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Production of High Yield Pulp and Paper from Jute Fibre in Bangladesh: A Comparison with Other Crop Residues

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Abstract

As the allocated forestland for pulp and paper production in Bangladesh is very limited and a substantial amount of crops residues are generated each year, the latter can substitute for pulp and paper production. In this context, eight residues of crops produced in Bangladesh were evaluated. Final pulp yields were 40 -65% with the kappa number of 11-32% depending on crops residues. The experimental processes are outlined. The physico-mechanical properties of handmade papers are estimated by standard procedure. Gram per Square Metre (GSM), brightness percentage, thickness and tearing strength of different handmade paper sheets shows acceptable papermaking properties. FT-IR analysis were carried out for identifying types of chemicals bonds (functional groups).The study indicates that these hand-made papers can be used for making eco-friendly paper bags, packaging material which will be suitable alternative to the non-biodegradable plastic, a cause of ecological and environmental pollution.

Keywords: Jute fibre, Crop residues, Kappa number, pulp production, and handmade paper.

INTRODUCTION

Bangladesh is facing acute shortage of fibre for pulp and paper industry and the demand of paper and paper products is increasing day by day. Forestland in Bangladesh is only 10.2 %, while the population density is very high (FAO, 2009). The use of forestland for the paper industry is decreasing as compared to other land uses. So, it is hard to supply pulpwood from forest to keep the growth of paper industry in the country. In order to achieve this growth, plantation of fast growing species must be established to compensate for the decreasing supply from forests. The present status of pulp and paper mills in Bangladesh was elaborately discussed by Quader (2011). Bangladesh Chemical Industries Corporation (BCIC) was a key player in the Bangladesh Pulp and Paper Industry. There were four pulp and paper mills under the umbrella of BCIC, namely: Karnaphuli Paper Mill (KPM), Khulna Newsprint Mill (KNM), North Bengal Paper Mill (NBPM) and Sylhet Pulp & Paper Mill (SPPM). Unfortunately, presently only KPM is in operation, producing quality paper, as well as packaging grade with yearly capacity of 30,000 MT. One of the main reasons of closing the other three mills was due to the shortage of fiber supply. KNM, a newsprint mill was started in 1959 with an annual capacity of 50,000 MT. This mill used Gewa wood from the Sundarban. UN has declared Sundarban as the world heritage site. Therefore, the government authority stopped the supply of wood to the mills; consequently the mill was forced to shut down. The BCIC's pulp and paper capacity accounted for around 90 % of the Bangladesh's total output some 25 years ago (Hossen *et al.,* 2020). But today BCIC is producing < 5 % of the total paper products in Bangladesh (Quader, 2011). The private investment in the Bangladesh Pulp and Paper Industry has been significant in the past years. It is expected that the Bangladesh Pulp and Paper Industry could have a rapid increase in the near future. In 2015, Bangladesh has imported about 200,000 MT market pulp at the cost of US$ 140 million, and also imported 500,000 MT paper and paper board (FAO, 2020). Therefore, it can be concluded that Bangladesh needs more pulp and paper mills to reduce the dependency on imported pulp, paper and paper products.

Bangladesh as an agricultural country generates a substantial quantity of agricultural residues (Jahan, 2016). Annual growth in agricultural sector in Bangladesh was reported by World Bank at 2.7863% in 2016, which indicates that the crops residues quantity increased consequently over the years (Anon, 2019). A significant solution to the raw materials problem of a forest deficient and agriculture dependent country could be the use of agricultural residues for pulp manufacturing (Okan, 2013; Kham *et al.*, 2005; Lam *et al.*, 2001). Therefore, to reduce the load on our forests, some agriculture residues available in Bangladesh have been carefully selected to study their suitability as pulping raw material.

