior plant has undergone unprecedented investigations, revealing its spinnability and successful utilization as a raw material for textile applications [10]. Similarly, the exploration of Agave vera-cruz [11], Euphorbia tirucalli [12], and Canna edulis [13] plants fibers has yielded encouraging results, particularly in the realm of textile applications.

TABLE I.
FEW FLFS PROPERTIES COMPARED TO OTHER NATURAL FIBERS

Sl. No.	Fiber/plant name	Fineness (tex)	Bundle strength (g/tex)
1	Furcraea foetida [19]	8.3	21
2	Cotton [19]	0.1-0.3	26.6-28.7
3	Pineapple leaf [19]	3.5-4.3	23-30
4	Sisal [27]	30-32	28-30
5	Abaca [28]	20-35	20-35
6	Ramie [28]	0.4-0.8	28-40
7	Coconut fruit [27,28]	50-55	11-12
8	Banana [28]	3-25	20-30
9	FLF	34.44	19

Agave fourcroydes, also referred to as Furcraea, is a plant that is indigenous to Mexico and Guatemala. It is closely related to the sisal fiber crop and is a member of the asparagus family. The plant has rosette of sword shape leaves rows up to 100 cm length. Growing from the sturdy stalk, the leaves are a greyish green color and 10 to 15 cm wide. Cazaurang-Martinez MN et al [14] reported chemical, few physical and mechanical properties of the Furcraea fiber. A chemical analysis of Furcraea leaf fibers revealed that cellulose comprises the largest portion (59%) of the fiber composition. Following cellulose, hemicellulose accounts for 28% of the fibers, while lignin makes up approximately 8%. The tensile strength of Furcraea fiber, determined through mechanical testing, is measured at 570 MPa. Additionally, the Young's modulus of Furcraea fiber, which represents its stiffness or elasticity, is found to be 14.7 GPa. The true density of the fiber was 1.2 kg/m3. These properties are comparable to many existing natural fibers and attracted many researchers. As a result, this natural fiber had predominantly been investigated and utilized in non-textile applications, such as composite materials [15-17]. The present work emphasizes the extraction and assessment of Furcraea leaf fiber for its textile qualities, which were previously underappreciated due to a lack of awareness.

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II. Material and Methods

A. Collection of leaves and Extraction of fibers

The process of water retting, as detailed by Madival AS et al. [18], was employed to effectively separate the fibrous bundles from the Furcraea leaves. This method involved submerging the leaves or bast in water for a specific duration to initiate the natural decomposition and separation of the fibers. In the present work, healthy Furcraea leaves were harvested from the Hyderabad Forest area in Telangana state, India. The selected leaves had almost equal sizes and colors. The length and width of the leaves were around 60–100 cm and 6–7.5 cm, respectively. These leaves were water retted for 20 days, followed by careful squeezing, and battering to separate the fibers from non-fibrous tissues. These fibers were sun-dried for four days before being kept in a polythene bag for future usage. Figure 1 shows its well-retted and dried Furcraea leaves fibers (FLFs).

Figure 1. Extracted FLFs

B. Determination of Textile properties

The fiber length measurements were performed in accordance with National Standard 08-1113-1989 for the Measurement of FLFs Length. Twenty bunches of fiber strand samples, each comprising at least 100 fibers, were put out loosely on a flat surface. The largest sample among the bunches was measured using the established methodology.

Color is one of the important characteristics of any fiber, and it can vary in appearance, including shades of grey, creamy pink, ivory, white, cyan, and more. In the case of FLFs, the color assessment was performed using the method developed by the Indian Jute Industries Research Association (IJIRA). This method involves the use of a whiteness index measurement device to quantify the color percentage in terms of different categories, ranging from creamy pink to brownish white (superior), brownish to reddish white with some light grey, brownish to light grey, and grey to dark (inferior). By employing this IJIRA method, the color characteristics of the FLFs samples were effectively evaluated and categorized based on their color variations.

