Journal of Korea TAPPI
Vol.36.No.5, 2004
Printed in Korea

Fiber Dimensions and Chemical Properties of Various Nonwood Materials and Their Suitability for Paper Production

M. Sarwar Jahan[*1], Sung Phil Mun[†], and Mamunur Rashid[*2]

(Received on May 29, 2004: Accepted on October 29, 2004)

ABSTRACT

Fiber dimensions, their derived values and chemical properties of cotton stalks (*Gosypium hirsutum L.*), jute stick (*Corchorus capsularis*) and dhancha (*Sesbania aculeate*) have been examined to assess their suitability for paper production. Cotton stalks have a good derived values especially slender ratio, which is comparable to hardwood. The flexibility coefficient of these three nonwood plants is better than hardwood. Anatomical analysis shows higher percentage of fibers and vessels than in general nonwood plants. Lignin, α-cellulose and pentosan contents in these three nonwood plants are within the range of hardwood. Neutral sugar analysis of cotton stalks, jute stick and dhancha shows that the glucose in the major sugar followed by xylose and mannose. The arabinose and galactose are present in minor amount. Alkaline nitrobenzene oxidation of cotton stalks, jute stick and dhancha wood meal exhibits that these nonwood plant lignins mainly consist of syringyl (S) and guaiacyl (V) units. The S/V ratios are 1.6, 1.2 and 2.1 for cotton stalks, jute stick and dhancha, respectively.

Keywords: cotton, jute, dhancha, fiber dimensions, anatomical analysis, alkaline nitrobenzene oxidation, neutral sugar analysis

• College of Agriculture and Life sciences, Division of Forest Science, Chonbuk National University, Jeonju, Jeonbuk, 561 756, Korea
*1 Pulp and Paper Research Division, BCSIR Laboratories, Dhaka, Dhaka-1205, Bangladesh
*2 Department of Botany, Jahanginnagar University, Savar, Bangladesh
† Corresponding author: E-mail: msp@chonbuk.ac.kr

1. Introduction

Over a last few years, an increasing concentration regarding forest preservation and rational use of forest and agriculture residues has occurred. This fact mainly motivated by the increasing consumption of wood fiber-based products, such as panel, paper and boards. In many countries, like Bangladesh, the wood supplies available will not continue to meet the rising demand for fiber. Nonwood species may mitigate the rising demand of fibers. Nonwood species offer several advantages including short growth cycle, low lignin contents resulting low chemical use during pulping.

Paper strength depends on lignin contents, carbohydrates contents, fiber dimensions and their derived values (slender ratio, flexibility coefficient and runkel ratio). It is well documented that under certain conditions, tearing resistance depends strongly on fiber length (1). Madakadze *et al.* (2) showed that pulp's mechanical strength, especially tensile strength is directly proportional to cellulose content, whereas lignin is an undesirable polymer and its removal during pulping requires high amount of energy and chemicals.

Different types of agricultural residues are available in Bangladesh, which have no industrial use at present. Cotton stalks is an agricultural waste, is available to the extent of over 36 thousands ton per annum in Bangladesh. The stalks are rich in cellulose and its fibers are close to the fibrous structure of hardwoods. Jute stick is the woody residue left after extraction of bast fiber from the jute plant. It is used as fuel, fencing, and roofing in the rural area in a limited extent. Dhancha is nitrogen fixing annual plant. The height of dhancha is about 1.5-2 meter long. It grows in the wet land. At present, it is also being used as domestic fuel in the rural area.

The objectives of the present investigation were to examine chemical properties, fiber morphology and their derived values of cotton stalks, jute stick and dhancha and estimate their suitability for paper production using various indices.

2. Materials and Methods

2.1 Raw material

The cotton stalks, dhancha and jute stick were collected from the Dhaka region of Bangladesh. These nonwood materials were chipped to 2-3 cm size. The chips were ground in a Wiley mill and 40-60 mesh size was used for chemical analysis.