MATERIALS AND METHODS

Materials

Seven crops residues that grows abundantly in Bangladesh and are either wasted or used as cattle feed or fuel for burning have been selected for pulping raw material in this study. Jute plants of variety C-145 (Corchorus Capsularies) were used for this experiment. Jute samples were collected from Agricultural Wing and the study was conducted at Chemistry Division, Bangladesh Jute Research Institute, Dhaka. The fibre was collected after 120 days of maturity. To compare with jute pulping and paper making, other plants (Banana fiber, sugarcane bagasse, rice straw, corn stalk, and pine apple fiber etc) were collected from different places of Bangladesh.

Methods

Determination of Chemical Properties of Jute Fibre

The physical, mechanical and chemical properties of jute fibre were tested using standard method. For the determination of fats, alpha-cellulose, hemi- celluloses and lignin content samples of fibre were ground machanically by a grinding machine and subjected to the following analyses.

Determination of Fats Content

1 gm powder sample of fibre was extracted with petroleum ether (b.p 60-80 ^{0}C) in an electro thermal soxhlet apparatus for 8 hours. The extract was evaporated to dryness and dried in an electric oven at 105 ^{o}C and weight to a constant weight.

Chemicals

Pulping of Jute Sticks

Treatment of Jute Fibre with Sodium Hydroxide Solution at Different Times

Different pulping process namely, soda, soda-anthraquinone (AQ), kraft, alkaline-sulfite-anthraquinone-methanol (ASAM), acetic acid and formic acid processes were also evaluated (Jahan, *et al.*, 2007). A good pulp yield (46-65%), strength and optical properties were obtained in all of these processes. The best pulp yield (61.7 %) and kappa number (13.4) were obtained in the ASAM process under the conditions of 17 % alkali charge at 180oC for 120 min of cooking. The digester pressure in the ASAM process is higher, and the recovery of methanol is another challenge. So the ASAM process is not realistic at this stage.

Jute fibre was immersed in sodium hydroxide (NaOH) solution (2-10% strength, w/v) at 170^{0}C for different times (3-6 hrs) in a closed digester. It was then washed successively with cold and hot water till alkali free. It was dried in air and stored in stopper bottle. Similar experiments were carried out for other species. Using less strength of NaOH (2%) and longer digester time (5-6 hrs) shows good pulp comparing with other strength and time.

Bleaching

Pulp bleaching is a chemical process to brighten the pulp through the removal of lignin. The major part of delignification occurs during the pulping process and rest is removed further in bleaching stages. Bleaching can be considered as a final delignification stage of pulp. Bleach ability is dependent on the raw material and can be influenced by the conditions in the cooking process (Hart, 2020). Many attempts have been made to correlate the chemical structure of the residual lignin to the bleachability of the pulp (Garside, M. 2019). Bleaching experiments of unbleached pulp (50 g) were carried out at 10% pulp concentration. The pH was adjusted to 11 by adding NaOH. The hydrogen peroxide was varied to 4% on pulp. The bleaching temperature was 100 °C for 2h. 0.5% sodium hypochlorite (80 °C for 3h) was also used as bleaching agent. But hydrogen peroxide is very effective.

EVALUATION OF PULPS

Determination of Moisture Content of Pulp

The test of moisture content is the most important general analytical method in the cellulose field, because almost all cellulose materials are sold on a basis which requires weight correction either to zero moisture content or to standard moisture content. 1-2 gram pulp was taken to previously oven dried and weighed containers. The open containers were heated 2-4 hours in the oven until a constant weight was obtained. Determinations were run in triplicate. The percentage of moisture content was calculated by the following formula:

Percentage = $(wt.\ of\ air\ dried\ sample - wt.of\ oven\ dried\ sample) \times 100$

$wt.of\ air\ dried\ sample$

Both bleached and unbleached pulp found less than 2% of moisture.

