Pulping of Keora (*Sonnertia appetula*) A Major Mangrove Species of Bangladesh

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ABSTRACT

Keora (*Sonnertia appetula*) is the main species in the coastal region of Bangladesh. At present, this species has no industrial or other application. In this paper, keora has been characterized and evaluated as a pulping raw material. It has a high lignin and a low α-cellulose content. Its fiber length is 0.88 mm, which is considered as short length fiber. Keora was subjected to kraft pulping with various cooking time and active alkali charge. A central composite design was used to investigate the influence of operational conditions on the pulp properties (total pulp yield, screened pulp yield, kappa number tensile index, burst index and tear index). A second order polynomial model consisting of two independent variables was found to accurately describe the kraft pulping of keora. The minimum R^2 value was above 0.8. Values of screened pulp yield, total pulp yield, kappa number, tensile index, burst index and tear index at the central point of operational variables were 39.9 %, 40.8 %, 35.2, 35.1 N.m/g, 3.9 kPa.m^2/g and 9.5 mN.m^2/g, respectively, which are within the range of predicted values.

Keywords: Mangrove species, Keora (*Sonnertia appetula*), Chemical characteristics, Pulping, Papermaking properties.

Introduction

The term 'mangrove' is commonly used to identify trees and shrubs that have developed morphological adaptations to the tidal environment, as well as to the ecosystem itself (1). Regular monitoring of mangrove forest is necessary for conservation and sustainable use of mangroves as a source of wood, food, income and recreation for present and future generations.

Keora (*Sonnertia appetula*) is the main species in the coastal region of Bangladesh. In 1961, the Forest Department of Bangladesh planted *Sonnertia appetula* in the entire belt of coastal region. These trees have now completely matured. At present this species has no industrial or other application. No study has been carried out on the characterization of keora and its pulping. Kharnaphuli Paper Mills is only virgin pulp producing mills in Bangladesh, which is far away from *Sonnertia appetula*'s source.

Khulna Newsprint Mill was the only newsprint producing industry in Bangladesh that used Gewa wood as raw material. The mill was shut down due to inadequate supply of raw materials. Keora may be a new source for medium quality paper in Bangladesh.

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Singh et al (2) studied on high yield pulping of mangrove species of Andaman/Nicobar Islands, i.e. Heritiera littoralis, Bruguieva conjugata and Rhizophora mucronata. Refining of cold NaOH- and hot Na_2SO_3-treated wood chips in a disk refiner gave corresponding chemimech. pulps in 75-84% screened yield having strength properties higher than those of mech. pulps obtained from the same species. Mansyur et al (3) studied on the chemical properties of different mangrove species for pulping. Chemical composition of various species of mangrove woods varied in lignin, pentosans and solubility. Koeppen and Cohen (4) obtained pulp yields ranged from 49.2 to 53.0%, from five mangrove species. and, as conditions for these five did not differ greatly, little difficulty in pulping mixed charges was anticipated.

In this paper, Keora (*Sonnertia appetula*) was characterized with respect to chemical, morphological and physical properties and evaluated as a pulping raw material. The primary purpose of this work is to optimize cooking conditions such as active alkali and cooking time. Multiple linear regression analysis was done based on cooking conditions and pulping properties.

Experimental

Raw materials

Keora (*Sonnertia appetula*) was collected from the Sunderban, Khulna. It was chipped in a laboratory wood chipper. The moisture content of dhaincha was determined according to TAPPI Standard Methods (T 18m-53). After determination of the moisture content of air dried chips equivalent to 300 gm oven dried (o.d.) was weighed separately in a polyethylene bag for subsequent cooking experiments.

Cooking

All pulping experiments were performed in an autoclave of 5 *l* capacity, made of stainless steel, rotating at 1 rpm, fitted with thermostat. The kraft cooking conditions are given in Table 2. At the end of the cooking the internal pressure was reduced to atmospheric pressure by venting before opening the digester. Recovered pulps were washed thoroughly to remove the residual chemicals. After washing, pulp was disintegrated and screened in a flat vibratory screener, Yasuda, Japan. Then the screened pulp yield and reject were determined gravimetrically as percentage on oven dried (o.d.) raw material. The kappa number (T 236 om-99) was determined in accordance with Tappi Test Methods.

Table 1. Physical, Chemical and morphological properties of Keora (*Sonnertia apetala*)

	Keora	*Acacia auriculiformis*
Holocellulose, %	71.0	76.1
α-cellulose, %	38.1	44.1
Lignin, %		
Klason	27.4	19.4
Acid soluble	4.15	3.3
Pentosan, %	21.6	17.5
Cold water solubility, %	5.33	3.2
1 % alkali solubility	20.3	27.9
Acetone extract, %	0.88	
Ash, %	2.1	0.6
Density, g/cc	0.587	0.568
Fiber length, mm	0.88	1.1
Fiber width, μm	21.3	20.6

Table 3. Normalized and absolute values of the independent variables.

