SODA PULPING OF SUN HEMP (CROTALARIA JUNCEA L.) AND ITS USAGE IN MOLDED PULP PACKAGING

https://doi.org/10.5281/zenodo.15184243

B.B. Amanturdiev
candidate of Agricultural sciences. Head of the Department of breeding and seed production of medicinal plants.
E.R. Abdimusaev
senior researcher.
Scientific and production Center for the cultivation and processing of medicinal plants.

Abstract

Petroleum-based materials are often used in the packaging industry. However, the single use value of such products can be problematic with regard to proper waste disposal. As such, molded pulp packaging can be used as an alternative, given its ease of recycling, composting, and eventual biodegradation. In this work, we aim to study the pulp properties of sun hemp and its usage as molded pulp products. For this purpose, unbleached beaten and unbeaten soda pulps derived from the whole stem of sun hemp were examined for their fiber morphology, fibrillation, fiber classification, and physical properties. The sun hemp pulp was subsequently molded using a batch molding machine. To determine the hydrophobicity of the molded pulp products, the molded samples were manufactured with and without additives. Finally, some properties of the molded pulp products were examined and compared with the commercially available bleached bagasse molded pulp products. It was observed that the molded products made from sun hemp pulp with additives had a higher water contact angle than that of the commercial products. In terms of general usage, the molded products from sun hemp pulp with additives were found to be capable of storing hot water, hot cooking oil, as well as microwaving water. We concluded that the sun hemp pulp could be used as an alternative fibrous raw material in the production of molded pulp packaging.

Keywords

Contact angle, fiber classification, fibrillation, molded pulp, soda pulping, sun hemp.

1. Introduction

Molded pulps used in the packaging industry are often made with cellulosic fiber materials. Such materials, which are made from sustainable and renewable sources, can reduce the dependence on plastic-based products and might eventually replace them. In recent years, molded pulp manufacturing has seen increased interest and development, and molded pulps have been widely used in packaging logistics and other fields as a potential substitute for plastic and solid wood (Didone and Tosello, 2018; Debnath et al., 2022). Many investigators have studied the use of biodegradable materials as a substitute for conventional petroleum-based plastics (Didone and Tosello, 2018; Wang et al., 2018; Liu et al., 2020; Debnath et al., 2022). In general, the pulp molding industry uses cellulosic fiber similar to that used by the pulp and papermaking industry, in which the final product can be classified based on source into three categories: wood, non-wood, and recycled paper. Non-wood material is an important source of fiber in areas where forest resources are scarce. Tree plantations generally provide the wood needed for making sustainable raw materials, given their economic viability and higher fiber yield to meet the market demand. However, the inordinate exploitation of forests during the past decades for pulp and papermaking has led to enormous deforestation, causing environmental imbalances and loss of forest ecological function (Sharma et al., 2018; Wang et al., 2018).

In order to sustainably address the deficit in the supply of raw materials, a major step taken by the paper industry is to utilize waste materials like bagasse, straw, grasses, waste paper etc., for making paper and paperboards (Fahmy et al., 2017; Sharma et al., 2018). The use of non-wood fibers to produce pulp and paper can help to prevent any further cutting of rainforests or primeval forests. The added advantage of non-wood plants as a fiber resource is their fast annual growth and a relatively low amount of lignin that binds the fibers together. Another benefit of non-wood materials is that the pulp can be produced at lower temperature with a less amount of chemical charges (Sridach, 2010; Alila et al., 2013). Many researchers have reported that pulp is molded from bio-based materials, such as cereal straw, bamboo, and sugarcane bagasse (Curling et al., 2017; Liu et al., 2020). The molded pulp made from non-wood represents an eco-friendly, low-cost, and biodegradable alternative to synthetic plastics used in packaging.

The *Crotalaria juncea* L. belongs to the Fabaceae family and is commonly known as sun hemp or Indian hemp. It is widely found in the tropical and subtropical regions of India, Nepal, Sri Lanka, and Southern Africa, and is known for its high-quality fiber (Tripathi et al., 2013). It is mainly grown as a fiber crop and is frequently used in the traditional manufacturing of ropes, strings, twines, floor mats, and fishing nets. It has seen renewed interest since the late 2000s as its fiber is reported to be environmentally friendly compared with synthetic fibers and has valuable characteristics for the paper industry (Sengupta and Debnath, 2018). Moreover, sun hemp can be used effectively as a rotation crop or even as a row rotation crop to increase the nitrogen content of the soil. Previously, White and Haun (1965) reportedly sun hemp as a promising new annual pulping material for use in USA. Its favorable properties cited were little or no need for nitrogen fertilization, ability to grow in poor soils, and drought resistance, with some strains having resistance to nematodes. In addition, Cunningham et al. (1978) and Tripathi et al. (2013) stated that the bast fiber of sun hemp is a versatile material and can be used in the manufacturing of high-quality tissue paper and cigarette papers in India. The major constituents of sun hemp fibers are cellulose and pentosan (Sengupta and Debnath, 2018). Hence, it is clear that sun hemp can be potentially used to make value-added products rather than just be used as a plant for fixing nitrogen. Thus, in the present study, we aimed to produce pulp from sun hemp using soda pulping to compare with the pulp derived from bagasse. With the intended purpose of usage in industrial molded pulp production, characteristics such as pulp morphology and hand sheet properties were evaluated. The selected sun hemp pulp was subjected to the molding process in an industrial molding machine, and its physical properties were compared with that of the commercial molded products.

2. Materials and methods

2.1 Materials

The whole stems of 6-month-old sun hemp were collected after seed harvesting from a plantation of green manure crop in Tashkent region, Uzbekistan. The stem height and diameter of sun hemp were 190 and 1,2 cm, respectively. The stems were cleaned of any leaves, roots, and soil. The air-dried stems were then cut into chips which were 2 inch in length and were stored in closed polyethylene bags for pulping. The properties were thus compared with commercial grade bleached bagasse pulp and molded pulp available in Uzbekistan.

2.2 Chemical properties

The stalks were split into small pieces and ground to a coarse powder according to the TAPPI T-257 cm-02 standard to determine the chemical composition using a laboratory mill (Thomas-WILEY Model 4, Arthur H. Thomas Company, USA). The sample was then screened to obtain a powder of particle size that could pass through a mesh ranging between 0.25 and 0.42 mm. The chemical composition of sun hemp was determined according to TAPPI standard test methods, i.e., preparation of the sample for chemical analysis (TAPPI T 264 cm-07), alpha cellulose (TAPPI T 203 cm-09), pentosan (TAPPI T 223 cm-10), acid-insoluble lignin (TAPPI T 222 om-15), solvent extractives in acetone (TAPPI T 204 cm-17), and ash (TAPPI T 211 om-16). The holocellulose content was determined according to the extraction method described by Wise et al. (1946).

2.3 Morphological characteristics

Sun hemp stalk samples were macerated with the Franklin's solution in glacial acetic acid and 30% hydrogen peroxide (in a ratio of 1:1) at 60 °C for 48 h in a water bath, until the color of the stick became white. After maceration, the sun hemp fibers were rinsed with distilled water and then disintegrated and stained with 1% safranin before the fiber morphology was analyzed with a transmitted light microscope (KF2-ICS, Carl Zeiss, Germany). The fiber length and width were determined using a fiber quality analyzer (FQA-360, Optus Equipment, Canada).

2.4 Soda pulping

Soda pulping was done in a laboratory rotating batch reactor (7-L Digester, SEW-Euro drive, Germany). An oven-dried equivalent amount of 300 g chips per cooking time was pulped with a variable percentage of active alkali Na_2O (20%, 22%, and 24%) at a ratio of 5:1 (liquor to sun hemp chips). Cooking was continued for 60 min until a target temperature of 165 °C was reached, and the setup was maintained at the temperature for another 120 min. At the end of pulping, the pressure was reduced to atmospheric pressure, and the black liquor was drained. The sun hemp pulp fibers were thoroughly washed until they were free of any residual cooking chemicals. The yield and pulp reject of the sun hemp pulp were calculated after washing and screened with a 0.15 mm slot screener. The kappa number of the pulp was determined according to the TAPPI T 236 om-06 standard.