Table 1: Fat, alpha cellulose, hemi-cellulose and lignin content of 0-9897 jute fibre

Chemical properties	Percentage
Fat content	0.88
Alpha cellulose content (%)	62.35
Hemi cellulose content (%)	19.51
Lignin content (%)	15.75

Kappa Number

Pulp yield was determined gravimetrically on raw material. The kappa number is an estimation of the amount of chemicals required during bleaching of pulp to obtain a pulp with a given degree of whiteness. The amount of bleaching chemical required is directly related to the lignin content of pulp. So, the kappa number is used to estimate the efficacy of the lignin-extraction phase of the pulping process. The kappa value is approximately proportional to the residual lignin content of the pulp. The kappa number of the resulting pulp was determined in accordance with Tappi test methods (T 236 om-99). Fibre powder (1 gm) was taken in quick fit ground bottom flask (250 ml). The content of each flask was then digested with 10 ml 72% (v/v) sulphuric acid by immersing the flask in each case in ice bath. The digestion is allowed for 2 hours with occasional stirring by means of dried and polished glass road. The content of the flask was then refluxed for about 6 h after diluting the content of each flask with 200 ml distilled water. The mixture was cooled and filtered through a sintered crucible (porosity-2) carefully and washed exhaustively with hot water until free from acid. The lignin was dried at 100-105^{o}C for 10-15 hours to a constant weight.

All experiments were carried out thrice and average reading was taken. It was observed that the degree of delignification is highest for rice straw with 40% pulp yield as compared to others (**Table2**). At optimum cooking conditions, kappa number of jute pulp was lower than other plants. It indicates the lowest residual lignin content of the pulp from jute samples.

Paper-making

Bleached pulps were soaked in water, blended and hand sheets were prepared for determining papermaking properties. The paper sheets were tested for physical and mechanical properties by standard methods. Standard hand-made paper-making equipments were used for transforming the pulp to hand-made paper. Calendering was done after paper production.

Table 2: Correlation between pulp yield and kappa number

Non-wood	Pulp yield	Kappa number
Jute fiber	65	11
Sugarcane Bagasse	50	17
Banana fiber	51	21
Corn stalk	51	30
Rice straw	40	32
Pineapple bagasse	45	23

RESULTS AND DISCUSSION

We used different samples (S-1 re pulping of jute fibre, S-2 banana fibre, S-3 rice straw, S-4 jute pulp, S-5sugarcane bagasse, S-6 corn stalk, S-7 pineapple bagasse, and S-8 cotton rag) and different temperatures(150 – 170^{o}C).

Basis weight of paper sheets made of jute

The basis weight is basic physical property of paper and paperboard. It is denoted by the weight per unit area and mainly expressed as GSM (grams per square meter). For paper production, for quality and productivity of paper, it is very essential (Karim *et al.*, 2019). Fluctuation of basis weight hampers the quality of paper and bad formation, uneven drying and calendaring, calendar cutting, bad mother roll development, blackish etc. are the results of fluctuation. Basic weight of paper sheets made from jute fibre is presented in (**Table 3**). Lowest value of basic weight of paper was estimated to 63.6 gsm (S-5). Sample 1 showed highest basic weight which was 117.8 gsm.

Brightness or Whiteness property of handmade paper sheets

Paper whiteness quantifies a paper's ability to equally reflect a balance of all wavelengths of light across the visible spectrum. Whiteness is a measurement of light reflectance across all wavelengths of light comprising the full visible spectral range (approximately 380 nm - 720 nm). Whiteness of the sample papers was estimated through standard method. In our experiment, we did not use any whitening agent. All of the samples observed more than 50% brightness.

Tear Resistance of Paper

The tear resistance is the force required to continue the tearing of an initial cut in a single sheet of paper. The tear index is the quotient of tearing resistance by basis weight.

Calculation: x = a/w

Where, x = the tear index, Nm^2/kg

w = grammage (substance) g/m^2

a = the tearing resistance, Nm

All of the samples show good tearing strength ranging from 28.8 – 38.6 N. Highest tearing strength observed from S-1 (re pulping of jute) and lowest from S-5 (sugarcane bagasse).

Thickness of paper

Thickness of our handmade paper is in the range of 0.12 – 0.2.