AA	Normalized	Time	Normalized
18	-3	2	0
20	-1	2	0
22	0	2	0
24	1	2	0
24	1	1.5	-1
24	1	2.5	1
22	0	1.5	-1
22	0	2.5	1
20	-1	1.5	-1
20	-1	2.5	1
18	-3	1.5	-1
18	-3	2.5	1

AA-active alkali, Suphidity, 25%, Wood to liquor ratio, 1:4, Max Temp. 170°C

Table 2. Experimental values of the dependent variables used in the experimental design

AA	Time	SPY	R	TPY	KN	TenI	TI	BI	Density
18	2	37.3	5.2	42.5	41.6	32.5	9.9	3.0	0.4320
20	2	39.0	2.2	41.2	37.4	34.1	9.1	3.3	0.4524
22	2	39.9	0.9	40.8	35.2	35.1	9.5	3.9	0.4370
24	2	37.5	0.2	37.7	28.3	37.9	7.4	4.0	0.4699
24	1.5	36.7	1.1	37.8	30.0	33.7	8.4	3.8	0.4412
24	2.5	37.3	0.1	37.4	24.3	36.1	7.1	3.4	0.4665
22	1.5	38.8	2.2	41.0	33.7	32.8	9.5	3.5	0.4423
22	2.5	39.8	1.0	40.8	32.9	35.6	8.8	3.9	0.4472
20	1.5	40.4	2.9	43.3	35.6	31.5	9.3	3.1	0.4511
20	2.5	39.3	1.8	41.1	33.0	35.2	8.7	3.5	0.4486
18	1.5	31.4	12.0	43.4	46.0	29.4	8.7	2.7	0.4301
18	2.5	38.1	4.1	42.2	37.2	33.8	9.8	3.5	0.4312

SPY-Screened pulp yield, R-Reject, TPY-Total pulp yield, TenI-Tensile index, TI-Tear index, BI-Burst index

Table 4. Snedecor's F, multiple-R, R2 and adjusted R2 values for Eqs. 3 8

Equation	F	Multiple-R	R^2	Adj-R^2
Total Pulp yield (4)	28.48	0.98	0.96	0.926
Screened pulp yield (3)	7.98	0.906	0.82	0.717
Kappa number (5)	18.298	0.969	0.938	0.887
Tensile index (6)	18.669	0.969	0.940	0.889
Burst index (7)	2.738	0.834	0.695	0.441
Tear index (8)	5.118	0.900	0.810	0.652

Experimental design

A central composite design was used to relate the dependent and independent variables. The model used a series of points (experiments) around central one and several additional points to estimate the first- and second-order interaction term of a polynomial (shown in Eq 1).

$$Y = ao + \sum_{i=1}^{2} a_0 Xni + \sum_{i=1}^{2} a_2 X_{ni}^2 + \sum_{i=1,j=1}^{2} a_3 X_{ni} X_{nj} \ldots (1)$$

This design meets the general requirement that each parameter in the mathematical model can be estimated from a fairly small number of experiments (5).
Independent variables were normalized by using the following equation:

$$X_n = \frac{X - \overline{X}}{(X_{max} - X_{min})/2} \ldots\ldots\ldots\ldots (2)$$

Where X is the absolute value of the independent variable concerned, is the average value, and X_{max} and X_{min} are its maximum and minimum value, respectively.

Results and discussion

Physical, morphological and chemical properties

Table 1 show the properties of keora and compared with the data of *Acacia auriculiformis* from literature (6). The basic density of Keora was 0.587 g.cc, which is similar to that of *A. auriculiformis* (Table 1). The fiber length of keora was 0.88 mm, which was in the range of tropical hardwoods (0.7-1.5 mm) considered as short fiber (7). The fiber width was in the medium range (21.3 m).

The klason lignin content in keora was 27.4 %, which was higher than that of *A. auriculiformis* (6) and temperate hardwood and within the range of tropical hardwood (8). The acid soluble lignin was also higher than the normal range of hardwood. The acetone extract and 1% alkali solubility of this species were 0.88 and 20.3 % respectively. The holocellulose and cellulose in keora were 71.0 and 38.1 % respectively, which were lower than the other hardwood grown in Bangladesh (9). The lower cellulose in keora may be the basis of lower pulp yield. The pentosan content was 21.6 %, which was higher that that of *A. auriculiformis*. The ash content (2.1%) was within the range of tropical species (1-3 %) (10).