2.5 Fiber classification

The fiber classification of sun hemp and bleached bagasse pulp fibers was done with a Bauer-McNatt classifier (Hangzhou Pusher Technology, China) using four slot plates (28, 48, 100, and 200 mesh) according to the TAPPI T 233 cm-15 standard. The mass of each fiber fraction was determined and expressed as a percentage of the over-dry initial pulp. Fiber length, fiber width, and fines content in each mesh was determined using a fiber quality analyzer (FQA-360, Optus Equipment, Canada).

2.6 Hand sheet properties

To compare the physical properties of sun hemp and bleached bagasse, which are used as raw material in the molded pulp production industry, both the pulps were beaten in a Valley beater (Kumagai Riki Kogyo, Japan) according to TAPPI T 200 sp-15 standard, for different beating times that included 0, 10, 20, and 30 min. After being beaten, the pulps were then measured for Canadian Standard Freeness (CSF) according to the TAPPI T 227 om-09 standard. The degree of fibrillation of the beaten pulps was determined using the Valmet fiber image analyzer (FS5, Valmet, Finland). A set of 10 hand sheets (60 g/m²) were formed for each of the beating time durations according to the TAPPI T 205 sp-06 standard. All hand sheets were conditioned at a relative humidity of (50 ± 2) % and a temperature of (23 ± 1) °C before testing. The apparent density and thickness were determined following the TAPPI T 220 sp-10 and TAPPI T 411 om-08 standards, respectively. The mechanical properties of the handsheet, i.e., tensile strength (TAPPI T 494 om-06), tearing strength (TAPPI T 414 om-04), bursting strength (TAPPI T 403 om-10), and folding endurance (TAPPI T 511 om-08), were determined by using a tensile tester (Thwing-Albert, USA), tearing resistance tester (Lorentzen and Wettre, Sweden), bursting strength tester (Lorentzen and Wettre, Sweden), and folding endurance tester (Kumagai Riki Kogyo, Japan), respectively.

2.7 Preparation of molded pulp from sunn hemp

The recommended freeness for mechanical mold production was limited to a minimum of 200 mL CSF. The sun hemp pulp obtained after different beating times (0, 10, and 20 min) was selected for making molded pulp through an industrial batch molding machine (Made in Fujian, China). Water retention aids and oil repellent agents were mixed with the pulp slurry under conditions similar to the processes used for making commercial products. Although the exact details of the chemicals are not reported for potential commercial reasons, the procedure consisted of the production of pulp slurry which was dehydrated in vacuum. After dehydration, the pulp was pressed and transferred for molding to a hot mold under a prescribed pressure and high temperature. To compare the hydrophobicity of the molded pulp products, the molded pulp samples were produced with and without additives.

2.8 Capability of molded pulp from sun hemp

The beating process can cause changes in fiber morphology and physical properties, which in turn can affect the quality of molded pulp. Therefore, the related data were analyzed and compared for: 1) the intrinsic mechanical properties of sun hemp pulp; 2) the performance of molded pulp products when compared with the commercial products.

2.8.1 Thickness, apparent density and bending resistance

The test specimens (Fig. 1) were conditioned at a room temperature of (23 ± 1) °C and relative humidity of (50 ± 2) % for 24 h. The thickness and basic weight of the molded pulp products were determined using a digital caliper and digital weighing scale accurate to three decimal places, respectively. The apparent density of the conditioned products was determined in accordance with the TAPPI T 220 sp-10 standard. The bending resistance of the molded pulp products was examined using a stiffness tester (150-B, Taber, USA) in accordance with the TAPPI T 489 om-08 standard.

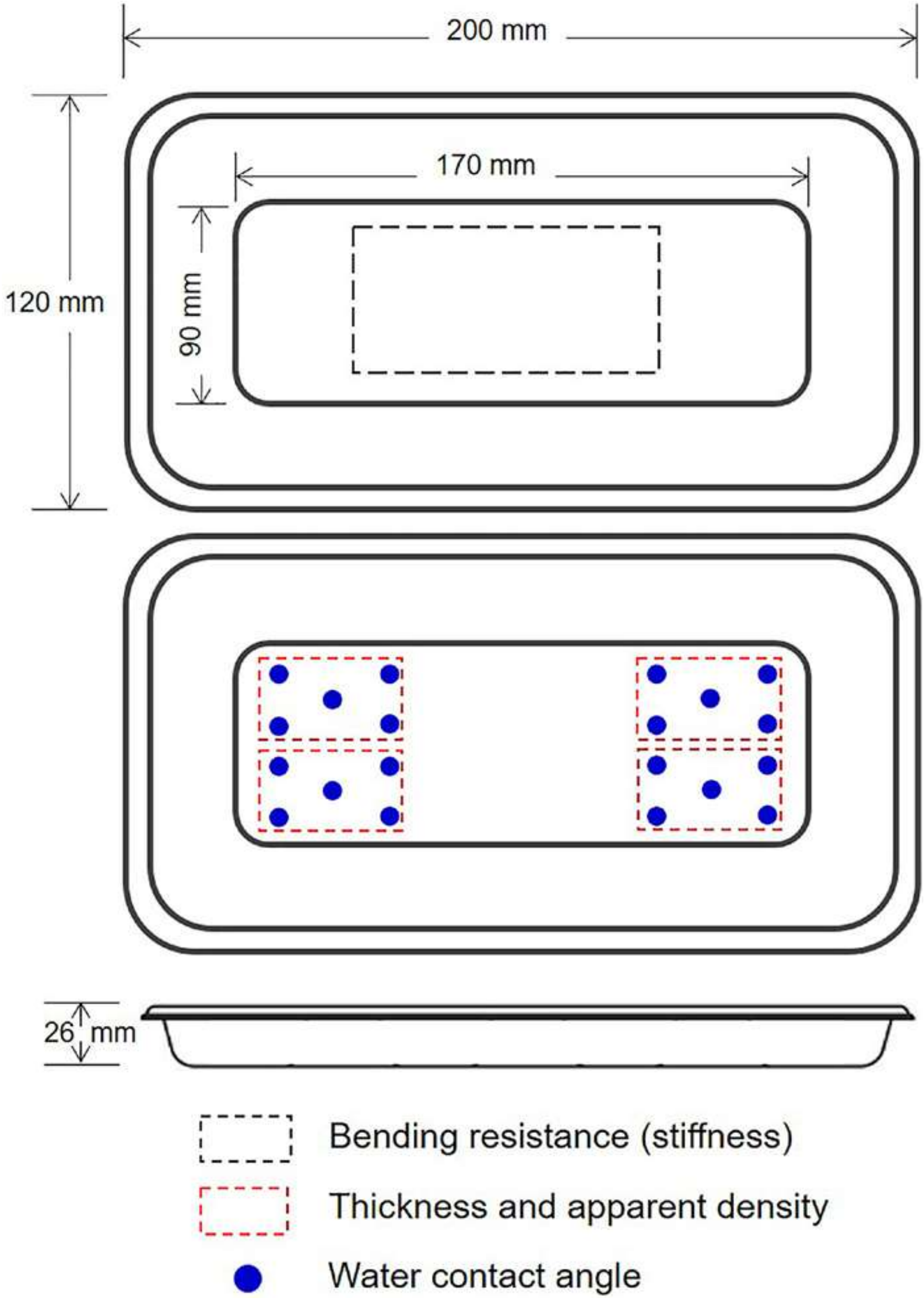

Figure 1. Cutting of test specimens for determination of bending resistance, thickness, basic weight, apparent density, and water contact angle.

2.8.2 Hydrophobic property, temperature-resistance and microwave heat-resistance

The hydrophobic property was characterized by measuring the water contact angle on the top surface of molded pulp products using a contact angle analyzer (OCA20, Dataphysics, USA) at ambient temperature. The position and dimensions of the test specimens for the determination of water contact angle were shown in Fig. 1. The temperature-resistance of the molded pulp was examined in accordance with the modified GB 18006—2008 standard. Approximately 50% of a sample volume of hot water (95 ± 5) °C or hot cooking oil (60 ± 5) °C was poured onto the test specimens for 10 min, which were observed for any deformations or traces of smearing, discoloration, or leakage. Heat-resistance to microwaving was examined in accordance with the modified GB 18006—2008 standard. Approximately 50% of the sample volume of water was poured into the sample molds, which were then heated in a microwave oven using a power of 1 300 W for 5 min. After the required heating time, the specimens were removed from the water, which were then cooled to room temperature to observe for any deformations, defects, leakages, as well as abnormalities.

