MIXED COOKING OF BAMBOO WITH HARDWOOD

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Bamboo is the main fibrous raw material for pulping in Bangladesh. Recently, *Trema orientalis* has been found as the fastest growing wood species suitable for pulping. However, the basic wood density *of T. orientalis* is low, which consequently decreases digester yield. On the other hand, basic wood density of bamboo is quite high. Optimum pulping conditions of these raw materials were similar. Therefore, mixed pulping of *T. orientalis* with bamboo can compensate digester yield. In this study, bamboo and *T. orientalis* chip mixtures were kraft cooked and the resulting pulp and paper properties were investigated. Cooking was carried out for five different chip mixtures (0, 25, 50, 75 and 100%). Pulp yield was increased and kappa number decreased with increasing *T. orientalis* proportion in the fiber mixture. The tensile index of the produced pulps was increased with increasing the proportion of *T. orientalis* in the chip mixture. The maximum tensile-tear was obtained for the 50:50 chip mixture. Bleaching was carried out by ECF sequences, and the bleached pulps were beaten in a PFI mill, and then tested for optical and physical properties. All pulps showed almost similar bleachability. Final pulp reached an 80% brightness level at ClO_2 consumption of 25 kg/ton of pulp.

Keywords: bamboo, *Trema orientalis*, mixed cooking, bleaching, pulp yield, kappa number

INTRODUCTION

Muli bamboo grows naturally in the Hill track region of Bangladesh, and it represents the main fibrous raw material for pulp production in Bangladesh. The average use of bamboo in Kharnaphuli Paper Mills (KPM) is of ADT 50000 MT. The basic wood density of bamboo is very high (0.85 g/cc). Recently, it has been observed that *Trema orientalis* is one of the fastest growing species, and it is omnipresent in Bangladesh.[1] *T. orientalis* prefers sites on well-drained and exposed soils for a fast growth. It is a nitrogen-fixing tree. Thus, the environment of Bangladesh favors a good growth of *T. orientalis*. The average height and diameter at breast height (DBH) of *T. orientalis* was reported to be of 11.6 m and 21.3 cm at the age of 24 months.[1] *T. orientalis* may be a suitable source of fiber for paper-making in the near future. The chemical composition of *T. orientalis* includes 20-24% lignin, 22-23% pentosan, 48-50% α-cellulose along with extractives, ash *etc*.[2] However, the basic wood density *of T. orientalis* is low, which consequently decreases digester yield.[1] On the other hand, basic wood density of bamboo is quite high. Therefore, mixed pulping of *T. orientalis* with bamboo can compensate digester yield.

The most important factor affecting pulp quality is fiber species. The chemical composition and fiber properties of raw materials vary among species and even within tree/plant.[3-5] Therefore, the properties of pulps produced under certain pulping conditions depend on species. Fortunately, optimum pulping conditions of *T. orientalis* and bamboo were similar.[6-7] Softwood fibers generally have higher fiber length than hardwood fibers. Higher strength papers are generally obtained from long-fiber species. However, these papers have a rough surface and are unsuitable for high-quality paper grades. A number of studies have been carried out on mixed cooking. Gulsoy and Tufek[8] studied the kraft cooking of *Pinus pinaster* and *Populus tremula* chip mixtures, and their results showed that pulps with higher kappa number, viscosity, and reject ratio were achieved from chip mixtures with higher pine ratio. However, a higher amount of pine in the mixture resulted in lower total and screened yield. Meanwhile, an increase in the poplar ratio in the mixture gave pulps that were easier to beat. Pine chips improved the strength properties and lowered the brightness and smoothness.