Pulping

Results of kraft pulping of keora are summarized in Table 3. Each result was the average for three (pulp properties) and ten samples (paper properties). Deviation from the respective means was all less than 5 %.

Equations 3-8 were obtained by linear regression analysis and the results confirmed the adequacy of the fitted models, where all models are significant at a level of 0.005 or less with satisfactory values of R^2.

The dependent variable Y represents the screened pulp yield (SPY), total pulp yield (TPY), Kappa number (KN), tensile index (TeI), burst index (BI) and tear index (TI). The independent variables denote the active alkali charge (X_A) and cooking time (X_t).

Table 2 shows the value of independent variables. The independent variables were normalized from 1 to +1 by using Eq. 2 to facilitate direct comparisons of coefficient and to better understand the effects of individual variables on the dependent variable.

The central combination is that for which all normalized independent variables are zero. Coefficients a_0, a_1, $a_2 \ldots a_n$ are unknown regression coefficient that must be estimated from experimental data. The multiple linear regression analysis was performed on all terms of Eq. 1. (by using the data in Table 3), those terms with Snedecor's *F* values below 4.5 were discarded by using the stepwise method.

The equations derived for the different dependent variables were as follows:

$$SPY = 39.39 - 0.104X_a - 0.494X_T \; 0.846X_a^2 - 0.65\, X_aX_T \ldots\ldots\ldots\ldots\ldots\ldots(3)$$

$$TPY = 40.315 - 2.237X_a \; 4.05X_T \; 0.483X_a^2 + 1.92X_T^2 + 0.152\, X_aX_T \ldots\ldots(4)$$

$$KN = 33.876 \; 4.326X_a \; 1.870X_T \; 384X_a^2 - 2.052X_T^2 + 0.844\, X_aX_T \ldots\ldots(5)$$

$$TeI = 35.487 + 1.196X_a + 1.606X_T + 0.088X_a^2 - 1.309\, X_T^2 - 0.090\, X_aX_T \ldots\ldots(6)$$

$$BI = 3.665 + 0.203X_a + 0.115\, X_T \; 0.002X_a^2 \; 0.076X_T^2 - 0.058\, X_a\, X_T \ldots\ldots(7)$$

$$TI = 8.11 \; 0.716X_a - 0.340X_T - 0.207X_a^2 + 0.026\, X_T^2 - 0.243\, X_aX_T \ldots\ldots(8)$$

Snedecor's *F*, multiple-R, R^2 and Eqs 4-9 are listed in Table 4.

Screened pulp yield

Figure 1 shows the variation of screened pulp yield as a function of two independent variables, cooking time and active alkali. The screened pulp yield was increased with increasing active alkali or cooking temperature up to certain point followed by decreased with further increase of these two variables. The maximum screened pulp was obtained at 20 % active alkali in 1.5 h of cooking. The experimental screened pulp yield in these conditions was 40.4 % while the predicted value was 38.6 % as observed from Eq 3.

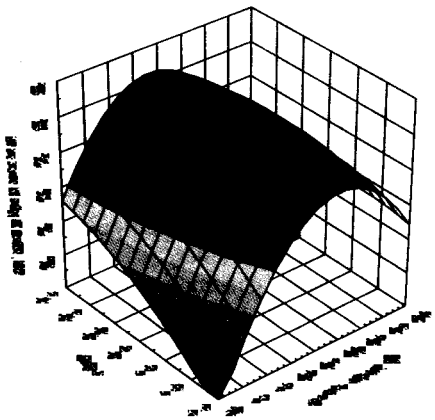

Fig 1. Variation of screened pulp yield with active alkali and cooking time.

Total pulp yield

Total pulp yield was decreased with increasing cooking time or active alkali (Fig. 2). Increased cooking time and active alkali charge gave the lowest total pulp yield (37.3 %) as observed cooking conditions the total pulp yield was 41.0 % (Table 2), where predicted value was 40.3 %.

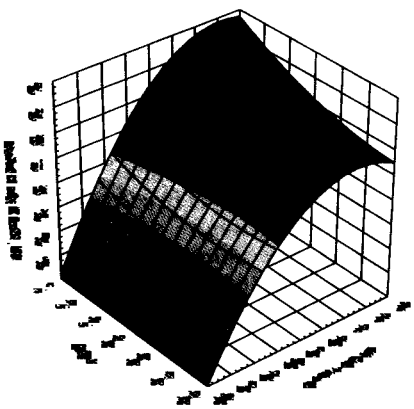

Fig. 2. Variation of total pulp yield with active alkali and cooking time

Kappa number

Based on Eq 5 and Fig. 3, one should use a higher active alkali charge and longer cooking time for lower kappa number. The kappa number is more sensitive to alkali concentration than cooking time. The experimental and predicted kappa number was 35.2 and 33.9, respectively, at the central point of independent variables. This value is very high as compared to other hardwoods (11, 12). At this point, screened pulp yield also was very low (39.0).