Table 3: GSM, Brightness percentage, thickness and tearing strength of different handmade paper sheets

Handmade paper sheet	GSM	Brightness (%)	Thickness	Tearing Strength (N)
S-1	117.8	56.6	0.15	38.6
S2	112.5	50.3	0.17	29.8
S-3	80.3	53.4	0.14	29.6
S-4	103.9	55.2	0.13	29.3
S-5	63.6	50.1	0.12	28.8
S-6	90.3	59.4	0.18	29.6
S-7	76.7	51.7	0.2	28.6
S-8	115.8	54.4	0.13	30

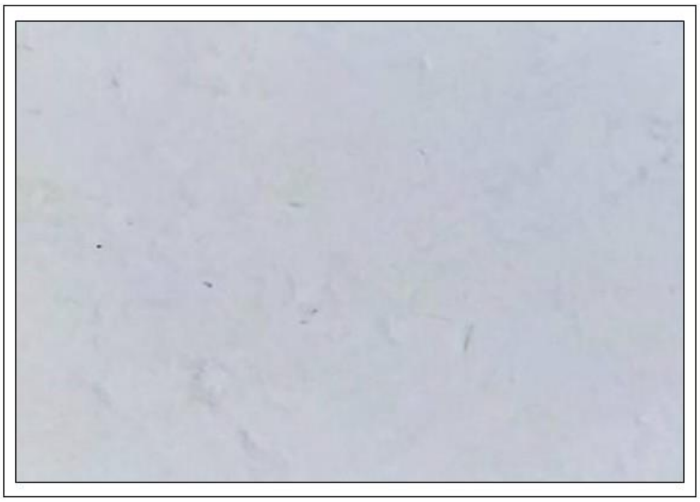

Figure 1: Handmade paper sheet produced from jute fibre (Sample 1)

Fig 2: Handmade paper sheet produced from rice straw (Sample 3)

FTIR ANALYSIS

FTIR is perhaps the most powerful tool for identifying types of chemical bonds (functional groups). The handmade paper from jute sticks and other samples were analyzed by FTIR to clarify the structural changes after the paper preparation. The assignments of the absorption bands are listed in (**Table 4**). The FTIR spectrum of S-1, S-2, S-3, and S-4 samples are shown in Fig. 3. The FTIR spectrum of S-5, S-6, S-7, and S-8 samples are shown in (**Figure 4**). Absorption band at around 3400 cm-1 is due to the stretching frequency of the –OH group as well as intramolecular and intermolecular hydrogen bonds in a cellulose (Pushpamalar *et al.*, 2006).The broad and intense absorption peaks in the 3700–3100 cm^{-1} correspond to the O-H stretching vibrations of cellulose, pectin, absorbed water, hemicellulose, and lignin (Shakhes *et al*, 2011). The presence of the peak at 1740-1700 cm^{-1} in the spectrum indicates the carbonyl (C=O) stretching vibration of the carboxyl groups of pectin, hemicellulose, and lignin in S-1, S-2, S-3, and S-4 samples. (Hameed *et al*, 2008) The peaks around 1620 to 1580 cm^{-1} are due to the C=C stretching that can be ascribed to the presence of aromatic in lignin of jute stick and other samples. The bands in the extent of 1300–1000 cm^{-1} can be attributed to the C-O stretching vibration of carboxylic acids and alcohols (Angin *et al.* 2014) the band in between 700 and 900 cm^{-1} contains different peaks assigned to aromatic out of plane C-H bending with varying degrees of substitution.

