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Research article

Preparation and characterization of handsheet using cellulose based Agri-weed: A sustainable utilization of *Urena Lobata* fiber

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ABSTRACT

The increasing depletion of reserves of natural resources has led to a growing worldwide focus on the exploitation of available waste in new domains. The presence of weedy plants is pervasive on a global scale and has detrimental effects on several aspects of the environment, agriculture, and people's health. Therefore, repurposing these Agri-weed plants for beneficial purposes would be a significant achievement. Furthermore, since raw materials constitute a substantial portion of manufacturing costs, using weeds as a feasible substitute for raw materials might potentially provide considerable advantages for manufacturers. In this study, an endeavor has been made to the utilization of agricultural waste "*Urena Lobata*", for the purpose of paper production. In the interim, the utilization of *Urena Lobata* as an alternative and sustainable raw material for pulp and paper industry could potentially offer a beneficial approach to mitigation of deforestation. The effective production of handsheets with weights of 70 g/m^2 and 80 g/m^2 was achieved using *Urena Lobata* fiber, Bleached *Urena Lobata* Fiber, and hardwood kraft pulp. Mechanical characteristics of handsheet's were comprehensively examined by the bursting index, tensile strength, tear index, brightness percentage and scanning electron microscope for handsheet's morphology. The results show that the handsheets produced by *Urena Lobata* fiber exhibit a much lower brightness percentage, high tensile strength and bursting index. Alongside, handsheets by bleached *Urena Lobata* fiber indicate higher brightness percentage, satisfactory values for tensile strength, bursting index, and tear index. The prepared materials are suitable for a broad spectrum of prospective applications, encompassing newsprint, tissue paper, filtration paper as well as high-quality writing and printing paper.

1. Introduction

The pulp and paper industry are a major global sector that requires substantial financial investments. Despite the advancements in information and communication technology, paper production continues to be recognized as a significant indicator of industrialization

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and educational progress globally. It is evident that the capacity for pulp and paper production is steadily growing [1]. It is a highly sought-after sector in the field of industrial manufacturing. The manufacture, usage, and disposal of pulp and paper have several adverse environmental and social consequences. The pulp and paper sectors are among the leading global contributors to air and water pollution, producing waste, and the emission of greenhouse gasses responsible for climate change. Furthermore, it is among the foremost consumers of raw materials, encompassing vital resources such as freshwater, power, and wood based fibers. Forests that play a crucial role in maintaining clean air and water, providing habitat for animals, protecting the climate, serving as a spiritual and recreational space, and ensuring the cultural survival of indigenous peoples, including old-growth and other ecologically significant forests, are being harvested for their fiber content. Additionally, in numerous locations, these forests are being cleared to make way for plantations that have lower ecological significance and rely on harmful chemical herbicides and fertilizers [2].

The use of sustainable resources, such as renewable natural raw materials like wood, non-wood, and recycled fibers, is a prevalent practice in the manufacturing of paper products [3–5]. In response to the significant increase in industrialization and urbanization, governments in developing and developed nations have implemented stringent regulations to mitigate carbon and greenhouse gas emissions and preserve environmental resources. This gives rise to the notion of sustainability, which pertains to matters of the harmonious coexistence of the natural and manmade realms. One potential strategy for enhancing material efficiency is maximizing the use of natural resources in diverse products [6]. A significant number of individuals involved in the papermaking industry, as well as consumers, exhibit a heightened level of environmental consciousness. They actively advocate against the utilization of primary wood fibers in the papermaking process. Within this particular context, the decrease in utilization of forest-derived materials for the purpose of promoting environmental sustainability, coupled with the amplified need for the production of pulp and paper, has necessitated the exploration of alternative sources of raw materials [7].

Non-wood plant fibers serve as valuable alternatives to traditional raw materials and are particularly significant in regions with limited forest resources, such as China, India, and Egypt. These fibers play an increasingly crucial role in these regions [8]. Hence, the use of non-wood resources could assist with solving the anticipated scarcity of fiber in the future [9]. Agricultural leftovers and weed plant waste may be used to meet the increasing need for raw materials in the paper and packaging industry, as well as in the production of hygiene and sanitation goods including paper towels, toilet paper, and disposable makeup wipes [10,11]. Thus, Non-woody and recycled fibers provide a promising opportunity to substitute woody fibers [12,13].

In contemporary times, several non-wood resources like spinning mill waste have been recognized for their potential in paper manufacture [14–16]. These materials exhibit superior pulpability, favorable bleaching characteristics, and outstanding fiber content [17–19]. Researchers showed that the chemical and morphological properties of jute make it a favorable choice as a raw material for pulping [20] which may contribute to the socio-economic development of jute-producing regions [21–24]. According to Jahan et al. (2016), jute fibers possess notable characteristics such as high strength and antibacterial capabilities. Consequently, these attributes make jute fibers a potential substitute for conventional raw materials in the production of tea filter papers within the pulping and papermaking sector [25,26]. The researchers' results also suggest that jute exhibits favorable characteristics as a viable source for producing various grades of pulp [9,20,25,27,28]. Jute's abundance, strength, eco-friendliness, and ability to enhance paper quality make it a valuable resource and its utilization supports sustainable practices for the paper industry.

In Bangladesh, the demand and consumption of paper have skyrocketed due to population growth, improved literacy rates, advancements in communication, and industrial development [29,30]. The pursuit of raw materials for the paper industry in Bangladesh results in the depletion of natural forest resources. The reduction in the supply of forest-based materials, along with the increased demand for pulp and paper manufacturing and growing awareness of environmental protection, has necessitated the exploration of alternative raw materials [2,7,31]. The primary limitation in the development of the paper industry in Bangladesh is the reliance on imported raw materials [27]. The pulp and paper mills have ceased operations as a result of a scarcity of fibrous raw materials. The production of newsprint quality pulp at Khulna Newsprint mill (KNM) was halted after the United Nation's (UN) classification of Sundarban as a world heritage site. The forest department of Bangladesh prohibits the use of gewa wood as a raw material for pulp preparation [32]. Conversely, the demand for paper and paper products is steadily rising in Bangladesh. The paper industry in Bangladesh mostly utilizes bamboo and a combination of hardwood. Both of these raw resources originate from the forests of Bangladesh. However, the current supply is inadequate to meet the demand for paper in the country, and it also has a negative effect on the environment owing to deforestation. As a result, the paper industry imported its raw materials.Similar to jute, *Urena Lobata*, an agronomically spontaneous plant, is a kind of bast fiber that is obtainable in both Bangladesh and Africa. *Urena Lobata*, often referred to as the "Caesar weed," has a long-standing history of use in the production of ropes, fishing nets, sacks, and ring blended yarn, owing to its notable attributes of robustness and longevity [33,34]. According to Babu, Madhuri, and Ali (2016) [35], the plant is also recognized for its medicinal attributes and is used in traditional medical practices. The utilization of *Urena lobata* stem fibers in the manufacturing of paper sheets is anticipated to have a significant impact on both the pulp and paper sector and the natural surroundings. This innovation not only allows for the effective utilization of the *Urena lobata* plant, which is considered a weed, but also reduces the reliance on wood fibers in paper production.