Runge *et al.*[9] studied the potential of co-cooking non-wood materials with hardwoods as a means to incorporate non-wood material into a paper furnish. All co-cooked pulps showed improved strength properties (up to 35%). The authors suggested that the strength increase was correlated with an enriched xylan content. Mixed cooking of wheat straw and corn stover with hardwood was carried out by Levit *et al.*[10] The substitution of 10, 15 and 20 wt% hardwood allowed a maximum 29% increase in tensile index and 12% increase in tear index for unrefined samples containing wheat straw. Pulp yields and kappa numbers changed slightly with increasing wood chip replacement levels. The strength improvement can be attributed to the increased xylan contents of the pulps made with agricultural residue. Runge *et al.*[11] also studied the co-cooking of non-wood materials with hardwoods in order to gradually include bamboo feedstock into an established pulp mill.

In this study, bamboo and *T. orientalis* chip mixtures were kraft cooked with varying active alkali charges and the resulting pulp and paper properties were investigated. Chip mixture ratios were of 0, 25, 50, 75 and 100%.

EXPERIMENTAL

Material and methods

Bamboo chips were collected from the Kharnaphuli Paper Mills (KPM) and *T. orientalis* was collected at Saver, Dhaka. Chips were prepared in a laboratory chipper.

Physical, morphological and chemical properties

For the measurements of fiber length, the sample was macerated in a solution containing 1:1 HNO_3 and $KClO_3$. A drop of macerated sample was taken on a slide and fiber length was measured by an image analyzer.

The basic wood density of bamboo and *T. orientalis* was determined according to PAPTAC Standard A 8P.

For chemical characteristics, bamboo and *T. orientalis* were ground (40/60 mesh) in a Wiley mill, extracted with acetone and dried in vacuum over P_2O_5.

The Klason lignin (T211 om83), pentosan (T223 cm01) 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 CH_3COOH-CH_3COONa buffer and α-cellulose was determined by treating holocellulose with 17.5% NaOH.[12]

Pulping

Pulping was carried out in a thermostatically controlled electrically heated digester. The capacity of the digester was 5 litres. The normal charge was 250 g of oven dried (o.d.) bamboo, *T. orientalis* and bamboo-*T. orientalis* mixtures (0, 25, 50, 75 and 100%). Kraft pulping conditions were as follows: active alkali: 16, 18 and 20% on oven-dry (o.d.) raw material as Na_2O; sulphidity: 25%; cooking time: 120 min at maximum temperature (170 °C); 90 min was required to reach maximum temperature (170 °C) from room temperature; liquor to material ratio: 4.

After digestion, the pulp was washed until it was free from residual chemicals, and screened by a flat vibratory screener (Yasuda, Japan). The screened pulp yield, total pulp yield and screened reject were determined gravimetrically as percentage of o.d. raw material. The kappa number (T 236 om-99) of the resulting pulp was determined in accordance with Tappi Test Methods.

Evaluation of pulps

Pulps were beaten in a PFI mill at different revolution and handsheets of about 60 g/m^2 were made in a Rapid Kothen Sheet Making Machine. The sheets were tested for tensile (T 494 om-96), burst (T 403 om-97), tear strength (T 414 om-98), and brightness (T525 om 92) according to TAPPI Standard Test Methods.

D_0EpD_1 bleaching

The pulps were bleached by D_0EpD_1 bleaching sequences (where D represents chlorine dioxide and Ep represents peroxide reinforced alkaline extraction). The chlorine dioxide charge in the D_0 stage was 2%. The temperature was 70 °C in the D_0 stage for 60 min. Pulp consistency was 10%. The pH was adjusted to 2.5 by adding dilute H_2SO_4. The alkaline extraction stage was performed at the temperature of 70 °C for 120 min in a water solution of 2% NaOH and 0.2% H_2O_2 (on o.d. pulp). Pulp consistency was 10%. In the D_1 stage, the pH was adjusted to 4.5. The ClO_2 charge in the D_1 stage was 0.5%. The brightness and viscosity (T 230 om-99) of the bleached pulp were determined in accordance with Tappi Test Methods.

RESULTS AND DISCUSSION

Chemical, morphological and physical properties

The characteristics of bamboo and *T. orientalis* are presented in Table 1. The α-cellulose content in *T. orientalis* was higher than in bamboo, therefore better pulp yield could be expected.