2.9 Statistics analysis

The hydrophobic property, temperature resistance, and heat resistance of the sun hemp molded pulp products to microwaving were analyzed using the analysis of variance (ANOVA) at a confidence level of 95% using the R software (version 1.2.1578, RStudio Team, 2019).

3. Results and discussion

3.1 Chemical composition

The chemical composition of a lignocellulosic plant indicates the behavior of materials for pulping and papermaking purposes. Lignocellulosic materials contain cellulose, hemicellulose, lignin, and extractives in various amounts. Table 1 shows the chemical composition of sun hemp and its comparison with other lignocellulosic materials. The holocellulose content of sun hemp was lower than that of bagasse, rice straw, and kenaf, but was roughly similar to that of hardwood (Khakifirooz et al., 2012). The alpha cellulose content of sun hemp, which is related to the pulp yield, was 38.77%, and was considered acceptable for pulp production (cellulose > 34%) (Shakhes et al., 2011a; Sharma et al., 2011; Syed et al., 2016; Khantayanuwong et al., 2023). The lignin content of sun hemp was lower than that of bagasse but approximately around that of rice straw. A lower lignin content is suitable for pulping as it reduces the amount of consumed cooking chemicals. Pentosan content in sun hemp was similar to that of bamboo and eucalyptus (Sharma et al., 2011). The presence of hemicelluloses favors the formation of hydrogen bonds which in turn improves the derived paper properties (Syed et al., 2016). The extraneous material percentage in sun hemp was 2.29%, which can reduce the pulp yield and increase the amount of chemicals consumed when dissolved and extracted from the material. A higher ash content can cause problems during pulping and recovery of cooking liquor (Shakhes et al., 2011). The ash content of sun hemp was higher than that of bagasse but lower than that of rice straw.

Table 1. Chemical properties and morphological characteristics of sun hemp and other non-wood materials.

Parameter	Sun hemp	Bagasse[a]	Rice straw[b]
Holocellulose (%)	69.62 ± 0.49	74.77	70.85
Alpha cellulose (%)	38.77 ± 0.46	55.81	35.62
Lignin (%)	18.24 ± 0.15	20.35	17.20
Pentosans (%)	16.29 ± 0.71	–	24.50
Extractives (%)	2.29 ± 0.02	3.15	3.52
Ash (%)	2.43 ± 0.02	1.74	16.60
Fiber length (mm)	0.70 ± 0.02	1.59	0.89
Fiber width (μm)	29.00 ± 0.10	20.96	14.80
Source: a, Samariha and Khakifirooz, 2011; b, Tutus et al., 2004.			

3.2 Fiber morphology

The fiber morphological characteristics indicate the physical properties of raw materials and the obtained pulp. The average fiber length and width of sun hemp were 0.70 mm and 29 μm, respectively (Table 1), which was identical to that reported by Saikia et al. (1997). Sun hemp is categorized as a short wood fiber (0.7–1.5 mm), with the fiber width categorized as medium-narrow and within the range of hardwoods (18.0–30.0 μm) (Mazhari Mousavi et al., 2013). The fiber length was the dominant factor for tensile strength, one of the most crucial properties of paper and paperboard. Moreover, strength property depends on fiber bonding and intrinsic fiber strength. The original fiber characteristics and its processing determine the papermaking properties of final products (Ferdous et al., 2021).

Research related to the anatomy of sun hemp as a fiber material resource has been conducted for decades (Saikia et al., 1997; Sonje and Bhuktar, 2016). The microscopic structure of sun hemp fiber was shown in Fig. 2. The fiber contains long flat elements and some small cylindrical elements, as the fiber is derived from the whole stem, which includes both stem and bast fibers. Both types of vessel elements, i.e., long and spiral shaped and slender and beaked shaped elements, are present at one or both ends.

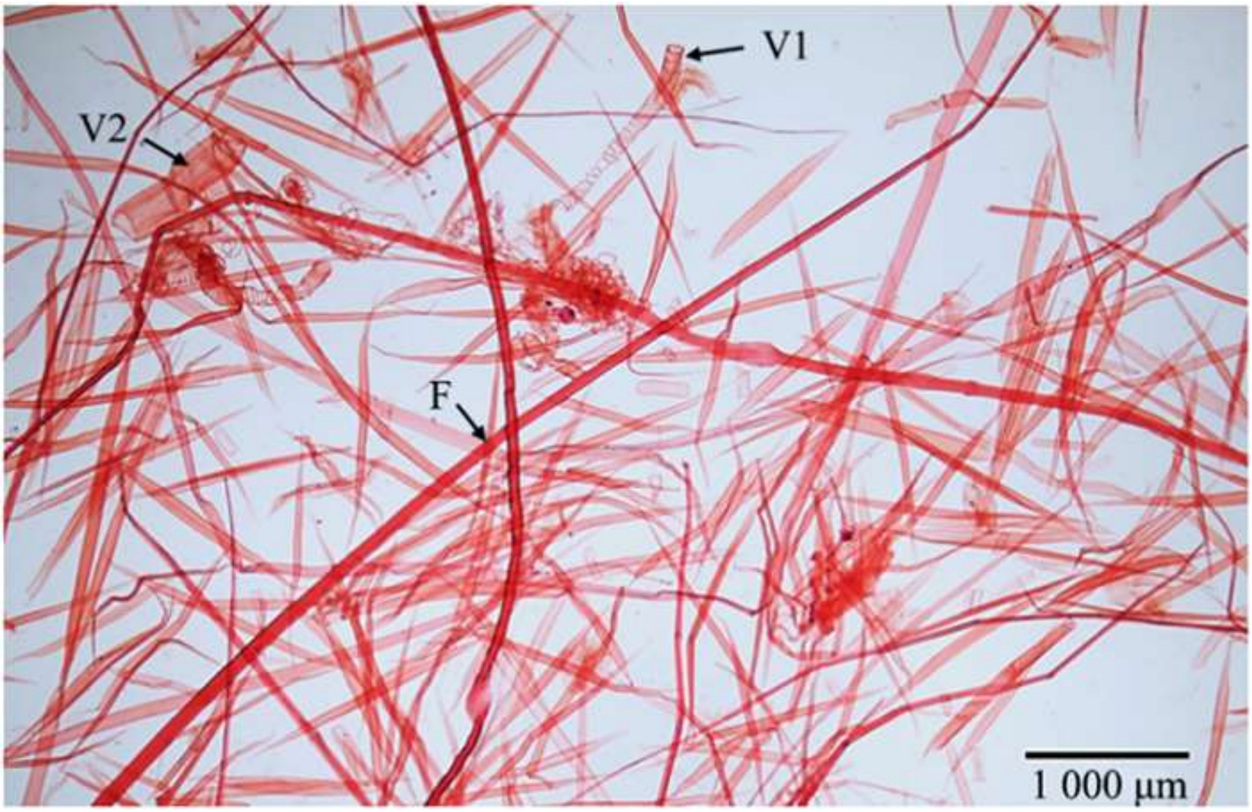

Figure 2. Images of macerated fibers derived from sun hemp as obtained from light microscope: F refers to fiber, V1 refers to long and spiral vessel elements, and V2 refers to slender and beaked vessel elements, at one or both ends.

3.3 Soda pulping.

Fig. 3 showed the active alkali and pulp properties of sun hemp, including pulp yield, Kappa number, and rejects during the pulping process. As expected, it was found that increasing the active alkali charge (from 20% to 24% as Na_2O basis) tended to decrease the pulp yield and Kappa number from 46.06% to 43.15% and 31.43 to 18.06, respectively. The pulp yield obtained from sun hemp, at a Kappa number of 20, was higher than that of bagasse and kens grass (Ferdous et al., 2020), but was lower than kenaf (Shakhes et al., 2011b) and rice straw (Bhardwaj et al., 2005). For pulping and bleaching purposes, pulp yield greater than 40% with Kappa number of around 20 is considered ideal to meet the product quality requirements. Therefore, in this study, the appropriate amount of active alkali recommended for producing sunn hemp pulp fiber was with a soda pulping of 24%.