2.2 Anatomical and morphological properties

For the measurements of fiber length, first the nonwood samples were macerated in a solution containing 1:1 HNO_3 and $KClO_3$. A drop of macerated sample was taken in a slide glass and fiber length was measured under a profile projector (Nikon V-12, Japan). The fiber diameter was measured by an image analyzer. For anatomical analysis, the transverse sections of the samples of cotton stalks, dhancha and jute stick were cut and the proportion of tissues were determined by an image analyzer. Three derived values were calculated according to the methods described by Saikia *et al.* (15).

2.3 Chemical analysis

The extractives(T204 om88), carbohydrate (T249 cm00), Klason lignin (T222 om98), acid soluble lignin (UM 250) and ash content (T211 os76) were determined in accordance with TAPPI Test Methods. Holocellulose was determined by treating extractive free wood meal with $NaClO_2$ solution. The pH of the solution was maintained at 4 by adding acetate buffer.

Alkaline nitrobenzene oxidation of cotton stalks, dhancha and jute stickwas carried out according to Mun's modified method (3). GC analysis was conducted using a Shimatzu GC 17A gas chromatograph equipped with CBP1 capillary column (25 m x 0.25 mm). Conditions used were as follows: column temperature was programmed to increase from 150 to 270℃ at the rate of 5 ℃/min; injection and detection temperature were 220 and 270℃, respectively; column flow was rate 1 ml/min and split ratio 20.

2.4 Pulping

In order to analyze the possibility of pulping of cotton stalks, dhancha and jute stick, these were cooked under identical conditions. The nonwoods were cooked in 15 % active alkali as Na_2O and 25% sulphidity for 90 min at 170℃. The liquor ratio was maintained at 4. Pulp yield was determined on the basis of oven-dried raw material. The Klason lignin (T222 om98) and acid soluble lignin (UM 250) were measured according to TAPPI Test Methods.

3. Results and Discussion

3.1 Morphological properties and their derived values

The fiber dimensions of cotton stalks, dhancha and jute stick and their derived values are shown in Tables 1 and 2. Among these nonwoods, cotton stalks have the longest and jute stick has the shortest fiber length and wider fiber diameter. The fiber length (0.95 mm) of cotton stalks observed in this investigation is higher than that reported in Turkish cotton stalk (0.82 mm) (4). Cotton stalks have good derived value especially slender ratios, but the slender ratios of these nonwood raw materials are lower than wood, which in turn reduces tearing resistance dramatically. This is partly because of short and thick fibers do not produce good surface contact and fiber-to-fiber bonding (5). However, as shown in Table 2, all three nonwood fibers are highly flexible with good runkel ratio. Therefore, paper made from cotton stalks and dhancha fibers are expected to have increased tensile, burst and folding endurance and thus suitable for writing, printing, wrapping and packaging papers.

Table 1. Fiber dimensions of cotton stalks, jute stick and dhancha

Nonwood	Fiber length, mm	Fiber width, μm	Wall thickness, μm	Lumen width, μm
Cotton stalks	0.945	21.1	2.6	16.8
Jute stick	0.660	33.3	1.7	23.4
Dhancha	0.772	20.2	2.0	17.1

Table 2. Derived values (indics) for plant materials

Nonwood	Slender ratio	Flexibility coefficient	Runkel ratio
Cotton stalks	44.8	79.6	0.31
Jute stick	19.8	70.3	0.15
Dhancha	38.2	84.5	0.23

3.2 Anatomical properties

The anatomical structure of cotton stalks, dhancha and jute stick was examined on the transverse sections and macerated samples. The light microscopy observation revealed the structural similarity of these samples. These three samples consist of fiber, vessel and parenchyma cell like hardwood (Figure 1). Figure 2 shows that the cotton stalks, dhancha and jute stick contain higher percentage of fibers(58, 55, and 56 %, respectively) and vessels (27, 26 and 24 %, respectively) than other nonwood materials (6).