Few researchers utilized this *Urena lobata* fiber as a reinforcement in a polymer composite [36–39], sorbent materials [40,41], extraction of leaves used in pharmacology [35] as an anti-diabetic [42], antidiarrheal activity [43,44], antimicrobial activities [43] and antioxidant and cytotoxic activities [33,45]. *Urena lobata* fiber is also used in textile as fiber for blend yarn manufacturing [34]. Up to the present time, there has been no attempt to manufacture a handsheet from *Urena lobata* fiber.

The present study aimed to explore the potential use of agricultural waste from the weedy plant *Urena lobata* for paper manufacture, marking the first instance of such utilization. The production of handsheets included the use of *Urena Lubata* fiber (ULF) and bleached *Urena Lobata* fiber (BULF). A comparative analysis was conducted to assess the physical properties (brightness%), mechanical characteristics (thickness, tensile strength, bursting index, tear index), and morphological analysis (fiber diameter and handsheet surface) of the handsheets produced, in relation to a reference handsheet manufactured from hardwood kraft pulp (HWKP). This particular kind of pulp is often used in the manufacturing of commercial-grade paper products.

2. Materials and methods

2.1. Materials and chemicals

The bast fiber of *Urena lobata* were sourced from Tangail, Dhaka, Bangladesh. The plants were identified and confirmed by the Agricultural University Bangladesh, as reported by Hasan, Rahman et al., 2023 [34]. Chemical composition of *Urena lobata* was cellulose- 55.45%, hemicellulose- 13.49%, lignin 24.03 [34] and ash content 8.95% [43]. Pilling process was employed to remove leaves and branches from the stem, which typically spanned a period of around 5–6 days. Once the fruits have attained the stage of maturity characterized by a brown coloration, the plants undergo a careful detachment from their roots. Then, a retting process is used to facilitate the extraction of the fiber. Extraction of *Urena Lobata* fiber was performed through a traditional water retting process for a duration of around 10–15 days, as seen in Fig. 1, with the expertise and broad knowledge of farmers specialized in jute cultivation. Following that, the fibers were thoroughly cleaned and then dried in direct sunshine for around three days. The fiber yield extracted from the stem has a range of roughly 20%–25%. Subsequently, the fibers are fragmented into dimensions smaller than 2 mm. The diameter and brightness of the raw fiber was 14 μm and 48.12% respectively.

For the production of a reference handsheet composed of HWKP, the HWKP material was obtained from Partex Paper Mills Ltd, Bangladesh. The fibers exhibited dimensions below 2 mm in length, breaking lengths ranging from 5000 to 7000 m, a diameter of 11.1 μm, and a brightness level of 79.67%.

Chemical reagents, including caustic soda (NaOH, 98% purity), hydrogen peroxide (H_2O_2), glacial acetic acid (CH_3COOH), and sodium carbonate (Na_2CO_3), Sodium Silicate (Na_2SiO_3), peroxide stabilizer), Ethylene diamine tetra acetic acid ($C_{10}H_{16}N_2O_8$) as for sequestering the metal ions in aqueous solution, Sodium Dodecyl Sulphate ($NaC_{12}H_{25}SO_4$, wetting agent) and alkyl ketene dimer (AKD) as a sizing material for handsheet making were collected from local supplier named Kuri & Company (Pvt.) Ltd which was authorized distributor in Bangladesh of Sigma Aldrich.

2.2. Methods

2.2.1. Preparation of handsheets

As per the guidelines outlined in TAPPI Standard T 205, a handsheet refers to a circular paper sheet measuring 15.9 cm (6.25 in) in diameter, which is meticulously crafted using manual techniques [46]. The objective of handsheet preparation is to expeditiously assess the quality criteria of paper that can be produced from a certain batch of pulp.

2.2.2. Modification of Urena Lobata fiber

The objective of the modification of *Urena Lobata* fiber using various chemicals was to eliminate the many impurities present in the fiber, such as fat, oil, wax, and a portion of lignin, while also disrupting its inherent coloration. The chemical treatment in this study

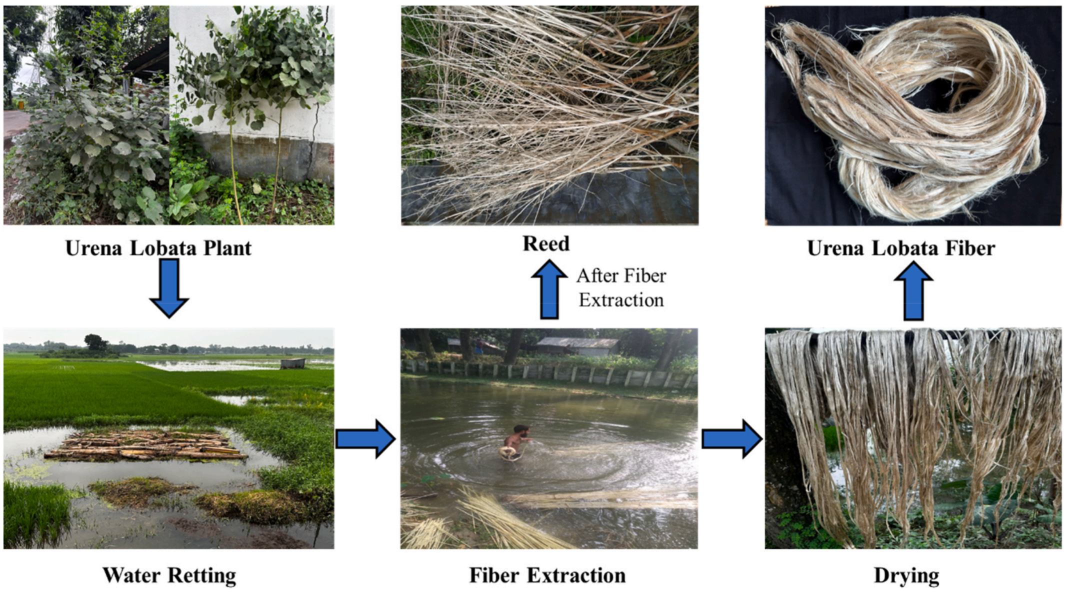


Fig. 1. Fiber extraction process of *Urena Lobata*.

was conducted using an Infra-red dyeing machine (Mathis, Switzerland) shown in flowchart 1 utilizing 8 g/L NaOH, 2 g/L Na_2CO_3, 10 ml/L H_2O_2, 2 g/L Sodium Silicate, 1 g/L Ethylene diamine tetra acetic acid (EDTA) and 1 g/L Sodium Dodecyl Sulphate, maintaining temperature 95 °C for 90 min with material and liquor ratio was 1:20. The measurements of the fiber diameter and brightness values of 15.7 μm and 81.61%, respectively. And pulp yield was 79.16%.

2.2.3. Cutting, soaping, and drying

The *Urena Lobata* fibers were manually chopped into little pieces of less than 2 mm and then subjected to a beating process in a container with hot water at a temperature of 90 °C to induce fibrillation. Subsequently, the fibers were fragmented into crumbs and readily saturated with water [47]. Then, the water was extracted and the fibers were gathered from the container in the form of a cohesive unit, which were then subjected to the drying process under the influence of sunshine.