Fineness is a crucial measurement that quantifies the thickness, diameter, breadth, or weight per unit length of the fiber. In this study, the fiber's fineness was assessed following the BIS Standard IS 271 (2003) using air flow equipment. To determine the fineness, chopped FLFs samples were precisely weighed and placed into a two-ended open cylindrical chamber attached to a manometer. The fibers were then crushed to achieve a consistent volume within the chamber. Compressed air was subsequently pumped into the chamber, and the amount of air flow was controlled. If a significant amount of air passed through the chamber, it indicated that the fiber was coarser. Conversely, if minimal air passed through, it indicated that the fiber was finer. By conducting extensive testing and analyzing the data, the average fineness of the fiber samples was expressed in Tex units. The diameter of the fiber could be determined by calculating the ratio of air flow pressure to differential pressure, providing valuable insights into the size and thickness of the fibers.

Strength refers to the fiber's capacity to withstand external forces such as tearing or stretching. In this study, the bundle strength, also known as the tenacity of the fiber, was evaluated following the guidelines of IS 271 (2003) using tensile strength testing equipment with a capacity of 100 kgf. Well-prepared test samples of the fiber were fed into the testing machine, which subjected the fiber to tension until it broke. The time taken for the fiber to break was recorded, with a duration of 20 ± 5 seconds. By analyzing the test results, the strength of the FLFs bundle was measured and expressed in g Tex^{-1}. This measurement provides valuable information about the fiber's ability to resist external forces and helps in assessing its overall strength and durability.

The bulk density, also referred to as the weight or body measure of the fiber, was determined by calculating the mass-to-volume ratio, including airspaces. The measurement followed the guidelines of IS 271 (2003) and utilized specialized devices for assessing bulk density. For the study, five samples of FLFs were prepared, each weighing 40 g and measuring 100 mm in length. These samples were placed between metal plates in a bulk density measuring device. A 10 kg weight was applied to apply pressure, and the volume of the fibers was recorded. By calculating the ratio of mass to volume, the bulk density of the FLFs was determined and expressed in g cc^{-1}. A higher bulk density is often regarded as an indicator of higher fiber quality, suggesting increased compactness and weight of the fiber.

C. Morphological properties

SEM (Scanning Electron Microscopy) was employed to examine the cross-section and surface characteristics of FLFs. The fractured samples of FLFs, which underwent sputter coating with gold, were analyzed using a SEM device manufactured by ZEISS in Germany. This equipment allowed for detailed imaging and analysis of the fiber's structure and surface morphology, providing valuable insights into its microstructure and properties.

III. Results and Discussion

The length of the FLFs was found to vary within the range of 60 to 100 cm. The FLFs extracted from the plant closely matched the length of the leaves being processed. This similarity in length suggested that the fiber length could be influenced by the size of the leaves being processed. The FLFs can be categorized as "extra-long staple fiber" based on its length. When it comes to producing high-quality yarn, longer raw fibers are favored over shorter ones. This preference is rooted in the understanding that longer fibers provide several advantages during the spinning process. One significant advantage is the increased surface area of longer fibers, which promotes better friction and reduces slippage between the fibers [19]. Longitudinal and Cross-sectional Microstructures of FLF shown in Figure 3 and Figure 4, it is evident that uneven surface with impurities and lumen spaces will promote requisite friction and reduced slippage while spinning. In accordance with Murthy H V S [20], utilizing long staple yarns in fabric production results in fabrics that are stronger, smoother, and more functional and are also valuable compared to fabrics made from short staple yarns. This indicates that high quality yarn can be produced using FLFs. It is recommended that the length of the fiber used should be