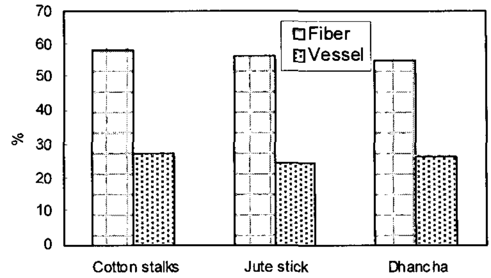

Fig. 2. Fiber and vessel of cotton stalks, jute stick and dhancha.

3.3 Chemical properties

The chemical analysis of cotton stalks, dhancha and jute stick are shown in Table 3. The alcohol-benzene and dichloromethane extracts value indicated the presence of considerable amount of lightweight aliphatic

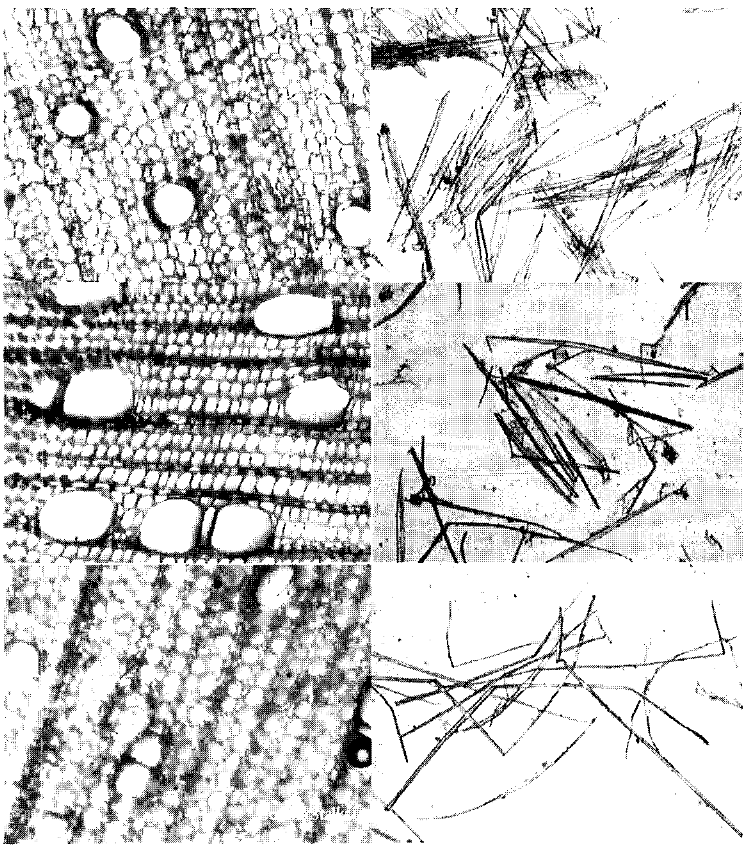

Fig. 1. Fibers, vessels and parenchyma cells of cotton stalks, jute stick and dhancha.

Table 3. Chemical properties of cotton stalk, jute stick and dhancha

	Cotton stalks	Jute stick	Dhancha
Extractives, %			
1% Alkali soluble	37.8	38.8	40.1
Alcohol-benzene	3.2	2.8	3.2
Dichloromethane	1.4	1.1	1.7
Lignin, %			
Klason	21.1	24.1	25.1
Acid soluble	2.3	2.1	2.3
Total lignin	23.4	26.2	27.4
Pentosan, %	20.4	22.7	23.1
α-Cellulose, %	48.9	45.7	48.7
Ash, %	2.8	2.7	3.8