2.2.4. Pulp refining

The processes of fiber shortening, straightening, fine formation, internal fibrillation, and swelling were conducted using the valley beater (model- PAP-3056, Pap Tech, India), as described by Refs. [48–50]. The *Urena Lobata* fiber underwent several refinement processes, and the resulting degree of SR (Schopper Riegler) was measured to determine the zenith breaking length of the handsheet. In this study, a 53° SR (Schopper Riegler) was achieved by subjecting the valley beater to a 120-min operation, resulting in the attainment of the maximum breaking length. The imported HWKP underwent further refinement using the valley beater. The machine was operated for about 1.5 h in order to get a 53° SR.

2.2.5. Preparation of handsheet

The handsheet former machine model PAP-3053-A used in this study was manufactured by Pap Tech Engineers & Associates, located in Jaipur, India. Three (03) types of handsheets were produced using *Urena Lobata* Fiber, Bleached *Urena Lobata* Fiber, and bleached hardwood kraft pulp. The handsheets were produced using the laboratory handsheets producing technique outlined in ISO 5269–1:2005 [51]. The experiment included the preparation of a solution with water by mixing refined soaking pulp and adding 1% (based on the dry weight of the pulp) of alkyl ketene dimer (AKD). This addition of AKD facilitated the sizing of the handsheet, which was afterwards agitated using a stirrer. Through this procedure, three different types of handsheets weighing 70 and 80 g/m^2 were manufactured. There is a significant market demand for writing and printing papers with weights of 70 and 80 g/m^2, which are typically manufactured using the HWKP. To facilitate the comparison of characteristics, the use of imported HWKP pulp was employed to generate a reference handsheet. Consequently, handsheets weighing 70 g/m^2 and 80 g/m^2 were fabricated for all samples.

2.3. Physio-mechanical properties of paper sheets

To investigate the physical and mechanical characteristics of handsheets, it was necessary to subject all samples to a pre-conditioning process, which was followed by conditioning as per the guidelines outlined in TAPPI T402 sp-08 [52]. This is crucial since the moisture content of the paper has been shown to have a substantial influence on its strength and several other properties [53].

2.3.1. Physical properties

After conditioning, the thickness of the handsheet was measured by digital thickness tester model PAP-2063 B-III manufactured by Pap Tech Engineers & Associates in Jaipur, India according to TAPPI T 411 om-21 standard. The measurement of the brightness of a handsheet was conducted by using the digital brightness tester model FSC-050, Fiber Scientific Corporation, India, in accordance with the TAPPI Test Method T452 om-08 standard [54].

2.3.2. Mechanical properties

Following the conditioning of the handsheets, a series of mechanical tests, including strength evaluations, were conducted in accordance with the guidelines outlined in TAPPI T 220 sp-01 titled "Physical testing of pulp handsheets". The tensile tests were carried out with a universal strength tester model S81838 manufactured by FRANK-PTI GmbH, Germany, which was equipped with a load cell capable of measuring forces up to 500 N. The tests were done at a speed of 50 mm/min, following the guidelines outlined in method TAPPI T 494 om-01. The determination of tearing resistance was conducted using an Elmendorf resistance type tear tester model PAP-2064-B manufactured by Pap Tech Engineers & Associates in Jaipur, India, in accordance with the TAPPI T 414 om-98 standard. The measurement of bursting strength was conducted using a Mullen type bursting strength tester model PAP-2064-B manufactured by Pap Tech Engineers & Associates, located in Jaipur, India. The testing procedure followed the guidelines outlined in the TAPPI T 403 om-97 standard. The experimental outcomes were assessed by calculating the mean of 10 measurements.

2.3.3. Scanning electron microscopy (SEM)

The analysis of the handsheets' surface morphology was conducted using a scanning electron microscope (SEM) named the VEGA3, TESCAN. The SEM was operated at an accelerating voltage of 30 kV. The average diameter of the fibers was determined by the use of ImageJ software, based on analysis of scanning electron microscope (SEM) images.

3. Results and discussion

3.1. Degree of refining and $Cobb_{60}$ value

The Schopper-Riegler test (SR°) was used to ascertain the degree of refining of the pulp. This test expeditiously offers an indication of the refining level in relation to the rate of drainage of the diluted pulp suspension. The objective of this experiment was to assess the potential for enhancing the mechanical characteristics of paper via the examination of different combinations of refining and free swelling techniques.

Fig. 2 illustrates the various levels of refining that have an impact on the mechanical characteristics of paper. As the degree of refining rises, there is a corresponding increase in breaking length up to a specific threshold. Once a particular threshold is reached, the breaking length starts to reduce as the degree of refining increases. The breaking length of a handsheet made from ULF, BULF, and HWKP pulp exhibits an increasing trend as the refining degree rises, reaching a maximum at 53° Schopper-Riegler (SR°). Following the observed pattern, the breaking length shows a reduction as the refining degree that means Schopper-Riegler (SR°) increases. $Cobb_{60}$ Value is the measurement of water absorbed by 1 m^2 AKD treated handsheet in 60 s according to TAPPI T441. In Fig. 2 (b) and (c) it was visualized that water absorbency was decreased after treatment of AKD for both handsheets. Here the 70 g/m^2 handsheet showed greater water absorbency than the 80 g/m^2 handsheet.

3.2. Visual appearance and brightness % of handsheets

As stated in the experimental part, a handsheet was manufactured using HWKP with the intention of serving it as a benchmark