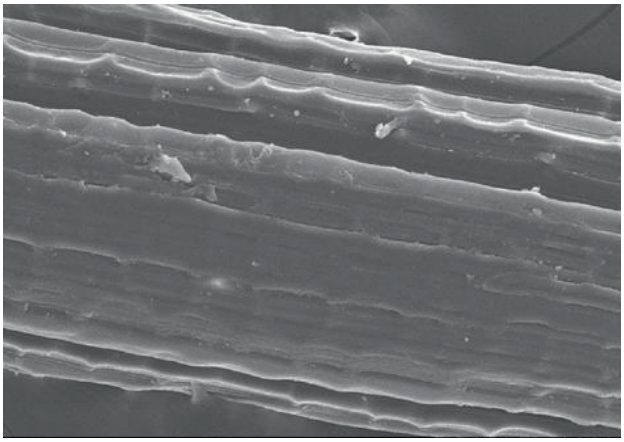

Figure 2. Microstructural analysis of FLFs: Longitudinal view.

at least 5 mm, ensuring a substantial length-to-diameter ratio to facilitate the manufacturing of yarn that maintains the integrity of individual fibers [20]. The configuration factor of spinning machines employed in fiber treatment is influenced by the length of the fiber, as it plays a crucial role in determining the suitability of the spinning process. This can be attributed to FLFs easy spinnability. The industrial handling of textile fibers is a crucial stage in the processing for making various products. The length of the fiber plays a significant role in the spinning system, as it determines the placement of rollers and helps prevent excessive twisting during processing. In the case of jute fiber, the required minimum length according to BIS systems IS 271 (2003) and IS 271 (2020) is approximately 100 cm. This length is considered optimal as it facilitates efficient feeding on breaker cards and minimizes handling operations [21]. According to Reddy N et al. [22], fibers should be at least 2 cm long to be suitable for textile applications. Based on a replicated study mentioned earlier, it can be concluded that the HFLs are suitable for use in textile applications. Due to the lower stiffness of the fibers, processing finer fibers for fabrics results in softer fabrics and has the potential to yield yarn with a greater thread count [21].

The HFLs were evaluated for their fineness in accordance with the IS 271 (2003) standard for jute fiber where its fineness is divided into four categories: very fine, fine, well-separated, and separated fibers. The testing of the fibers revealed that HFLs have a fineness of 34.44 tex, placing them in the 'separated fibers' range. This fineness is unusual and significantly coarser compared to jute fiber. Table 1, which compares the FLFs' characteristics with those of other lignocellulose fibers, clearly shows their notably high fineness value. According to Murthy H V S [20], fiber fineness plays a significant role in various crucial yarn qualities, such as packing and flexural rigidity. Coarser fibers have a lower specific surface area, which leads to decreased fiber cohesion and capillary activity within the yarn structure. As the yarn count decreases, the torsional resistance of the fiber worsens. Coarser fibers are generally more challenging to twist, but once twisted, they store more strain energy compared to finer fibers. This can lead to undesirable kinks and snarls in the relaxed state of the yarn.

The performance of the finished product heavily depends on the mechanical characteristics of textile fibers, such as their response to loads and deformations. Factors such as plant type and growth pattern determine fiber strength.

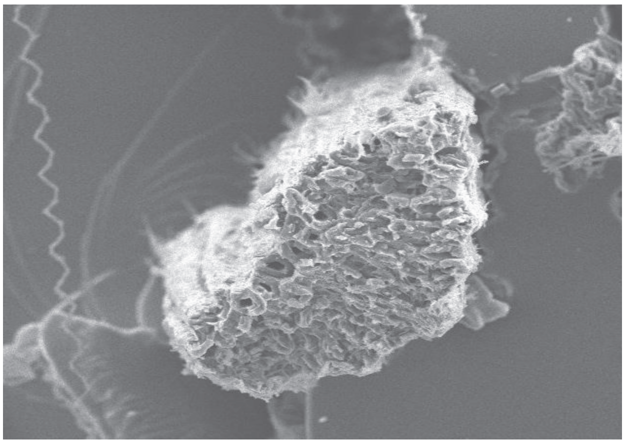

Figure 3. Microstructural analysis of FLFs: Cross-sectional view.