There were very little differences in the pentosan and lignin contents between *T. orientalis* and bamboo. The ash content in bamboo was double that of *T. orientalis*, which is undesirable in pulp processing.

In the assessment of raw material quality for pulping, wood density is one of the most important parameters. High densities are advantageous considering the better use of digester capacity. The wood density of bamboo was more than double that of *T. orientalis*. The impact of basic wood density becomes clearer when pulp production for a given digester volume is computed, factoring in the pulp yield. Goyal *et al.*[13] showed that a eucalyptus clone with a specific density of 0.31 produced 2 tons higher pulp yield than the clone with a specific density of 0.30 in a digester of 4000 ft^3. Certainly, the higher wood density of bamboo will overcome the shortfall of *T. orientalis* in mixed chips cooking.

Bamboo fiber was longer, while that of *T. orientalis* was shorter, as shown in Table 1. Much stronger paper can be produced from longer fiber softwood pulps. These pulps are generally used as reinforcement pulp in paper production.[14] On the other hand, hardwood pulps are generally preferred for producing smooth and high-quality writing papers. Therefore, it is a good choice to combine short and long fiber pulp.

Pulping

Bamboo and *T. orientalis* were cooked by the kraft process varying the active alkali charge. As shown in Table 2, both raw materials were properly cooked at 18% active alkali, which is advantageous in mixed cooking. Figure 1 clearly shows that the screened pulp yield was maximum at 18% active alkali, followed by a decrease. Besides, the decreasing rate of kappa number was slowed down after this active alkali charge. *T. orientalis* gave a higher pulp yield and a lower kappa number than bamboo. This can be explained by the higher cellulose and lower lignin content in *T. orientalis* (Table 1). Pulp yields and kappa numbers were within the range of reported data on *T. orientalis* and bamboo.[6,15]

Table 1
Chemical, physical and morphological characteristics of bamboo and *T. orientalis*

Chips	α-cellulose (%)	Pentosan (%)	Lignin (%)	Ash (%)	Wood density (g/cc)	Fiber length (mm)	Fiber width (µm)
Bamboo	45.2	24.2	25.5	2.2	0.835	2.1	24.4
T. orientalis	49.1	23.5	24.1	1.1	0.368	1.34	24.5

Table 2
Effect of kraft cooking on paper-making properties of mixed pulps of bamboo and *T. orientalis*

Ratio	Active alkali	SPY	R	TPY	Kappa number
0% Bamboo/100% *T. orientalis*	16	44.3	3.9	46.8	27.6
	18	45.7	0.2	45.9	21.8
	20	43.5	0	43.5	17.6
25% Bamboo/75% *T. orientalis*	16	44.6	2.2	46.8	28.0
	18	45.1	0.7	45.8	23.7
	20	44.0	0	44.0	20.4
50% Bamboo/50% *T. orientalis*	16	43.5	2.4	45.9	28.3
	18	44.6	0	44.6	22.2
	20	42.3	0	42.3	20.8
75% Bamboo/25% *T. orientalis*	16	43.6	1.8	45.4	31.8
	18	41.5	0.2	41.7	24.6
	20	40.9	0	40.9	22.8
100% Bamboo/0% *T. orientalis*	16	42.8	2.1	44.9	39.3
	18	44.3	0	44.3	28.1
	20	40.9	0	40.9	22.0