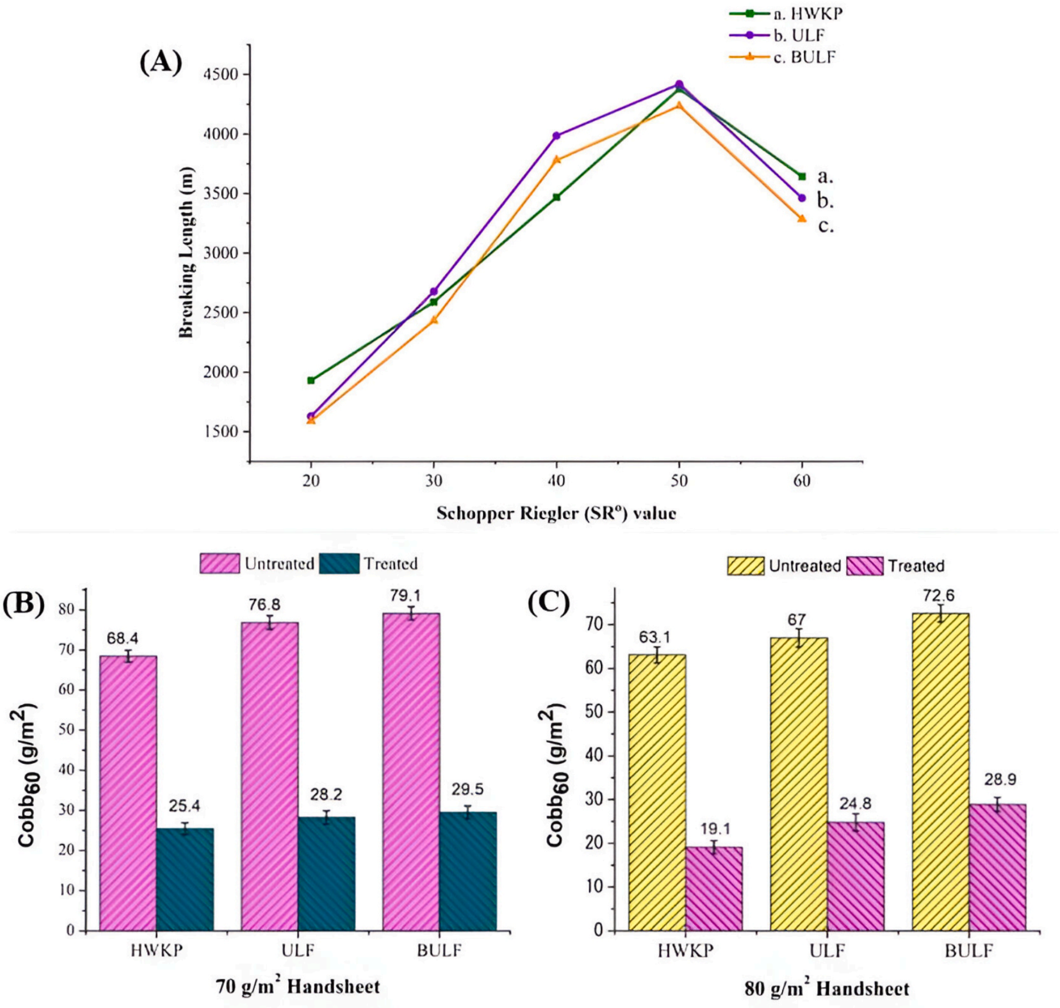


Fig. 2. (A) Degree of refining Schopper-Riegler (SR°) for the pulp of HWKP, ULF and BULF and $Cobb_{60}$ values for handsheets prepared with 70 g/m^2 handsheet (B) and 80 g/m^2 handsheet (C).

material, against which the attributes of the handsheets developed in the present study could be compared. The handsheet made from ULF, as seen in Fig. 3a, has a little reddish or golden tint. The handsheet produced by BULF, as seen in Fig. 3b, has a much higher degree of whiteness compared to the handsheets made by ULF and HWKP, as shown in Fig. 3a and c, respectively.

Fig. 3 (d) depicts the brightness percentage of various handsheets. The study determined that the brightness of the reference handsheet, which was created using HWKP, was measured to be 79.67%. Lowest brightness (48.12%) was shown by the ULF handsheet as there was no chemical treatment applied. The use of BULF in the production of a handsheet resulted in a notable enhancement in brightness (81.61%). This improvement was achieved by the process of scouring and bleaching of *Urena Lobata* fiber [55]. The use of bleached non-wood pulp has significant potential and promising outcomes in the field of paper production. So, the use of BULF in the production of writing and printing paper is feasible for achieving the desired paper grade.

The visual inspection of fibres along the torn edge of the hand sheets under a scanning electron microscope (SEM) is shown in Fig. 4. The hand sheets made from HWKP demonstrate a decreased presence of elongated fibers at the torn edge, as seen in Fig. 4c–as compared to both ULF and BULF hand sheets. The handsheet fabricated utilizing ULF and BULF (as shown in Fig. 4a and b) has many elongated fibres that are clearly visible on their surfaces near the ripped edge.

3.3. Handsheet thickness and mechanical properties

Fig. 5a illustrates the handsheets' thickness. The thickness of the handsheet composed of BULF with basis weights of 70 g/m^2 and 80 g/m^2 exhibited a marginal increase compared to the handsheet by HWKP due to fiber swelling [56]. But a handsheet composed by ULF showed the highest thickness than others as the fibers were stiff due to the presence of lignin and other substances. This increase in thickness may be attributed to the swelling and stiffness behavior of the *Urena Lubata* fiber. Beside thickness, Table 1 indicates the bulk value of the handsheets'. Here it was visualized that the bulk value of handsheets for both 70 and 80 g/m2 made ULF and BULF was higher than HWKP which is desirable for absorbent product.

Fig. 5(b–d) illustrate the mechanical properties of handsheets. The bursting index of a 70 g/m^2 handsheet made from ULF and BULF was found to be 26.51% and 24.46% higher, respectively, compared to handsheets made from HWKP with a bursting index of 2.79 kPa m^2/g. The 80 g/m^2 handsheets of ULF and BULF were found to have a bursting index that was 20.63% and 18.22% higher, respectively, than the handsheet made from HWKP, which had a bursting index of 2.68 kPa m^2/g. It is worth noting that the ULF fiber demonstrated a modest increase of around 2% in the bursting index compared to the BULF. This phenomenon may be attributed to the diminished strength of the fibre resulting from the chemical treatment (scouring and bleaching) processes [57–59].

In comparison to the HWKP handsheet, the ULF handsheet exhibited a higher tensile strength by 3.91% and 1.61% for the 70 g/m^2 and 80 g/m^2 handsheets, respectively as for longer fiber length [59]. However, in the case of BULF, it was observed that the tensile strength fell by 6.77% and 2.15% compared to HWKP for both 70 g/m^2 and 80 g/m^2 handsheets, respectively. The observed phenomenon may be attributed to chemical modification, resulting in a decrease in the strength of the fibre [57,60].

The tear index of a 70 g/m^2 handsheet made from ULF and BULF fibres was found to be 5.91% and 10.23% lower, respectively, compared to handsheets made from HWKP with a tear index of 5.70 mN m^2/g. The tear index of the handsheet with a basis weight of 80 g/m^2 was found to be 15.16% and 15.73% lower than the tear index of the handsheet made from HWKP, which had a tear index of 5.78 mN m^2/g. The observed phenomenon may be attributed to the propensity of the fibres to quickly disentangle from the handsheet, which can be attributed to the stiff and bonding ability (cohesiveness) characteristics of the fibres [61]. A comparison study of mechanical and optical properties with other bast fiber shown in Table-2.

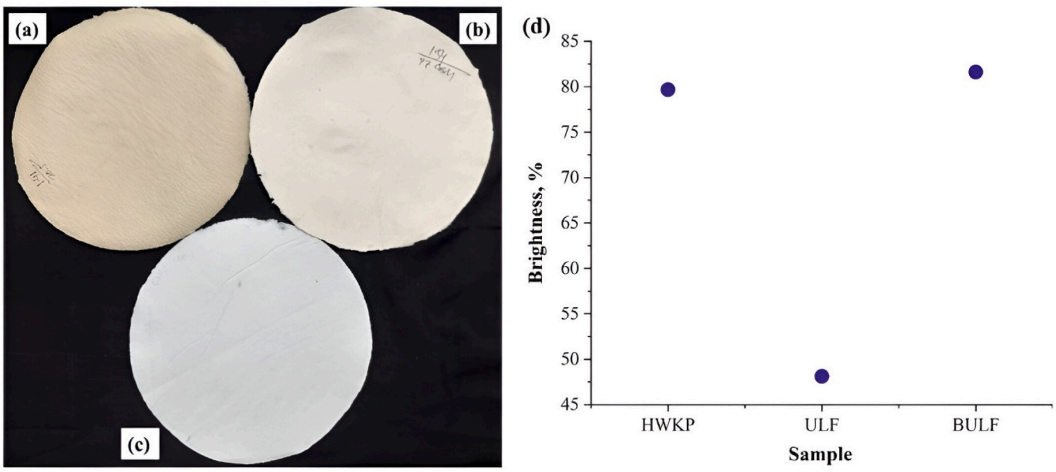


Fig. 3. Images of handsheets made with (a) ULF, (b) BULF (c) HWKP (left side) and brightness % (d).