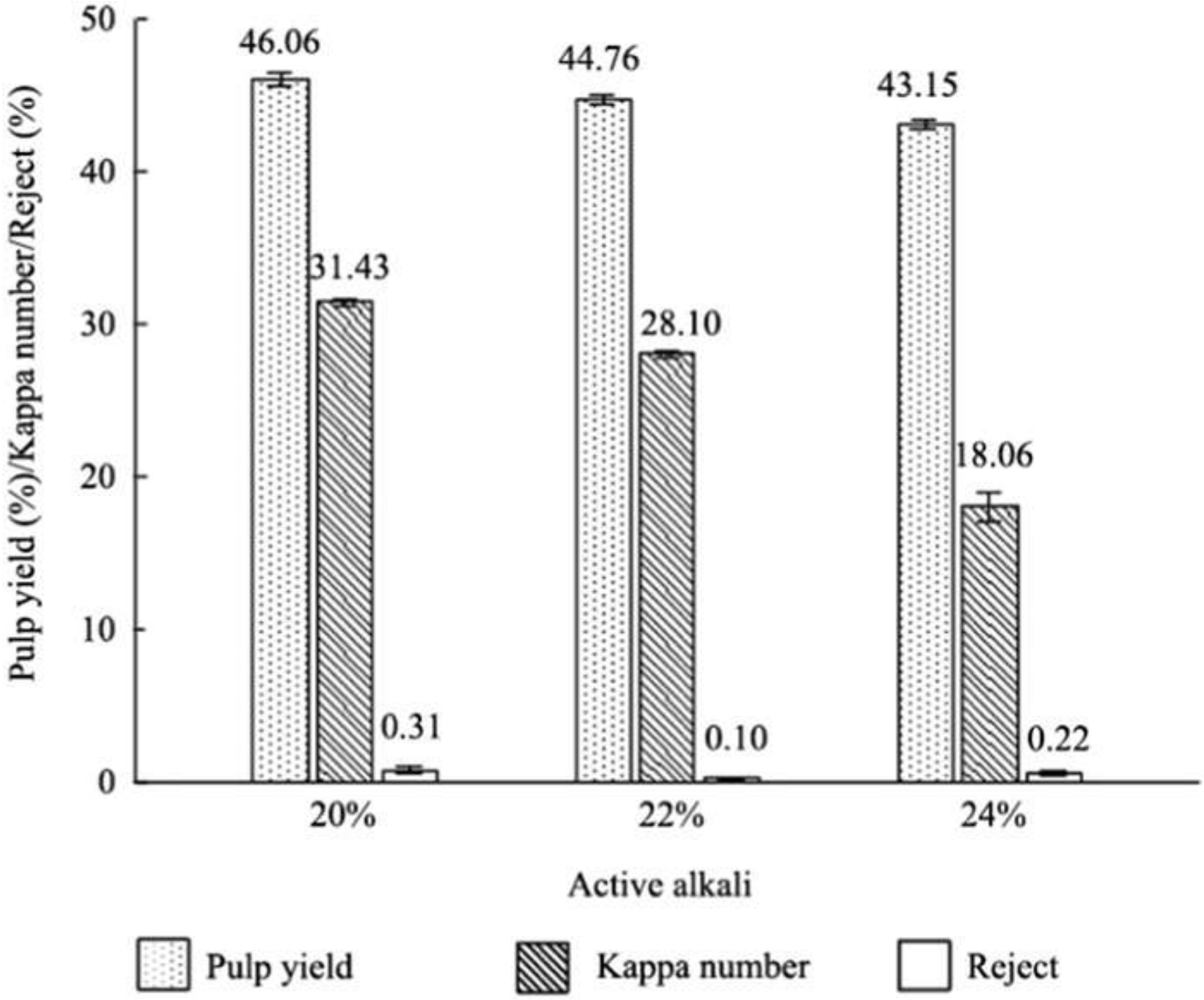

Figure 3. Changes in sun hemp pulp yield and Kappa number with various amounts of soda pulping.

3.4 Fiber classification.

Fiber ratio, fiber length, and fiber width in terms of the fiber fraction were shown in Fig. 4 and Table 2. The two groups of fiber lengths were either of the bast or stem fiber type. The first group that was retained on a R28–R48 screen was the bast fiber between lengths of 1.15 and 2.10 mm. The second group on a screen of R100–R200 had a total fiber ratio above 50% and fiber length range between 0.49 and 0.55 mm. The group of short length fibers could be assumed to be the stem fiber. This result corresponded with the fiber length obtained from fiber quality analyzer, which indicated that the sun hemp pulp fiber had an average length and width of 0.70 and 29.03 µm, respectively. The width of sun hemp pulp fiber ranged between 27.77 and 29.57 µm. Fines are defined as the fraction that can pass through the R200 screen. At almost 10% of fines, sun hemp had less fines than bleached bagasse. The results were similar to that of Saikia et al. (1997), who reported that sun hemp had a uniform fiber size distribution. The effects of mixing ratios on paper properties have been previously reported (Chauhan et al., 2011; Hassan et al., 2011; Lukmandaru et al., 2019; Nasroun, 2019), with long fibers acting as a reinforcing material, while short and fine fibers forming a good printing base. Short fibers can physically intertwine with long fibers to form tight networks that can further enhance the mechanical properties of the derived end products. We observed that the fiber mixing of two groups, i.e., short and long fibers, in a ratio of 70:30, enhanced the mechanical properties of the finished paper. Paper mills usually use 20%–30% long softwood fiber to improve the strength of paper sheets (Hassan et al., 2011; Nasroun, 2019). Therefore, sun hemp can be utilized in varying pulp mixtures to improve specific characteristics desirable in the final product.

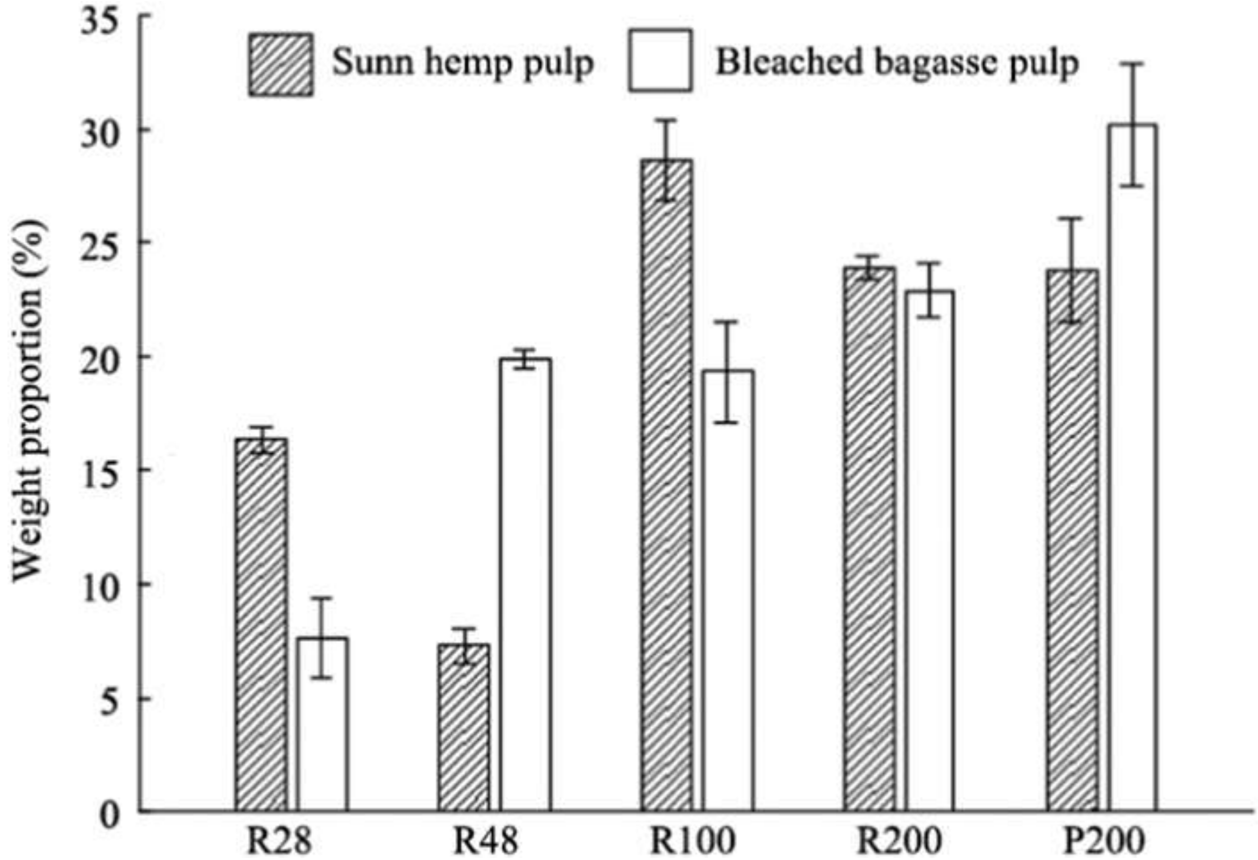

Figure 4. Mass fractions of sun hemp pulp and industrial bleached bagasse pulp, after Bauer-McNatt classification into five fiber length fractions.