and aromatic compounds. All three nonwood materials show high 1 % alkali solubility, which indicates easy access and degradation of the cell wall materials. These three nonwood materials contain about 23-27 % lignin compared with 20-28 % in most hardwoods and more than 30 % in some tropical species (7). The lignin in cotton stalks is 23.4 %, which is lower than American stalks (26.9%) and higher than Egyptian stalks (22.5%) (8). Klason lignin in jute stick has been determined to be 24.1 %, which is in good agreement with the value reported by Roy *et al.* (9). Pentosan contents in these three nonwood materials were higher when compared with wood (10) as shown in Table 3. The pentosan contents in *Arundo donax* was about 31 % (6) and 26-32 % in grain straw (11). α-cellulose content is satisfactory (above 40 %) in all three nonwood materials. The α-cellulose in cotton stalks, dhancha and jute stick are 48.9, 48.7 and 45.7 %, respectively. According to the rating system designated by Nieschlag *et al.* (12), plant materials with 34 % and over α-cellulose contents were characterized as promising for pulp and paper manufacture from a chemical composition point of view. High ash contents are undesirable in pulping process. Ash content is also satisfactory level in all three nonwood materials. It is higher in dhancha (3.8 %) than cotton stalks (2.8 %) and jute stick (2.7 %). As a whole, the chemical analysis of cotton stalks, dhancha and jute stick show values similar to hardwood and deviation from various other nonwood materials.

The results from the analysis of neutral sugars from cotton stalks, dhancha and jute stick are summarized in Table 4. As expected, glucose is the predominant sugar after the hydrolysis of nonwood stem and it is 50.0 % for cotton stalks, 47.6 % for jute stick and 49.1 % for dhancha. Xylose is the second abundant

Table 4. Neutral sugars in cotton stalks, jute stick and dhancha

Neutral sugar, %	Cotton stalks	Jute stick	Dhancha
Glucose	50.0	47.6	49.1
Xylose	20.8	22.1	23.2
Mannose	2.2	2.0	1.7
Arabinose	0.7	1.4	1.2
Galactose	1.1	1.3	0.9

Table 5. Alkaline nitrobenzene oxidation products from cotton stalks, jute stick and dhancha

Nonwood	Aldehyde, %			
	P	V	S	S/V (molar ratio)
Cotton stalks	2.6	16.2	25.6	1.6
Jute stick	1.8	17.2	20.2	1.2
Dhancha	0.5	9.3	19.3	2.1

sugar in all three nonwood materials followed by mannose. The xylose and mannose are about 21, 22 and 23 % and 2.2, 2.0 1.2 % for cotton stalks, dhancha and jute stick, respectively.

3.4 Alkaline nitrobenzene oxidation

Table 5 shows the yield of alkaline nitrobenzene oxidation products obtained from cotton stalks, dhancha and jute stick wood meals. From the Table it is seen that the predominant product is identified to be syringaldehyde (S), which comprised 19-26 % of lignin. It is resulted from the degradation of noncondensed syringyl unit. Vanillin (V) appeared as the second major degradation products resulted from the noncondensed guaiacyl unit. The relative ratio of S to V was 1.5. The results are appeared to be in general agreement with the range of S to V ratios obtained from hardwood lignin (13). Cotton stalks lignin contains more *p*-hydroxy phenyl unit than jute stick and dhancha lignins (Table 5).

3.5 Pulping

Table 6 shows the pulp yield and residual lignin of cotton stalks, dhancha and jute stick pulps. Pulping was carried out in an identical condition in order to know the delignification nature and pulp yield of these nonwood raw materials. Although, it was not an optimum condition, it is clearly seen from Table 6 that pulp yield is quite acceptable (>48%), but residual lignin is high for bleachable pulp. The lignin content in dhancha is higher than cotton stalks and jute stick (Table 3), but it is lower in dhancha pulp than cotton stalks and jute stick pulp, which may be explained by higher S/V ratio of dhancha lignin (Table 5). Syringyl lignins show higher reactivity in kraft pulping than guaiacyl lignins (14). The delignification rate does not depend on the accessibility of lignin but rather on its chemical structure and it is directly proportional to syringyl to guaiacyl ratio (14).

4. Conclusions

The following conclusions may be drawn from the above results:

(1) The fiber length of cotton stalks is longer and fiber width is shorter than jute stick and dhancha, hence cotton stalks gives better slender ratio. The flexibility of all three

Table 6. Pulp yield and residual lignin of cotton stalks, jute stick and dhancha

Nonwood	Pulp yield, %	Lignin, %		
		Klason	Acid soluble	Total
Cotton stalks	48.0	8.8	0.7	9.5
Jute stick	50.2	12.3	0.9	13.2
Dhancha	49.3	6.7	0.7	7.4

nonwood fibers is comparable to hardwood fibers.