Tenacity, sometimes referred to as bundle strength, is a crucial characteristic that indicates the fiber's capacity to withstand stresses and significantly influences grading evaluation [21]. According to IS 271(2003), there are six classifications for bundle strength: weak mixed, average, fair average, fairly good, excellent, and very good. The bundle strength of the extracted FLFs was measured to be 19.0 g tex^{-1} (i.e., 2.11 g den^{-1}). This measurement clearly confirms that the FLFs possess a notable level of average strength. This FLFs bundle strength value highlights their robustness and suggests that they are well-suited for various applications that require moderately strong and durable fibers. It is evident from Table 1 that FLFs are comparable to a variety of lignocellulosic fibers. The strength of the FLFs surpasses the minimum bundle strength requirement of 1 g den^{-1}, making them suitable for textile applications [19,20]. These fibers can also be used in clothing and home applications since their strength level almost matches the advised range of 3 to 7 g den-1 [19,20]. This suggests that the raw FLFs have a strength profile that makes them suitable for a variety of textile goods, assuring their viability and efficiency in a variety of situations, such as apparel and household items.

Bulk density is categorized as either heavy-bodied (compact and heavier) or medium-bodied (loose and lighter) by IS 271 (2003). FLFs extracted from leaves, and its bulk density was determined to be 0.37 g cc-1 which is less than a common jute fiber bulk density of 0.45 g cc-1 [23]. This demonstrates the medium-bodied nature of the FLFs. However, it is important to note that the most recent BIS systems (IS 271(2020)) no longer considers bulk density as one of the criteria for classifying mother jute fiber [24].

The capacity of a fiber to distinguish between appearances of redness, whiteness, yellowness, blueness, and other colors is known as its color. Its aesthetic value is influenced by this trait. FLFs color was easily measured using a hand-held color meter with indicators. According to the BIS method, the color of FLFs was determined to be 36%, which is a fairly good color (grey to dark grey). This demonstrates that FLFs, whose color comes from the natural pigmentation of the plant, grows in a range of hues ranging from brown to green and may be utilized for textile, clothing, and craft applications [25]. Dyeing textile items is one of the costliest steps in the finishing process since it uses a lot of water and energy, generates a lot of reject, and emits a lot of pollutants. Up to 50% of the overall cost of producing textiles may be saved by eliminating the dying step for naturally colored fibers. The textiles that will be made from FLFs don't need to be dyed since they already have a good color [25, 26].

According to recent research on ramie fiber [21] and banana fiber [29], grading any new or potential natural fiber is critical for predicting how it will behave during the manufacturing process, determining its best use in the development of various types of yarns, and determining its blending compatibility with other commercial natural fibers. Since FLFs is a novel natural fiber, there are no recognized grading criteria. The current study investigated the criteria of fiber fineness, bundle strength, bulk density, and color which are a few of the parameters used to assess the grade of jute fiber (BIS system) has been utilized for FLFs. The remaining two variables as per the BIS system are root content and defects. Because FLF is a leaf fiber, Tis BIS system was not used to determine root content or defects as they vary from bast fiber to leaf fiber. If root content and defects are eliminated, FLFs evaluated according to BIS method IS 271(2003) will yield at least W-2 grade fibers, which are useful for producing packaging bags of food grains. Also, this type of grade evaluation could certainly aid in blending of jute fiber and FLFs [30].

IV. Conclusions

This study was conducted to investigate the viability of utilizing FLFs as textile fibers. The research demonstrated that FLFs can be efficiently produced from plants using a cost-effective water retting method. While FLFs were observed to possess a coarser fineness compared to many natural fibers, they showcased a natural color range from grey to dark grey, negating the necessity for additional dyeing processes in textile production. Furthermore, FLFs were categorized as long staple fibers and exhibited adequate bundle strength, positioning them as comparable to well-established textile fibers suitable for yarn spinning. These findings strongly suggest that FLFs have the potential to emerge as a compelling alternative to traditional yarns within the textile industry. In conclusion, this study indicates that FLFs can effectively function as textile fibers, offering benefits such as cost-effectiveness, ease of production, natural coloration, and competitive performance when compared to established fibers. Consequently, FLFs present promising prospects as a sustainable and feasible option in textile manufacturing.

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