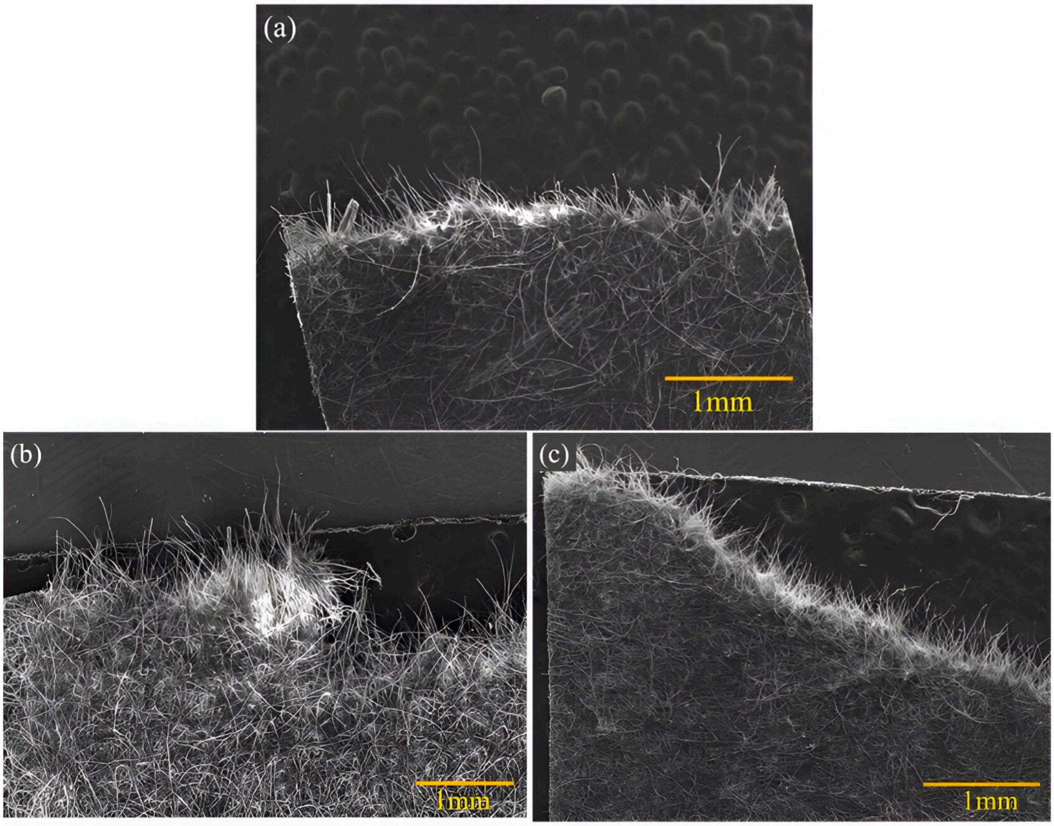


Fig. 4. SEM images of torn edge of handsheets prepared from HWKP (a), BULF(b) and ULF (c) at 64 × magnification.

3.4. *Morphological properties*

Fig. 6 displays scanning electron microscope (SEM) images of ULF and BULF fiber and all handsheets. Fig. 6a displays the untreated ULF fiber, which is characterized by a smooth and plain surface. Following the application of chemical treatment, the ULF fiber undergoes a transformation resulting in a surface that is both rough and scaled, as seen in Fig. 6b.

The handsheets produced with BULF and HWKP exhibit a much smoother and plain surface compared to the handsheets created using ULF, as seen in Fig. 6(c–e). The handsheet produced by ULF (Fig. 6c) has a coarse fiber surface texture characterized by fewer tubular-shaped long fiber structures, which are arranged in a random manner as there is no chemical modification. The sheet network has a significant number of unoccupied regions, while the fibers' diameter ranges from 13 μm to 6 μm. However, it is evident from the comparison of the handsheets composed of BULF and HWKP (as seen in Fig. 6d and e) that both exhibit a high level of fiber coherence, smooth surface with little presence of cavities within the longer fibers.

Based on an analysis of the brightness percentage and mechanical characteristics (Figs. 3 and 5), it can be inferred that ULF has potential as a novel raw material for the production of newspaper grade paper and packaging material. The use of BULF has been seen in the production of many types of papers, including text paper, filtration paper, writing and printing paper.

3.5. *Costing for paper production*

The production expenditures related to different kinds of pulp are shown in Table 3. The current research provides evidence that including ULF and BULF into the production process led to a decrease in expenses when compared to using 100% commercial HWKP. Nevertheless, it has been noted that the production of chemically treated BULF handsheets resulted in greater expenses in comparison to ULF. This may be attributed to the use of extra chemicals and processing steps.

4. Conclusions

The effective production of handsheets was achieved using ULF and BULF, which are derived from agro-based waste. When comparing the commercial grade handsheet created using HWKP to the handsheet generated from ULF, it was seen that the ULF handsheet exhibited a much lower brightness percentage (48.12%). Conversely, the brightness percentage was notably greater in the case of the handsheet made from BULF (81.61%). In terms of mechanical qualities, the ULF handsheets (70 g/m^2, 80 g/m^2) exhibited a