Table 2. Fiber fractionation of sun hemp pulp and industrial bleached bagasse pulp.

Fiber fraction	Sun hemp			Bleached bagasse	
	Fiber length (mm)	Fiber width (µm)		Fiber length (mm)	Fiber width (µm)

AMERICAN JOURNAL OF EDUCATION AND LEARNING
ISSN: 2996-5128 (online) | ResearchBib (IF) = 9.918 IMPACT FACTOR
Volume-3| Issue-4| 2025 Published: |30-04-2025|

Fiber fraction	Sun hemp		Bleached bagasse	
	Fiber length (mm)	Fiber width (µm)	Fiber length (mm)	Fiber width (µm)
R28	2.10 ± 0.11	29.60 ± 0.40	1.90 ± 0.02	30.60 ± 0.20
R48	1.15 ± 0.00	29.10 ± 0.10	1.33 ± 0.00	30.10 ± 0.10
R100	0.55 ± 0.00	28.70 ± 0.20	0.68 ± 0.00	28.80 ± 0.20
R200	0.49 ± 0.00	28.70 ± 0.20	0.49 ± 0.00	27.90 ± 0.10
P200	0.45 ± 0.00	27.80 ± 0.20	0.39 ± 0.00	27.90 ± 0.50

Notes: R28, R48, R100, and R200 represent pulp fractions retained on the 28-, 48-, 100-, and 200-mesh screen; P200 represents pulp fraction passing through the 200-mesh screen.

3.5 Hand sheet properties.

Table 3 presents the fiber characteristics of sun hemp pulp and bleached bagasse pulp after the beating process. As the beating time was gradually increased, fibrillation and tiny components became evident on the surface of the loose fibers, with shortened length and reduced width. The results indicate that the fine contents of sun hemp increased from 4.93% to 5.81%, whereas that in bleached bagasse increased from 14.80% to 17.50%. As beating increased both fiber flexibility and collapsibility, so did the degree of fibrillation. Beating produced several tiny fibers in the pulp, which could fill up the gaps between the long fibers, increasing the number of hydrogen bonds and improving fiber network (Khantayanuwong et al., 2021).

Table 3. Effect of beating times on fibers morphology and degree of fibrillation between sun hemp pulp and industrial bleached bagasse pulp.

Item	Fiber length (mm) Sun hemp	Fiber width (µm)	Fines content (%)	Degree of fibrillation (%)
0 min (unbeaten)	0.72 ± 0.01	28.40 ± 0.10	4.93 ± 0.06	1.29 ± 0.01
10 min	0.70 ± 0.01	28.30 ± 0.10	5.01 ± 0.10	1.49 ± 0.02
20 min	0.67 ± 0.02	28.40 ± 0.10	5.32 ± 0.06	1.69 ± 0.03
30 min	0.64 ± 0.02	28.50 ± 0.10	5.81 ± 0.11	1.87 ± 0.04
Item	Bleached bagasse			
0 min (unbeaten)	0.90 ± 0.01	29.10 ± 0.00	14.80 ± 0.10	1.28 ± 0.02

AMERICAN JOURNAL OF EDUCATION AND LEARNING
ISSN: 2996-5128 (online) | ResearchBib (IF) = 9.918 IMPACT FACTOR
Volume-3| Issue-4| 2025 Published: |30-04-2025|

Item	Fiber length (mm) Sun hemp	Fiber width (µm)	Fines content (%)	Degree of fibrillation (%)
10 min	0.86 ± 0.01	29.30 ± 0.10	15.33 ± 0.12	1.51 ± 0.03
20 min	0.78 ± 0.00	29.50 ± 0.10	16.17 ± 0.12	1.77 ± 0.02
30 min	0.69 ± 0.01	30.00 ± 0.20	17.50 ± 0.15	2.11 ± 0.02

The physical properties of sun hemp and bleached bagasse beaten pulps are shown in Fig. 5. The freeness of both pulps gradually decreased with the increased beating time. A lower fines content in sun hemp exhibited a higher CSF compared with the bleached bagasse pulps. The freeness value of both pulps gradually decreased due to swelling and fibrillation of the fiber wall as well as fines generated during the beating process.

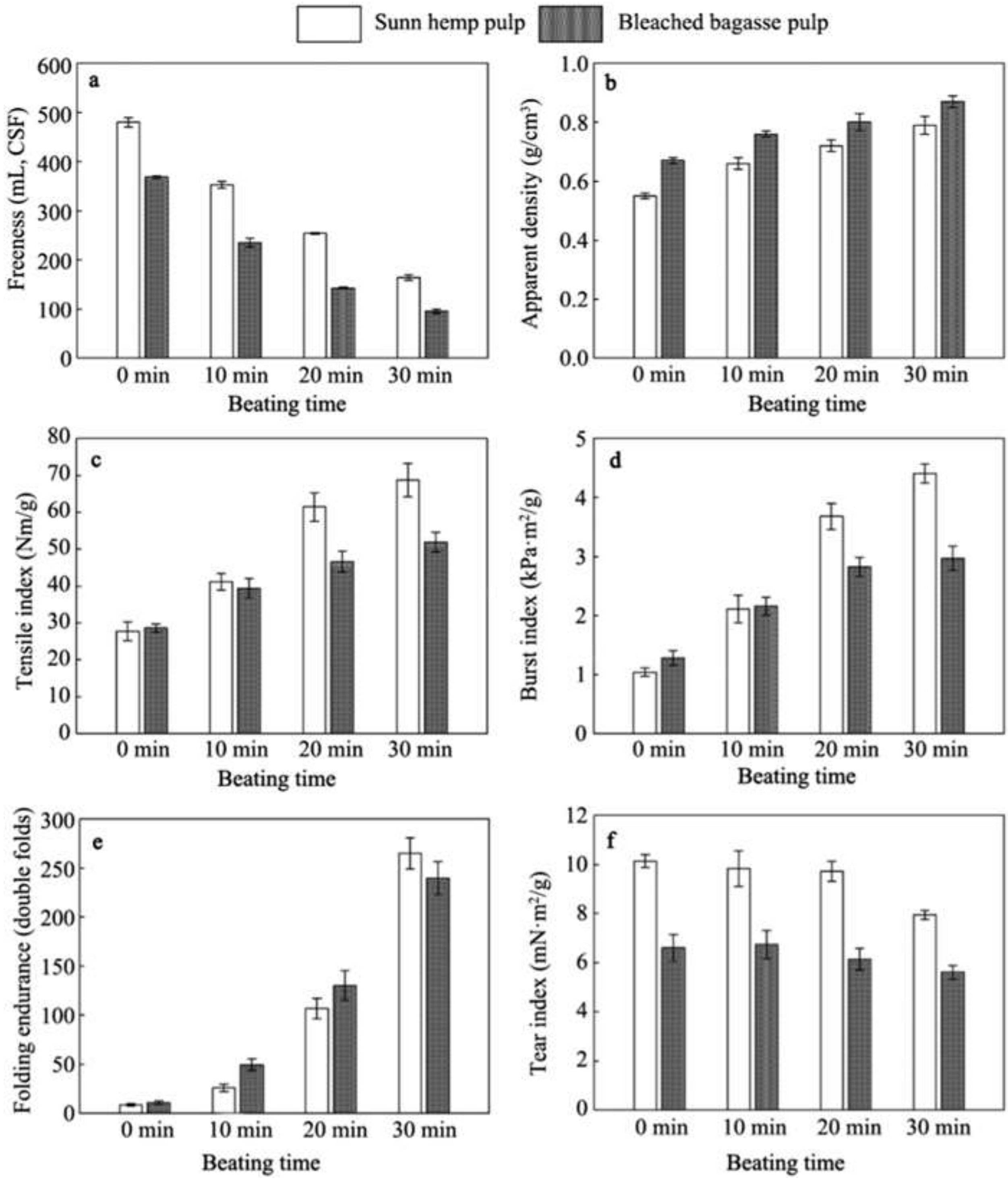

Figure 5. Hand sheet properties of sun hemp pulp and bleached bagasse pulp subjected to various beating time.