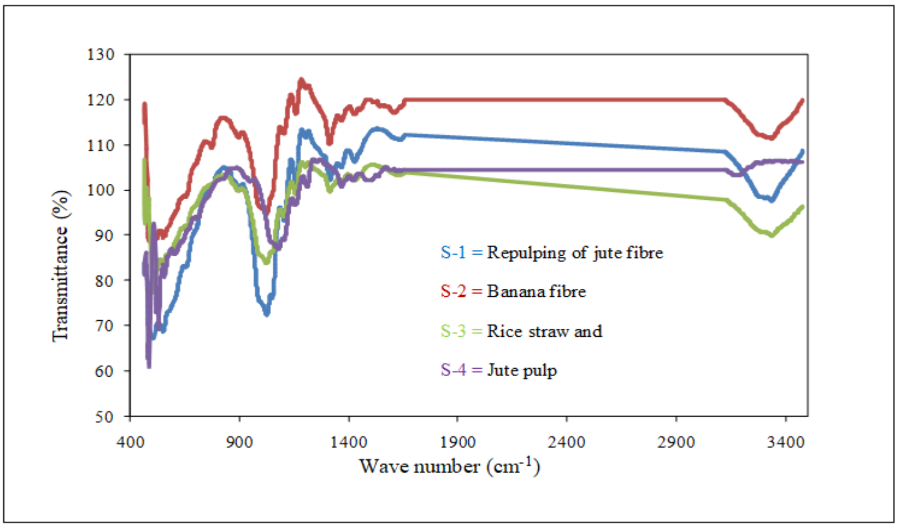

Figure 3: FT-IR spectra of different handmade papers from S-1 to S-4

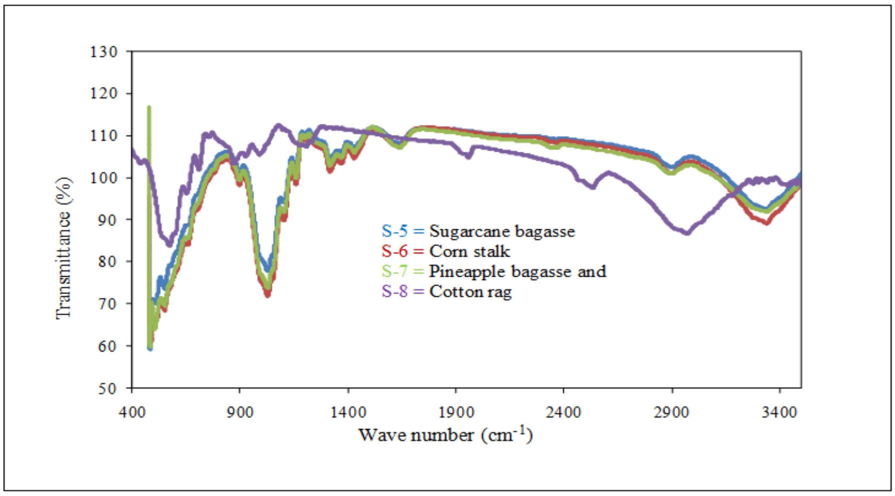

Figure 4: FT-IR spectra of different handmade papers from S-5 to S-8

Table 4: Peak assignments of functional group of different handmade paper samples

Wave number (cm-1)	S-1	S-2	S-3	S-4	S-5	S-6	S-7	S-8
3400-3000 O-H stretching	3354	3367	3344	3190	3154	3267	3144	3090
1740-1700 C=O stretching	1701	1706	1680	1685	1601	1506	1580	1585
1620-1580 Aromatic C=C stretching	1594	1597	1580	1587	1494	1497	1480	1487
1300-1000 C-O stretching	1225	1217	1150	1160	1125	1117	1050	1060
900-500 stretching of C-H Group in alkane, alkene and aromatic group	744	630	550	560	644	530	540	550

The result shows that these papers can be used for shopping bag, book cover, packaging material, etc. For making paper bags for shopping and grocery, packaging material, cover page of books, magazine, etc. The properties of hand-made paper prepared from jute fibre and others indicate its suit- ability (**Figure 1** & **Figure 2**).

CONCLUSION

In these study eight crops residues were evaluated by chemical and morphological characterization. A lot of variation in the chemical and morphological properties of the samples was observed. It was found that the alpha-cellulose contents in these samples were quite acceptable to consider as pulping raw materials. The study shows that jute and other fibres are currently wasted after harvesting is good cellulosic source and contains low content of lignin. The chemical composition of jute fibre and others described in this study, shows that those are good raw material for pulp and paper making industry. Thus the utilization of crop residues helps us to save our forest and decrease environmental issues.

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