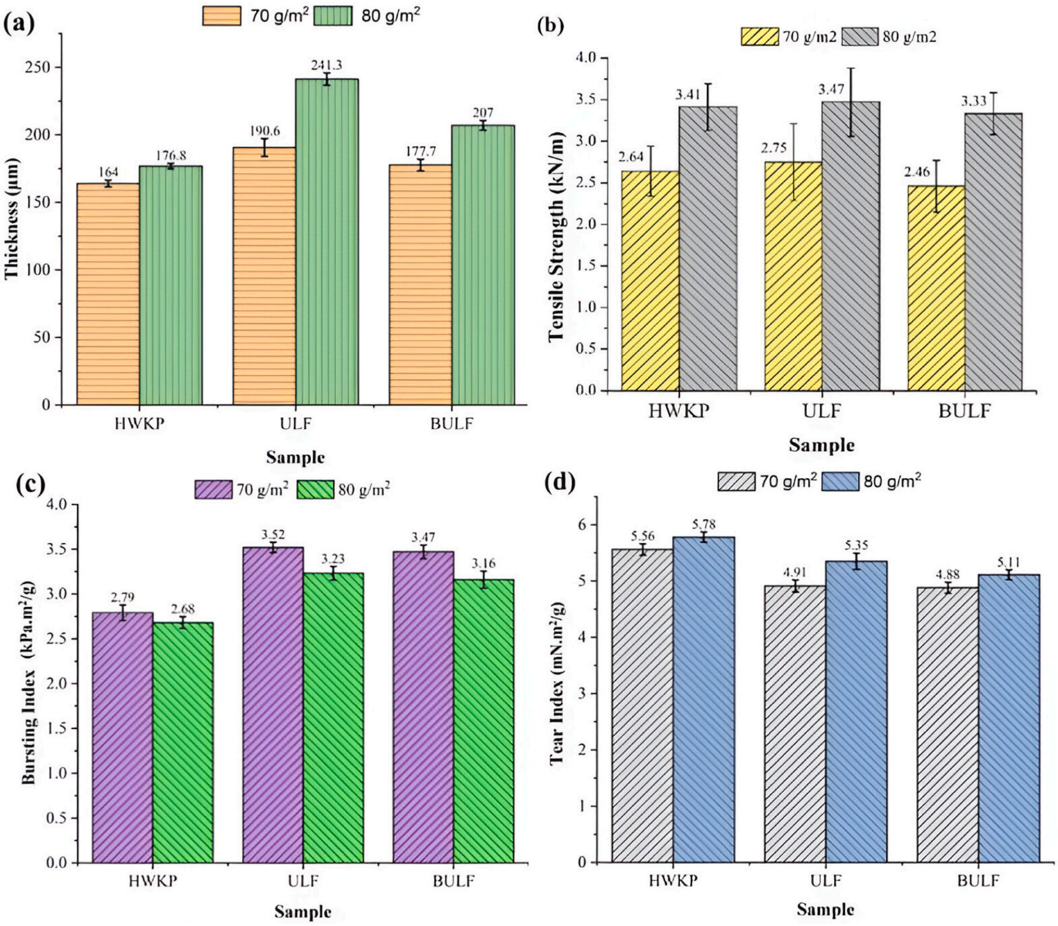


Fig. 5. Thickness(a), tensile strength (b), bursting index (c), and tear index (d) of handsheets made using HWKP, ULF and BULF at different surface densities.

Table 1
Bulk value of handsheets.

Sample	Bulk Value, cm^3/g	
	70 g/m^2	80 g/m^2
HWKP	2.34	2.21
ULF	2.72	3.02
BULF	2.54	2.59

Table 2
Comparison study of mechanical and optical properties with other bast fiber.

Particular	Brightness%	Tensile index (N·m/g)	Burst index (kPa·m^2/g)	Tear index (mN·m^2/g	Reference
Urena Lobata Fiber	81.61	41.62	3.16	5.11	Current study
Bagasse	86.38	58.96	3.41	6.6	[62,63]
Bamboo	87	25.8	1.2	12.1	[62,63]
Cotton stalks	39.2	25.2	1	5.6	[62,64]
Jute fiber	85	28.9	2.2	18.7	[59,62]
Rice straw	32.44	60.5	2.9	5.7	[62,65]
Wheat straw	78.6	36.1	2.14	5.6	[62,63]
Kenaf	28.40	52.4	7.2	14.7	[66]

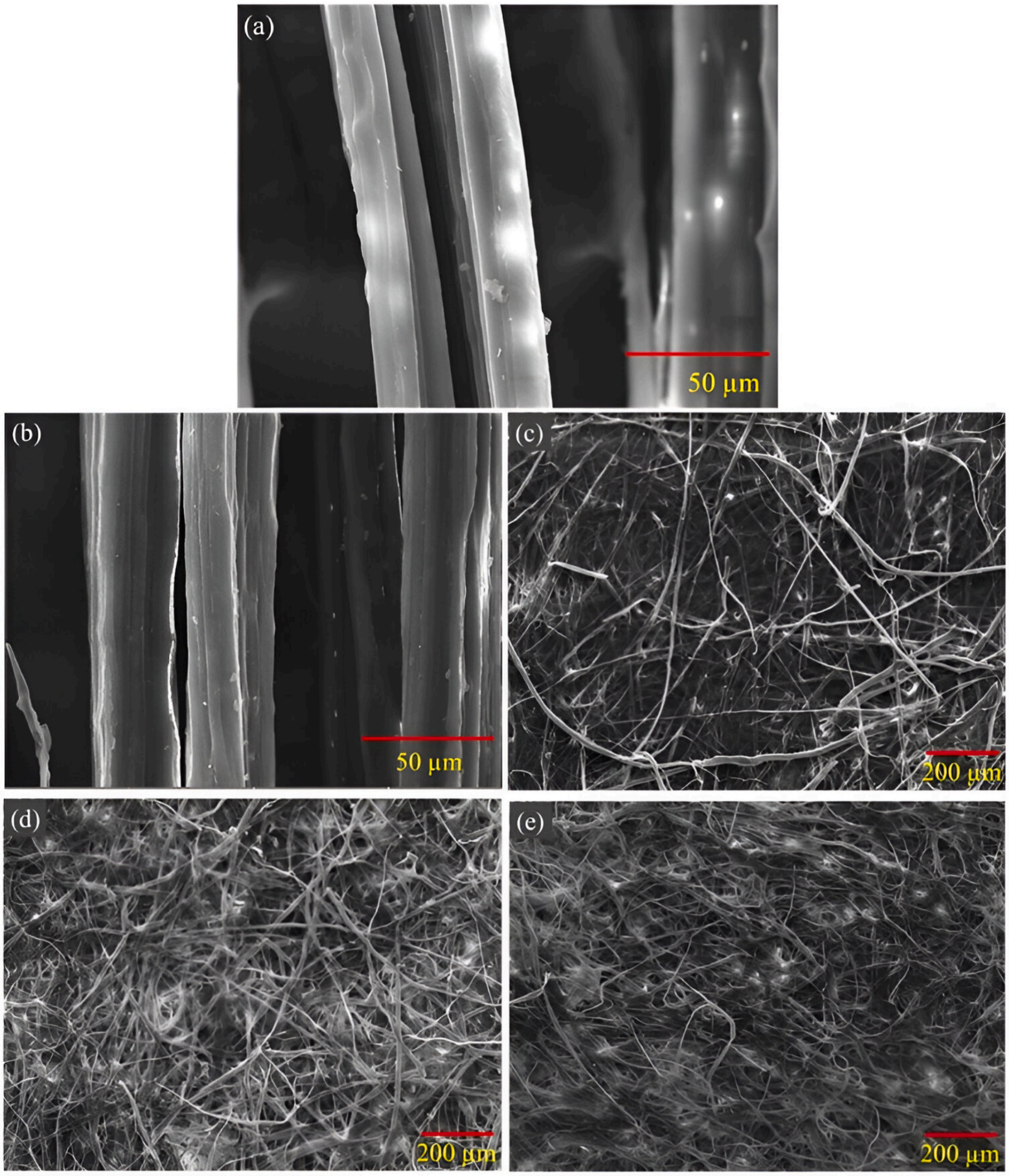


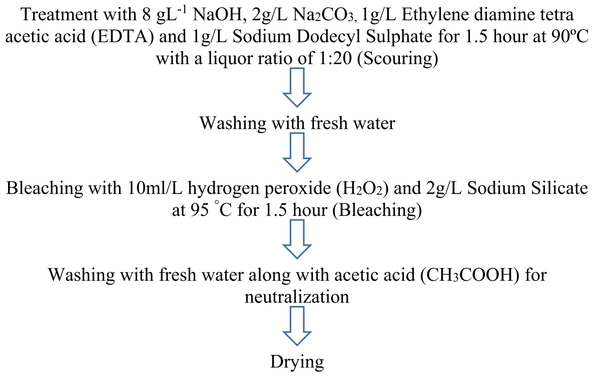
Fig. 6. SEM images of fibers ULF (a), BULF (b) at 1500 × magnification, and handsheets prepared with ULF (c), BULF (d) and HWKP (e) at 200 × magnification.