The apparent density, tensile index, burst index, and folding endurance of hand sheets increased with the increased beating time (Fig. 5b-e). The beating process enhanced the internal delamination and fibrillation in the pulp fibers, increasing the bonding ability as well as collapsibility resulting from the beating process. The tensile strength after the beating of sun hemp pulps was consistently higher than that of the bleached bagasse pulps. However, beating might decrease

AMERICAN JOURNAL OF EDUCATION AND LEARNING
ISSN: 2996-5128 (online) | ResearchBib (IF) = 9.918 IMPACT FACTOR
Volume-3| Issue-4| 2025 Published: |30-04-2025|

the tearing strength of hand sheets derived from both pulps due to fiber shortening during the beating process (Fig. 5f). The tear index of sun hemp hand sheets was also higher than that of bagasse hand sheets.

3.6 Quality analysis of molded pulp from sun hemp.

3.6.1 Thickness, apparent density and bending resistance of molded pulp

The thickness and apparent density of molded pulp obtained from sun hemp and industrial bagasse molded are plotted in Fig. 6. The thickness of sun hemp molded pulp was not different between the unbeaten and beaten pulp due to the quality control of the molding process to obtain a specific weight. However, the sun hemp molded materials were significantly thinner ($P < 0.05$) than the commercial products.

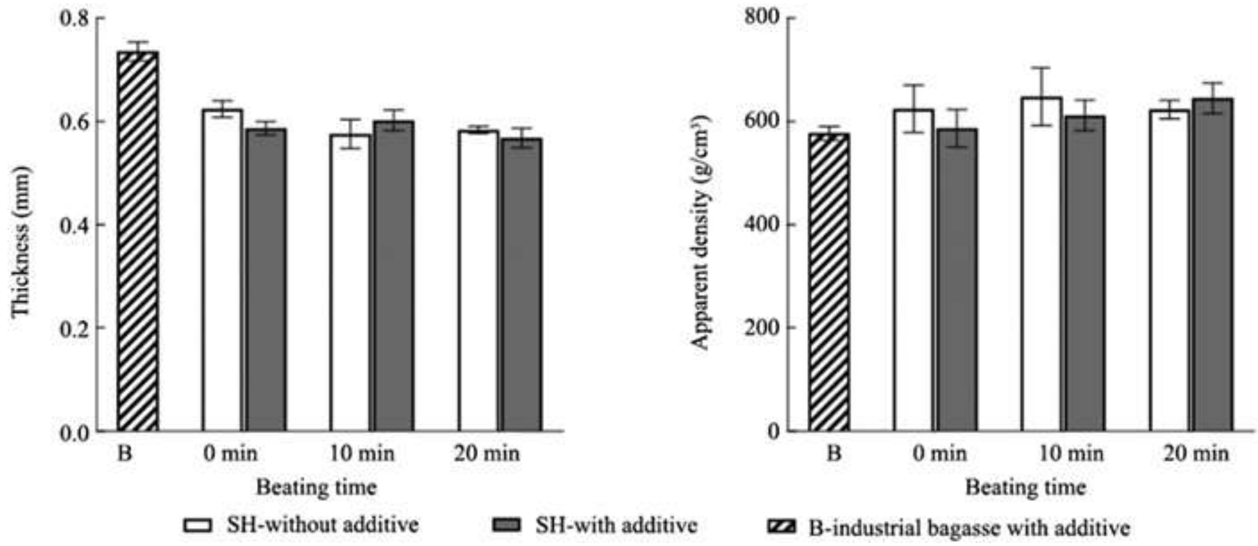

Figure 6. Thickness and apparent density of molded sun hemp pulp samples compared with commercial molded pulp products after subjecting to various beating time.

The apparent density of molded pulp products indicated that the sun hemp based molded materials had a higher apparent density ($P < 0.05$) than the commercial products. As a result, the weight per unit area of sun hemp molded pulp products was much higher.

The bending stiffness of sun hemp molded pulp, with the industrial bagasse molded pulp was shown in Fig. 7. The bending stiffness was not significantly different ($P > 0.05$) between the sun hemp and bagasse molded pulp products. On the other hand, the beating process tended to decrease the bending stiffness of the sun hemp molded pulp.

AMERICAN JOURNAL OF EDUCATION AND LEARNING
ISSN: 2996-5128 (online) | ResearchBib (IF) = 9.918 IMPACT FACTOR
Volume-3| Issue-4| 2025 Published: |30-04-2025|

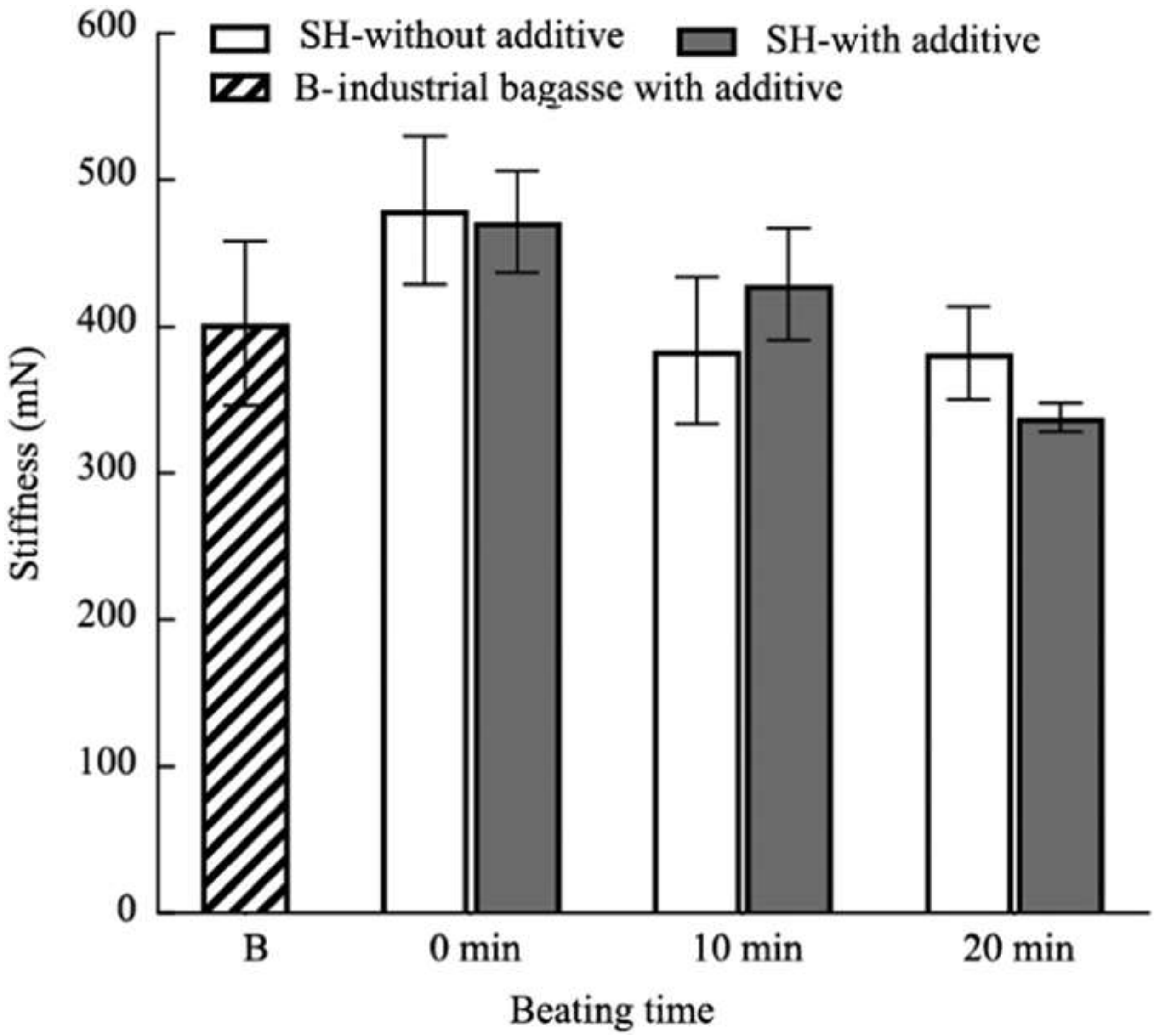

Figure 7. Bending stiffness of molded sun hemp pulp samples compared with commercial molded pulp products after subjecting to various beating time.