(2) The extractives, lignin and α-cellulose contents in cotton stalks, jute stick and dhancha are in acceptable range for paper production. Xylose in the predominant sugar followed by mannose in these three nonwood plants.

(3) Alkaline nitrobenzene oxidation shows that the structural units of cotton stalks, jute stick and dhancha lignin are mainly syringyl and guaiacyl units. The *p*-hydroxy phenyl unit in cotton stalks lignin is higher than jute stick and dhancha lignin.

(4) Pulp yield in all three nonwood plants is about 50 % with high residual lignin in identical cooking conditions. Jute stick is less delignified than cotton stalk dhancha, which is attributed to lower S/V ratio.

Literature Cited

1. Seth, R. S. and Page, D. H., Fiber properties and tearing resistance, Tappi J. 71(2): 103 (1988).
2. Madakadze, I. C., Radiotis, T. Li, J., Goel, K., Smith, D. L.,Kraft pulping characteristics and pulp properties of warm season grasses, Bioresource Technology 71: 83 (1999).
3. Mun, S. P., Wi, H., Alcohol-bisulphite cooking of Hyun-aspen wood - Characterization of carbohydrates and lignin in the spent liquor, J. of Korea Tappi 23(4): 25 (1991).
4. Kirci, H., Ozturk, E. and Eroglu, H.,Alkaline sulfite anthraquinone pulping of cotton stalks (*Gosypium hirsutum L.*), Tr. J. of Agriculture and Forestry 21: 573 (1997).
5. Ogbonnaya, C. I., Roy-Macauley, H., Nwalozie, M. C., Annerose, D. J. M., Physical and histochemical properties of kenaf (*Hibiscus cannabinus L.*) grown under water deficit on a sandy soil, Ind. Crops Prod 7:9 (1997).
6. Shatalov, A. A., Quiho, T. and Pereira, H., *Arundo donax* L., Reed New perspectives for pulping and bleaching 1. Raw material characterization, Tappi J. 84(1):1 (2001).
7. Sarkanen, K.V., Hergert, H. L., Classification and Distribution. *In*: Lignins; Occurrence, formation, structure and reactions, Eds Sarkanen K. V. and Ludwig C. H., Wiley-interscience, New York (1971).
8. Ali, M., Byrd, M. V. and Jameel, H., Soda-AQ pulping of cotton stalks, Tappi Pulping Conference Proceedings (CD version) (2001).
9. Roy, A. K., Bag, S. G. and Sen, S. K., Studies on chemical nature of milled wood lignin of jute stick, Cellulose Chem. Technol. 21: 342 (1987).
10. Grace, T. M. and Malcolm, E. W., Pulp and Paper Manufacture (M. J. Kocurek, Ed.), Vol. 5 Alkaline pulping, TAPPI, CPPA (1993).
11. Atchison, J. E., "Data on non-wood plant fiber", in Pulp and Paper Manufacture (M. J. Kocurek, Ed.), Vol. 3 Secondary fibers and nonwood pulping, TAPPI, CPPA 1993, p.4. (1993).
12. Nieschlag, H. J., Nelson, G. H., Wolf, J. A., Perdue, R. E., A search for new fiber crops, Tappi 43(3): 193 (1960).
13. Creighton, R. H. J., Gibbs, R. B., Hibbert, H., Studies on lignin and related compounds LXXV: Alkaline nitrobenzene oxidation of plant materials and application to taxonomic classification, J. Amer. Chem. Soc. 66:32 (1944).
14. Fergus B. J., Goring, D. A., The location of guaiacyl and syringyles lignin in birch xylem tissue, Holzforschung 24(4):113 (1970).
15. Saikia, S. N., Goswami, T., Ali, F., Evaluation of pulp and papermaking characteristics of certain fast growing plants, Wood Sci. Technol. 31:467 (1997).