zenith tensile strength (2.75, 3.47 kN/m) and bursting index (3.53, 3.23 kPa m^2/g), while demonstrating a decrease in tear strength (5.36, 4.91 mN m^2/g). The BULF handsheets (70 g/m^2, 80 g/m^2) demonstrated modest values for tensile strength (2.46, 3.33 kN/m), bursting index (3.47, 3.16 kPa m^2/g), and tear index (5.12, 4.87 mN m^2/g). Besides these, handsheets by BULF appeared to have better surface smoothness than ULF handsheets.

The derived handsheet of ULF has the potential to be employed in the production of newspapers, magazines, tissue and packaging papers. The use of BULF in the production of handsheets demonstrates its viability as a material for the creation of text paper, filtration paper, writing and printing papers. Very slight differences in brightness% was observed in the prepared handsheet but this can be overlooked in the targeted application. In the future, enzymatic assisted biological pulping will be introduced in ULF pulping.

Ethics approval and consent to participate

The ethical approval and consent have been obtained where necessary. Where approval has been waived, credit has been given via appropriate citation.



Flow chart 1. Preparation of bleached Urena Lobata fiber (BULF).

Table 3
Paper manufacturing cost from different pulp.

Sample type	Raw material cost per 100 kg, $	UL processing cost per 100 kg, $	Chemicals cost per 100 kg, $	Manufacturing cost per 100 kg, $	Total cost per 100 kg, $
Commercial HWKP	80	–	–	32	112
ULF	0	25.5	–	32	57.5
BULF	0	25.5	43.5	32	101

Consent for publication

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Data will be made available on request.

CRediT authorship contribution statement

Sadikur Rahman: Writing – original draft, Resources, Methodology, Investigation, Formal analysis, Conceptualization. **Kamrul Hasan:** Writing – original draft, Validation, Resources, Methodology, Investigation, Data curation. **Md. Reazuddin Repon:** Writing – review & editing, Visualization, Validation, Supervision, Software, Resources, Methodology, Funding acquisition, Conceptualization. **Md. Mahbubul Haque:** Writing – review & editing, Software, Resources, Methodology.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