The results of sun hemp molded pulp products in each property were not significantly different when compared the molded pulp products without and with additives ($P > 0.05$).

3.6.2 Hydrophobic property, temperature-resistance and microwave heat-resistance.

Hydrophobic property is an important index influencing the applications of molded pulp products (Wang et al., 2018). Fig. 8 showed images of the water contact angle on the surface of the molded pulp samples with and without the additive. The angle was calculated using the instrument software and the values, representing the average angles measured from both sides of the droplet. The water contact angle of products with additives (about 108°–130°) was significantly different ($P < 0.05$) from the products without additives, due to the effects of

AMERICAN JOURNAL OF EDUCATION AND LEARNING
ISSN: 2996-5128 (online) | ResearchBib (IF) = 9.918 IMPACT FACTOR
Volume-3| Issue-4| 2025 Published: |30-04-2025|

hydrophobic sizing agent, which is capable of slowing the absorption of liquid water. The contact angle of water showed a tendency to decrease as the beating time increased from 10 to 20 min, because water penetrated the cracks generated in the fiber cell wall of beaten pulp which was as high surfaces capillaries (Jin et al., 2022). This could be due to the fact that beating created secondary fines, mostly from the fiber surface, increasing the number of hydrogen bonds between the fibers that increased the hydrophilic property. Thus, freeness and fines content are important factors which influence the range of usage for molded pulp products and should be considered during the production process.

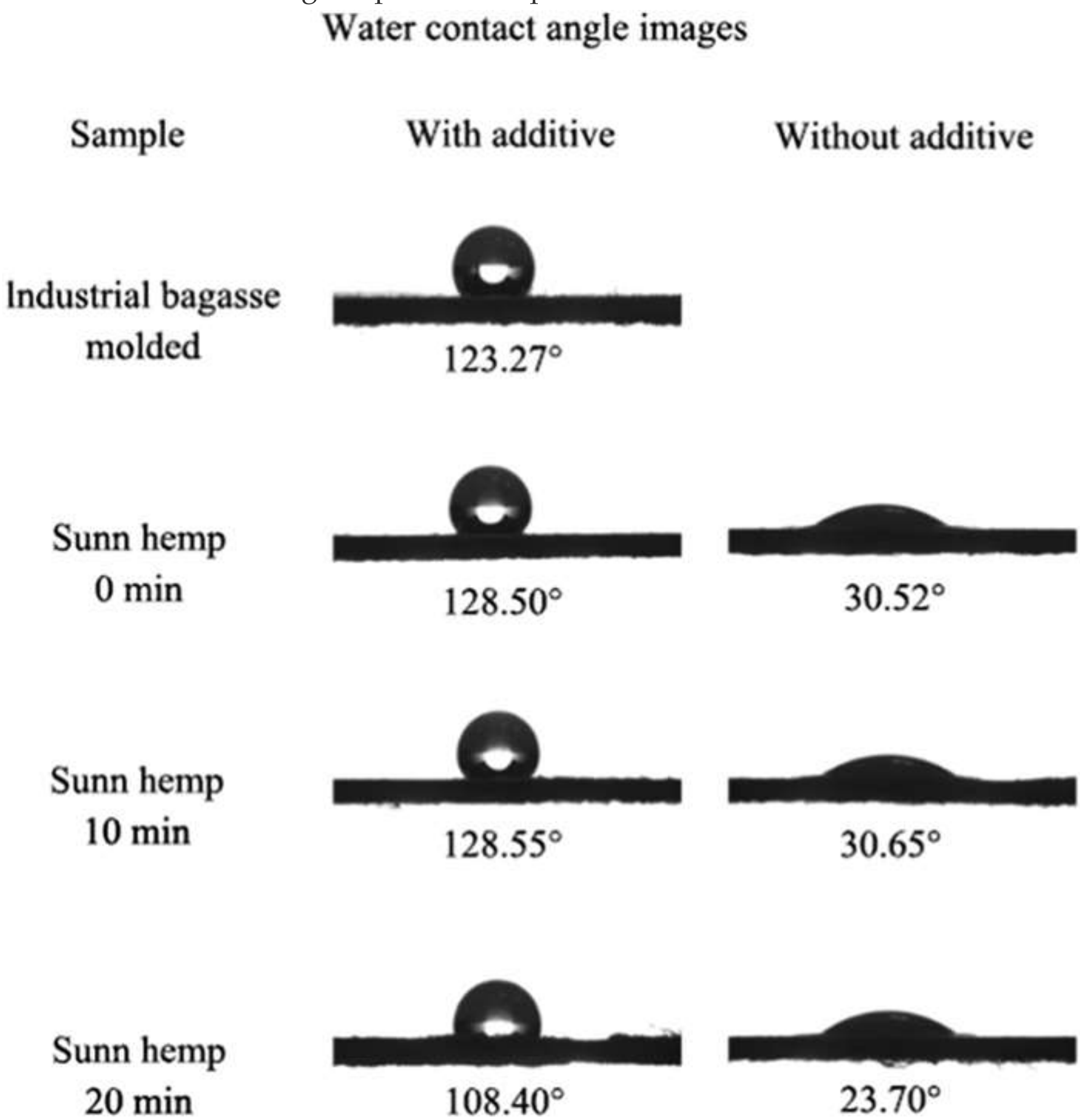

Figure 8. Images of water contact angle on surface of molded pulp samples from sun hemp when compared with commercially used products.

Molded pulps derived from sun hemp (with and without additives) were measured for their liquid resistance properties with hot water at a temperature of (95 ± 5) °C and hot cooking oil at the temperature of (60 ± 5) °C for 10 min. The products derived from sun hemp with additives were able to resist the high temperatures of hot water and hot cooking oil, as shown in Fig. 9. On one hand, the hot water test on products derived from molded pulp products, beaten for 10 and 20 min, experienced changes in color on the surface and absorbed water without any sign of leakage from the bottom. On the other hand, the sun hemp molded pulp without additives had leakage resulting from pouring of hot water and hot cooking oil.

Figure 9. Comparison of top and bottom sides of sun hemp molded pulp products after temperature-resistance and heat-resistance tests.

After being heated in a microwave and cooled to room temperature, the sun hemp molded pulp with additives did not have any deformations or defects. As shown in Fig. 9, the surface of molded pulp products beaten for 10 and 20 min, experienced a change in color and absorbed water, but no visible leakage was evident at the bottom.

4. Conclusions.

This study reports the potential of using pulp from sun hemp as alternative fiber and its feasibility of pulp and paper properties from sun hemp to usage in molded pulp packaging. The chemical composition of sun hemp had a higher lignin content than rice straw. Holocellulose and alpha cellulose contents of sun hemp were acceptable with regards to papermaking. It was found that the sun hemp contained low amounts of extractives. The sun hemp fiber length and fiber width were in the range of hardwood. During the soda process, sun hemp needed a high alkali charge to obtain low Kappa number and produced a higher pulp yield of 24% active alkali. The pulp fibers could be divided into two kinds of fibers, i.e., long and short length fibers, which were obtained from the bast and stem, respectively. The physical properties of sun hemp indicated that it had acceptable papermaking properties. Sun hemp molded pulp had a higher density than that of the commercial molded pulp products manufactured using the same molding machine processing. The water contact angle indicated that the beating decreased the water holding capacity. Sun hemp products with additives were able to resist the high temperatures of hot water, hot cooking oil, and microwave heating. The overall results indicated that sun hemp could be used as a potential replacement for the non-wood pulps in papermaking and the production of molded pulp.

REFERENCES:

1. Alila, S., Besbes, I., Vilar, M.R., Mutjé, P., Boufi, S., 2013. Non-woody p lants as raw materials for production of micro fibrillated cellulose (MFC): a compar ative study. Ind. Crop. Prod. 41, 250–259.doi: 10.1016/j.indcrop.2012.04.028

2. Bhardwaj, N., Goyal, S.K., Gupta, A., Upadhyaya, J.S., Ray, A.K., 2005. Soda and soda-anthraquinone pulping of rice straw. Appita J. 58, 180–185.

3. Chauhan, V., Kumar, N., Kumar, M., Chakrabarti, S.K., Thapar, S., 201 1. Effect of separate and mixed refining of hardwood and softwood pulps on paper

properties. J. Korea Techn. Assoc. Pp Paper Indust. 43, 1–10.