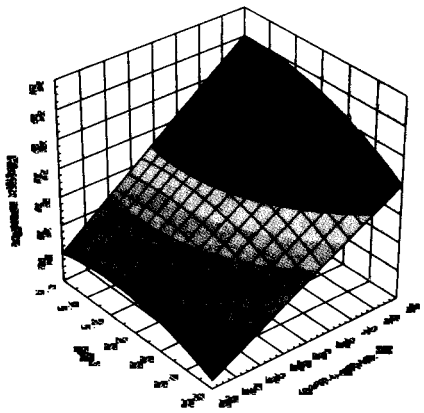

Fig 3. Variation of kappa number with active alkali and cooking time

Tensile index and burst index

Regarding tensile index and burst index, a higher alkali charge and a longer cooking time should be used to get higher tensile index and burst index.

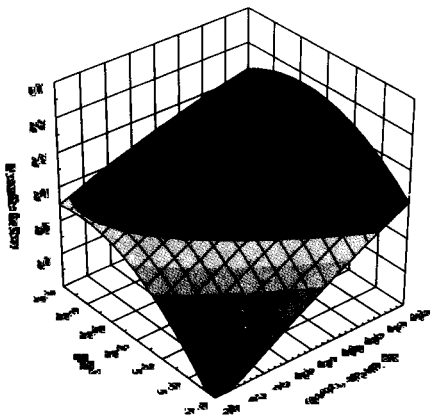

Fig. 4. Variation of tensile index with active alkali and cooking time

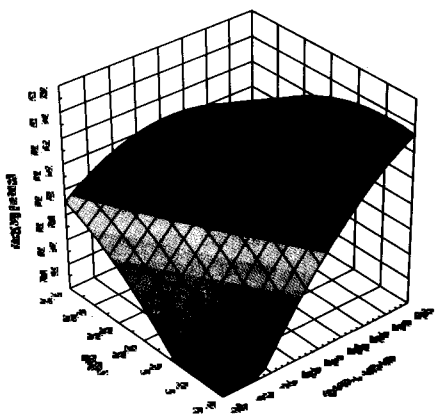

Fig. 5. Variation of tensile index with active alkali and cooking time

Higher tensile index will be obtained if central point of active alkali charge is used (Figs. 4 and 5). The maximum burst index values were obtained at 24 % alkali charge in 2 h of cooking. At this point predicted value was 36.8 (Eq 7). The same tensile index was observed in experimental and predicted value at the central point.

Tear index

Tear index was decreased with increasing active alkali charge, cooking time and temperature as observed from Fig. 6 and Eq. 8. Maximum tear index was obtained at 18 % active alkali in 2 h of cooking. Variation in tear index with alkali was 2.5 $mN.m^2/g$, while it was 1.3 $mN.m^2/g$ for time. Tear index was above 80 % fitted in the proposed Eq. 8 (Table 4).

The density value of Keora (*Sonnertia appetula*) pulp was 0.4301-0.4699 g/cc

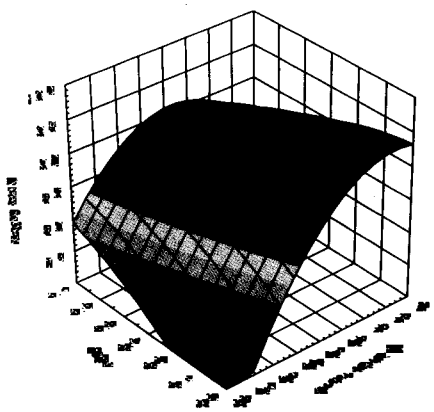

Fig. 6. Variation of tensile index with active alkali and cooking time

under the cooking condition employed. Density was increased in increasing drastic cooking condition (Table 3).

Conclusions

The following conclusions may be drawn from this study:-

The á-cellulose content was lower and lignin content was higher in krora than those of other common hardwood.

- Keora fiber can be considered as short length fiber.
- Keora showed higher kappa number and lower pulp yield.
- Pulp properties were well fitted with independent variable in second order polynomial equation.
- The best screened pulp yield was obtained at the central points of independent variables.
- More drastic conditions were needed to get acceptable kappa number.
- Considering all dependent variable (papermaking properties and kappa number), +1 points of normalized value showed the best results.

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