[1] L.A. Worku, et al., Agricultural residues as raw materials for pulp and paper production: overview and applications on membrane fabrication, Membranes 13 (2) (2023) 228.
[2] P. Bajpai, Green Chemistry and Sustainability in Pulp and Paper Industry, Springer, 2015.
[3] P. Bajpai, Biermann's Handbook of Pulp and Paper: Volume 1: Raw Material and Pulp Making, Elsevier, 2018.
[4] F. Mannai, et al., Cellulose fiber from Tunisian Barbary fig "Opuntia ficus-indica" for papermaking, Cellulose 23 (2016) 2061–2072.
[5] F. Mannai, et al., Alkaline delignification of cactus fibres for pulp and papermaking applications, J. Polym. Environ. 26 (2018) 798–806.
[6] A.S. Ullah, S. Shahinur, H. Haniu, On the mechanical properties and uncertainties of jute yarns, Materials 10 (5) (2017) 450.
[7] M. Ali, T. Sreekrishnan, Anaerobic treatment of agricultural residue based pulp and paper mill effluents for AOX and COD reduction, Process Biochem. 36 (1–2) (2000) 25–29.
[8] W.A. Laftah, W.A. Wan Abdul Rahman, Pulping process and the potential of using non-wood pineapple leaves fiber for pulp and paper production: a review, J. Nat. Fibers 13 (1) (2016) 85–102.
[9] E.S. Abd El-Sayed, M. El-Sakhawy, M.A.-M. El-Sakhawy, Non-wood fibers as raw material for pulp and paper industry, Nord. Pulp Pap Res. J. 35 (2) (2020) 215–230.
[10] A.M. Adel, et al., Microfibrillated cellulose from agricultural residues. Part I: papermaking application, Ind. Crop. Prod. 93 (2016) 161–174.
[11] S.M.M. Mousavi, et al., Papermaking potential of rapeseed straw, a new agricultural-based fiber source, J. Clean. Prod. 52 (2013) 420–424.
[12] H.A. Saeed, et al., Sudanese agro-residue as a novel furnish for pulp and paper manufacturing, Bioresources 12 (2) (2017) 4166–4176.
[13] A. Nayak, B. Bhushan, An overview of the recent trends on the waste valorization techniques for food wastes, J. Environ. Manag. 233 (2019) 352–370.
[14] D. Kaur, N.K. Bhardwaj, R.K. Lohchab, A study on pulping of rice straw and impact of incorporation of chlorine dioxide during bleaching on pulp properties and effluents characteristics, J. Clean. Prod. 170 (2018) 174–182.
[15] S. Rahman, A.J. Uddin, Unusable cotton spinning mill waste: a viable source of raw material in paper making, Heliyon 8 (8) (2022) e10055.
[16] S.H. Osong, S. Norgren, P. Engstrand, Processing of wood-based microfibrillated cellulose and nanofibrillated cellulose, and applications relating to papermaking: a review, Cellulose 23 (2016) 93–123.
[17] M. Pydimalla, H.V. Chirravuri, A.N. Uttaravalli, An overview on non-wood fiber characteristics for paper production: sustainable management approach, Mater. Today: Proc. 92 (2023) 1–9.
[18] M.S. Jahan, M.M. Rahman, Y. Ni, Alternative initiatives for non-wood chemical pulping and integration with the biorefinery concept: a review, Biofuels, Bioproducts and Biorefining 15 (1) (2021) 100–118.
[19] M.A. Azeez, Pulping of Non-woody Biomass. Pulp and Paper Processing, 2018, pp. 55–86.
[20] M.S. Jahan, A. Al-Maruf, M. Quaiyyum, Comparative studies of pulping of jute fiber, jute cutting and jute caddis, Bangladesh J. Sci. Ind. Res. 42 (4) (2007) 425–434.
[21] H.T. Sahin, R.A. Young, Auto-catalyzed acetic acid pulping of jute, Ind. Crop. Prod. 28 (1) (2008) 24–28.
[22] S.N. Bag, U.C. Kumar, A.K. Pal, Status and scope of the jute industry in India in comparison to other world producers, Fibres Text. East. Eur. 6 (120) (2016) 19–25.
[23] H.M. Feroz, J. Nahar, M. Rahman, Eco-friendly jute processing in Bangladesh, J. Chem. Eng. 26 (2011) 70–74.
[24] R. Kumar, Indian jute industry and its future, Int. J. Bus. Gen. Manag. 6 (4) (2017) 21–32.
[25] M.S. Jahan, et al., Alternative pulping process for producing dissolving pulp from jute, Bioresources 3 (4) (2008) 1359–1370.
[26] G. Nong, et al., Preparing tea filter papers with High air permeability from jute fibers for fast leaching, Ind. Crop. Prod. 140 (2019) 111619.
[27] M.S. Jahan, B.G. Gunter, A. Rahman, Substituting wood with nonwood fibers in papermaking: a win-win solution for Bangladesh, Bangladesh Development Research Working Paper Series (BDRWPS) 4 (2009).
[28] J.C. Del Rio, et al., Structural characterization of the lignin from jute (Corchorus capsularis) fibers, J. Agric. Food Chem. 57 (21) (2009) 10271–10281.
[29] A.A. Enayati, et al., Papermaking potential of canola stalks, Bioresources 4 (1) (2009).
[30] P. Bajpai, Biotechnology for Pulp and Paper Processing, Springer, 2012.
[31] C. Sharma, S. Kumar, Detection of chlorophenolics in effluents from bleaching processes of rice-straw pulp, J. Environ. Monit. 1 (6) (1999) 569–572.
[32] M.S. Jahan, D.N. Chowdhury, M.K. Islam, Characterization and evaluation of golpata fronds as pulping raw materials, Bioresour. Technol. 97 (3) (2006) 401–406.
[33] M.T. Islam, M.A. Uddin, A revision on Urena lobata L, Int. J. Med. 5 (1) (2017) 126–131.
[34] K. Hasan, et al., A sustainable approach to utilize an agro-based weedy plant "Urena lobata" in blend yarn manufacturing in short-staple ring spinning, Cellulose (2023) 1–13.
[35] S.S. Babu, D.B. Madhuri, S.L. Ali, A pharmacological review of Urena lobata plant, Asian J. Pharmaceut. Clin. Res. 9 (2) (2016) 20–22.
[36] C.E. Njoku, et al., Characterization of Urena lobata fibers after alkaline treatment for use in polymer composites, J. Nat. Fibers 19 (2) (2022) 485–496.
[37] P.K. Jena, et al., Utilization of chemically modified novel urena lobata fibers as reinforcement in polymer composites–an experimental study, J. Nat. Fibers 19 (7) (2022) 2479–2489.
[38] C.E. Njoku, et al., Physical and abrasive wear behaviour of Urena lobata fiber-reinforced polymer composites, J. Reinforc. Plast. Compos. 40 (9–10) (2021) 341–351.
[39] A.G. Wedaïna, et al., Performance of unidirectional biocomposite developed with Piptadeniastrum Africanum tannin resin and Urena Lobata fibers as reinforcement, J. Renew. Mater 9 (2021) 477–493.
[40] O.O. Fasanya, et al., Characterization of Sansevieria liberica & Urena lobata fibers as potential sorbent materials for crude oil clean up, J. Nat. Fibers 19 (5) (2022) 1756–1771.
[41] C. Njoku, et al., Chemical modification of Urena lobata (Caeser weed) fibers for reinforcement applications, in: Journal of Physics: Conference Series, IOP Publishing, 2019.
[42] Y. Purnomo, et al., Anti-diabetic potential of Urena lobata leaf extract through inhibition of dipeptidyl peptidase IV activity, Asian Pac. J. Trop. Biomed. 5 (8) (2015) 645–649.
[43] E. Fagbohun, R. Asare, A. Egbebi, Chemical composition and antimicrobial activities of Urena lobata L.(Malvaceae), J. Med. Plants Res. 6 (12) (2012) 2256–2260.
[44] A.K. Yadav, V. Tangpu, Antidiarrheal activity of Lithocarpus dealbata. and Urena lobata. Extracts: therapeutic implications, Pharmaceut. Biol. 45 (3) (2007) 223–229.
[45] M.S. Ali, K.O. Faruq, M.A.A. Rahman, Antioxidant and cytotoxic activities of methanol extract of Urena lobata (L) Leaves, Pharma Innov. 2 (2) (2013).
[46] TAPPI, Forming Handsheets for Physical Tests of Pulp July 11, 2006 TAPPI..
[47] S. Gharehkhani, et al., Basic effects of pulp refining on fiber properties—a review, Carbohydr. Polym. 115 (2015) 785–803.
[48] O. Garcia, et al., Effect of cellulase-assisted refining on the properties of dried and never-dried eucalyptus pulp, Cellulose 9 (2) (2002) 115–125.
[49] B.W. Jones, et al., Enhancement in enzymatic hydrolysis by mechanical refining for pretreated hardwood lignocellulosics, Bioresour. Technol. 147 (2013) 353–360.
[50] S. Park, et al., Hard to remove water in cellulose fibers characterized by high resolution thermogravimetric analysis-methods development, Cellulose 13 (1) (2006) 23–30.
[51] S. ISO, Pulps–Preparation of laboratory sheets for physical testing–Part. 1 (2005), 5269-1.
[52] TAPPI, Standard Conditioning and Testing Atmospheres for Paper, Board, Pulp Handsheets, and Related Products, TAPPI T 402 Sp-21, April 2013.
[53] J.-W. Rhim, Effect of moisture content on tensile properties of paper-based food packaging materials, Food Sci. Biotechnol. 19 (2010) 243–247.
[54] A.J. Ragauskas, Brightness properties of pulp and paper, Surface Analysis of Paper (2020) 109–118.

[55] E. Abdel-Halim, Simple and economic bleaching process for cotton fabric, Carbohydr. Polym. 88 (4) (2012) 1233–1238.
[56] Y. Ji, et al., Fiber evolution during alkaline treatment and its impact on handsheet properties, Bioresources 13 (4) (2018) 7310–7324.
[57] M.M. Nazhad, et al., The influence of formation on tensile strength of papers made from mechanical pulps, Tappi J. 83 (12) (2000).
[58] C. Saikia, T. Goswami, F. Ali, Evaluation of pulp and paper making characteristics of certain fast growing plants, Wood Sci. Technol. 31 (6) (1997) 467–475.
[59] M.S. Jahan, et al., Chemical characteristics of ribbon retted jute and its effect on pulping and papermaking properties, Ind. Crop. Prod. 84 (2016) 116–120.
[60] R. Wathén, Studies on Fiber Strength and its Effect on Paper Properties, 2006.
[61] J. Pere, et al., Influence of the hemicellulose content on the fiber properties, strength, and formability of handsheets, Bioresources 14 (1) (2019) 251–263.
[62] T. Ferdous, et al., Non-wood fibers: relationships of fiber properties with pulp properties, ACS Omega 6 (33) (2021) 21613–21622.
[63] S.N. Kazi, Pulp and Paper Processing, BoD–Books on Demand, 2018.
[64] M. Ali, M. Byrd, H. Jameel, Chemimechanical pulping of cotton stalks, in: Tappi Pulping Conference Proceeding, 2002.
[65] S.M. Jani, et al., Mechanical properties of beating pulp and paper from rice straw, J. Trop. Agric. Food Sci. 44 (2016) 103–109.
[66] L.S. Ang, C.P. Leh, C.C. Lee, Effects of alkaline pre-impregnation and pulping on Malaysia cultivated kenaf (Hibiscus cannabinus), Bioresources 5 (3) (2010).