SPY – screened pulp yield, R – reject, TPY – total pulp yield

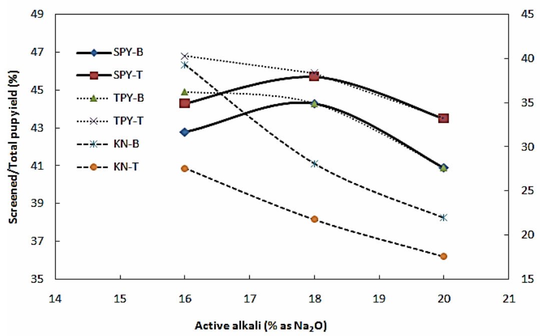

Figure 1: Pulp yield and kappa number of bamboo, *T. orientalis* and mixed pulps

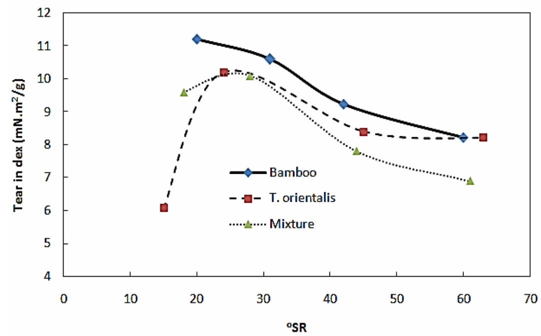

Figure 2: Tear index evolution with beating degree of bamboo, *T. orientalis* and mixed pulps

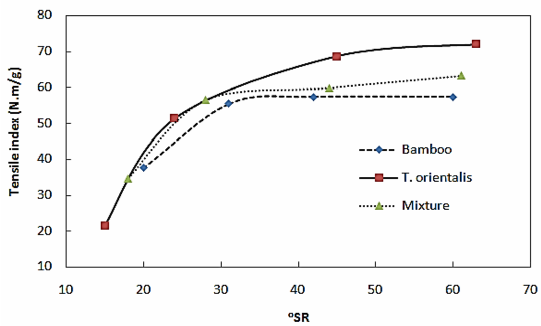

Figure 3: Tensile index evolution with beating degree of bamboo, *T. orientalis* and mixed pulps

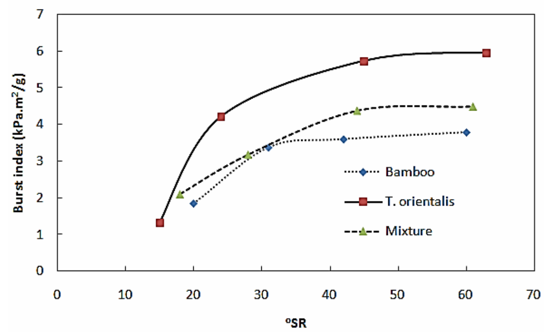

Figure 4: Burst index evolution with beating degree of bamboo, *T. orientalis* and mixed pulps

The pulp yield was increased and kappa number decreased when increasing the proportion of *T. orientalis* in the chip mixture. The highest and the lowest kappa numbers were determined in the 100% bamboo and 100% *T. orientalis* pulping, respectively. As shown in Table 2, depending on the active alkali charge, the kappa number of the mixed pulps was in the range of 20.4 to 31.8, which is compared to 17.6-27.6 for *T. orientalis* and 22.0-39.3 for bamboo. A similar kappa number increase was observed in kraft pulps of eucalyptus/pine chip mixtures.[16] Pulp with a higher kappa number was also observed for higher pine ratio in populus-pine chip mixtures.[8] Considering the pulp yield and the kappa number, the chip mixtures of 25% *T. orientalis* and 75% bamboo, and 50% *T. orientalis* and 50% bamboo with 18% active alkali charge were optimum, where the screened pulp yield and the kappa number were of 45.8% and 23.7, and of 44.6% and 22.2, respectively, with no reject. A species with higher density usually leads to a worse penetration of the cooking liquor into the fiber, which causes higher reject. The wood density of bamboo is higher than that of *T. orientalis* (Table 1), which is supposed to lead to higher reject in 100% bamboo than in 100% *T. orientalis*. However, in this case, the reject data are reverse. The bamboo we used in our pulp mill always showed lower reject, which has no explanation so far. We need to study extensively the morphology of this bamboo species, which may explain the results. At present, bamboo is being used as a main raw material for pulping in Bangladesh, therefore, maximum use of bamboo in the chip mixture is our target. Hence, the 50:50 chip mixture was used for subsequent bleaching and evaluation of paper-making properties.