4. Cunningham, R.L., Clark, T.F., Bagby, M.O., 1978. *Crotalaria juncea* ann ual source of papermaking fiber. TAPPI J. 61, 4165–4167.

5. Curling, S.F., Laflin, N., Davies, G.M., Ormondroyd, G.A., Elias, R.M., 2017. Feasibility of using straw in a strong, thin, pulp moulded packaging material. Ind. Crop. Prod. 97, 395–400.doi: 10.1016/j.indcrop.2016.12.042

6. Debnath, M., Sarder, R., Pal, L., Hubbe, M.A., 2022. Molded pulp prod ucts for sustainable packaging: production rate challenges and product opportuniti es. BioResources 17, 3810–3870.doi: 10.15376/biores.17.2.debnath

7. Didone, M., Tosello, G., 2018. Moulded pulp products manufacturing with thermoforming. Packag. Technol. Sci. 32, 7–22.

8. Fahmy, Y., Fahmy, T.Y., Mobarak, F., El-Sakhawy, M., Fadl, M., 2017. Agricultural residues (wastes) for manufacture of paper, board, and miscellaneous products: background overview and future prospects. Int. J. ChemTech. Res. 10, 42 4–448.

9. Ferdous, T., Ni, Y.H., Quaiyyum, M.A., Uddin, M.N., Jahan, M.S., 2021 . Non-wood fibers: relationships of fiber properties with pulp properties. ACS Om ega 6, 21613–21622.doi: 10.1021/acsomega.1c02933

10. Ferdous, T., Quaiyyum, M.A., Salam, A., Jahan, M.S., 2020. Pulping of bagasse (*Saccrarum officinarum*), kash (*Saccharum spontaneum*) and corn stalks (*Zea mays*). Curr. Res. Green Sustain. Chem. 3, 100017.doi: 10.1016/j.crgsc.2020.100017

11. Hassan, E., Hassan, M., Oksman, K., 2011. Improving bagasse pulp pa per sheet properties with micro fibrillated cellulose isolated from xylanase-treated bagasse. Wood Fiber Sci. 43, 76–82.

12. Jin, H.L., Kose, R., Akada, N., Okayama, T., 2022. Relationship betwee n wettability of pulp fibers and tensile strength of paper during recycling. Sci. Rep. 12, 1560.doi: 10.1038/s41598-022-05514-2

13. Khakifirooz, A., Kiaei, M., Nouri Sadegh, A., Samariha, A. 2012. Studie s on chemical properties and morphological characteristics of Iranian cultivated ke naf (*Hibiscus cannabinus* L.): a potential source of fibrous raw material for paper ind ustry in Iran. Res. Crop. 13, 715–720.

14. Khantayanuwong, S., Boonpitaksakul, W., Chitbanyong, K., Pisutpiche d, S., Puangsin, B., 2021. Physical properties of hand sheets derived from Coi (*Streb*

lus asper Lour.) pulp fiber as papermaking material traced from ancient times. BioResources 16, 6201–6211.doi: 10.15376/biores.16.3.6201-6211

15. Khantayanuwong, S., Yimlamai, P., Chitbanyong, K., Wanitpinyo, K., Pisutpiched, S., Sungkaew, S., Sukyai, P., Puangsin, B., 2023. Fiber morphology, chemical composition, and properties of kraft pulping hand sheet made from four Thailand bamboo species. J. Nat. Fiber. 20, 2150924.doi: 10.1080/15440478.2022.2150924

16. Liu, C., Luan, P.C., Li, Q., Cheng, Z., Sun, X., Cao, D.X., Zhu, H.L., 2020. Biodegradable, hygienic, and compostable tableware from hybrid sugarcane and bamboo fibers as plastic alternative. Matter 3, 2066–2079.doi: 10.1016/j.matt.2020.10.004

17. Lukmandaru, G., Setiaji, F., Siagian, R. M., 2019. Effects of mixing ratio of heavily beaten *Pinus merkusii* pulp on physical properties of kraft *Acacia nilotica* pulp sheets. Wood Res. J. 10, 53–60.

18. Mazhari Mousavi, S.M., Hosseini, S.Z., Resalati, H., Mahdavi, S., Rasooly Garmaroody, E., 2013. Papermaking potential of rapeseed straw, a new agricultural-based fiber source. J. Clean. Prod. 52, 420–424.doi: 10.1016/j.jclepro.2013.02.016

19. Nasroun, T.H., 2019. Effect of cooking mixtures of kenaf and bagasse and blending their pulps on paper properties. Int. J. Res. Public. 37, 1–11.

20. Saikia, C.N., Goswami, T., Ali, F., 1997. Evaluation of pulp and paper making characteristics of certain fast-growing plants. Wood Sci. Technol. 31, 467–475.

21. Samariha, A., Khakifirooz, A., 2011. Application of NSSC pulping to sugarcane bagasse. BioResources 6, 3313–3323.doi: 10.15376/biores.6.3.3313-3323

22. Sengupta, S., Debnath, S., 2018. Development of sun hemp (*Crotalaria juncea)* fibre based unconventional fabric. Ind. Crop. Prod. 116, 109–115.doi: 10.1016/j.indcrop.2018.02.059

23. Shakhes, J., Marandi, M.A.B., Zeinaly, F., Saraian, A., Saghafi, T., 2011a. Tobacco residuals as promising lignocellulosic materials for pulp and paper industry. BioResources 6, 4481–4493.doi: 10.15376/biores.6.4.4481-4493

24. Shakhes, J., Zeinaly, F., Marandi, M.A.B., Saghafi, T., 2011b. The effects of processing variables on the soda and soda-AQ pulping of kenaf bast fiber. BioResources 6, 4626–4639.doi: 10.15376/biores.6.4.4626-4639

25. Sharma, A. K, Dutt, D., Upadhyaya, J.S., Roy, T. K, 2011. Anatomical, morphological, and chemical characterization of *Bambusa tulda*, *Dendrocalamus hami ltonii*, *Bambusa balcooa*, *Malocana baccifera*, *Bambusa arundinacea* and *Eucalyptus teretic ornis*. BioResources 6, 5062–5073.doi: 10.15376/biores.6.4.5062-5073

26. Sharma, N., Godiyal, R.D., Bhawana, Thapliyal, B.P., Anupam, K., 201 8. Pulping and bleaching of hydro distillation waste of *Citronella* grass (*Cymbopogon winterianus* jowitt) for papermaking. Waste Biomass Valoriz. 9, 409–419.doi: 10.100 7/s12649-016-9791-y

27. Sonje, S.B., Bhuktar, A.S., 2016. Anatomical studies of *Crotalaria junce a* L. J. Glob. Biosci. 5, 4071–4074.

28. Sridach, W., 2010. The environmentally benign pulping process of non -wood fibers. Suranaree J. Sci. Technol. 17, 105–123.

29. Syed, N.F.N., Zakaria, M.H., Bujang, J.S., 2016. Fiber characteristics an d papermaking of seagrass using hand-beaten and blended pulp. BioResources 11, 5358–5380.

30. Tripathi, M.K., Chaudhary, B., Sarkar, S.K., Singh, S.R., Bhandari, H.R. , Mahapatra, B.S., 2013. Performance of sun hemp (*Crotalaria juncea* L.) as a summer season (pre-monsoon) crop for fibre. J. Agric. Sci. 5, 236–242.

31. Tutus, A., Deniz, I., Eroglu, H., 2004. Rice straw pulping with oxide ad ded soda-oxygen-anthraquinone. Pak. J. Biol. Sci. 7, 1350–1354.doi: 10.3923/pjbs.20 04.1350.1354

32. Wang, Q.L., Xiao, S.L., Shi, S.Q., Cai, L.P., 2018. Effect of light-delignifi cation on mechanical, hydrophobic, and thermal properties of high-strength molde d fiber materials. Sci. Rep. 8, 955.doi: 10.1038/s41598-018-19623-4

33. White, G.A., Haun, J.R., 1965. Growing *Crotalaria juncea*, a multi-purpo se legume, for paper pulp. Econ. Bot. 19, 175–183.doi: 10.1007/BF02862829

34. Wise, L.E., Murphy, M., D'Adieco, A.A., 1946. Chlorite holocellulose, it s fractionation and bearing on summative wood analysis and studies on the hemic elluloses. Paper Trade J 122, 35–43.