Paper-making properties

The paper-making properties of bamboo, *T. orientalis* and mixed pulps, at different beating levels, are shown in Figs. 2-4. It can be clearly observed that the tear index of the bamboo pulp was the highest, while it was lower in the mixture with *T. orientalis*. An increase in tear index with the increase in long fiber softwood chips in the mixture with hardwood was also observed in a previous study,[8] and can be attributed to the fiber length of the raw materials (Table 1).[17] The maximum tear index of *T. orientalis* pulp was obtained at a beating degree (°SR) of 24. At this point, the pulp from the chip mixture also showed a similar tear index. The burst and tensile indices of the *T. orientalis* pulp were better than those of the bamboo pulp (Figs. 3-4). The burst and tensile indices of the pulp from the chip mixture were also better than those of the bamboo pulp at any beating degree.

Bleaching

All pulp showed almost similar bleachability. Final pulp reached to 80% brightness level at the ClO_2 consumption 25 kg/ton of pulp. The fully bleached pulps in this study represent end product; therefore, the tensile, tear, and burst properties were measured at °SR 30. Beatability of pulps is an important parameter in terms of energy consumption of a mill. Bamboo pulp required 3000 PFI revolution to reach °SR 30, while *T. orientalis* and mixed chips pups required 2400 and 2750 revolution. Improved pulp beating efficiency was observed with high hemicellulose content.[18-19] To get a desire freeness level, an increasing beating time was observed with increasing pine chips ratio in aspen chips.[8] However, in this study hemicelluloses content in the pulp was almost similar. Bamboo pulp fibers are supposed to respond well in PFI beating than do wood fibers due to outer secondary wall layer of bamboo fibers has a microfibril angle of about 20° with respect to the fiber axis which is much smaller than that of the S1 layer of wood fibers.[20] Easier beatability of *T. orientalis* pulp can explain by thinner its fiber wall thickness.[1] Therefore, longer fiber length of bamboo (Table 1) can explain the higher PFI revolution in this case. Tear index of bamboo pulp at °SR number 30, was 11.5 mN.m^2/g, which was slightly decreased to 10.3 mN.m^2/g on 50% *T. orientalis* mixing during pulping. Tear index is dependent on the fiber length of the raw material. Therefore, higher tear index was obtained for bamboo pulp. Tensile index of *T. orientalis* pulp was 43.5 N.m/g, which was 34.7% higher than that of bamboo pulp. Tensile index of mixed chips pulp reached to 40.3 N.m/g. Molin and Teder[21] studied on the strength properties of different types of pulps and found that the tensile strength decreased with decreasing hemicelluloses. Similar result was found for burst index. In this case, *T. orientalis* pulp fiber was collapsed easily within °SR 30 and fiber was properly fibrillated due to thin fiber wall[1-2] that facilitated fiber-fiber bond depended paper-making properties. But bamboo pulp needs longer beating to get desire paper-making properties.

Table 3
Physical properties of bleached pulps

Sample	Beating revolution	°SR	Tear index, mN.m^2/g	Busting index, kPa.m^2/g	Tensile index, N.m/g	Brightness, ISO%	Viscosity, mPa.s
Bamboo	3000	30	11.5	2.59	32.34	80.66	19.61
T. orientalis	2400	30	9.3	4.29	43.53	80.56	8.55
50:50	2750	30	10.3	2.93	40.29	80.08	13.53

CONCLUSION

Mixed chips pulping of high density bamboo and low density *T. orientalis* was conducted in kraft process. The cooking conditions of both raw materials were identical, which facilitate mixed chips pulping properly. Increasing *T. orientalis* chips proportion in the chip mixture increased pulp yield and decreased kappa number. Results of this study also demonstrated that better beatability and paper-making properties of pulps could be possible when up to 50% *T. orientalis* chips mixed with bamboo chips. Bleachability of bamboo, *T. orientalis* and mixed chips pulps was almost similar. Finally, it can be concluded that use of 50% substitution of *T. orientalis* chips by bamboo chips can overcome the problem related to basic wood density without affecting pulping and paper-making properties.

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