PULPING OF HYBRID *ACACIA* PLANTED IN A SOCIAL FORESTRY PROGRAM IN BANGLADESH

Md. MOINUL HAQUE,[*,**] M. IQBAL AZIZ,[**] M. SHARIF HOSSAIN,[**] M. A. QUAIYYUM,[**] M. ZAHANGIR ALAM[**] and M. SARWAR JAHAN[*]

[*]*Pulp and Paper Research Division, BCSIR Laboratories, Dhaka, Dr. Qudrat-i-Khuda Road, Dhaka 1205, Bangladesh*
[**]*Department of Applied Chemistry and Chemical Engineering, Dhaka University, Dhaka*
✉ *Corresponding author: M. Sarwar Jahan, sarwar2065@hotmail.com*

Received January 4, 2019

Acacias have been planted and it was found that *Acacia auriculiformis*, *Acacia mangium* and their hybrid are promising species with respect to their survival and growth performance in Bangladesh. Therefore, these three species have been introduced into a social forestry program in Bangladesh.
In this study, the chemical, physical and morphological characteristics of wood originating from plantation *A. auriculiformis*, *A. mangium* and their hybrid, grown in Bangladesh, were assessed for their suitability in papermaking. The α-cellulose content of the *Acacia* hybrid was 45.5%, which was 1.3% lower than that of *A. mangium* and 2.1% higher than that of *A. auriculiformis*. Kraft pulping of *Acacia* hybrid was carried out, with varying active alkali charge and cooking time, and it was observed that the hybrid required a high chemical charge to cook properly. Under the cooking conditions of 18% active alkali charge, 120 min of cooking, a pulp yield of 45.9% was reached, with kappa number 27.6 and with no reject. The pulp yield was quite high, as compared to those of *A. auriculiformis* and *A. mangium*. *Acacia* hybrid and *Acacia auriculiformis* pulps showed almost similar papermaking properties. The maximum tear index of *Acacia* hybrid was achieved at a tensile index of 76.3 N.m/g, while it was 61.9 N.m/g for *A. auriculiformis* and 57.2 N.m/g for *A. mangium*. At these peak levels, the tear index values are almost similar (10 mN.m^2/g) for *A. auriculiformis* and the hybrid. With respect to pulp yield and papermaking properties, the hybrid produced the best pulpwood.

Keywords: *Acacia* hybrid, α-cellulose, pulp yield, kappa number, papermaking properties

INTRODUCTION

Hybrid *Acacia* is produced from natural cross-pollination of *Acacia mangium* and *Acacia auriculiformis*, and is much faster growing than its parent trees.[1] Acacia hybrid is a medium-sized leguminous tree, which is generally long and straight, having a clear bole with light branching. It is resistant to heart rot disease.[2]

It has been found that *Acacia auriculiformis*, *Acacia mangium* and *Acacia* hybrid are promising species with respect to the survival and growth performance in Bangladesh. Therefore, these three species have been introduced into a social forestry program in Bangladesh. In other Asian countries, the plantation area of *A. mangium*, *A. auriculiformis* and acacia hybrids has also increased steadily.[3,4] In Vietnam, about 0.5 million hectares of land have been planted with these species mainly to supply raw material for pulp, paper, and timber industries.[4,5] Bangladesh Forest Department has 46,000 ha forestland for the social forestry program. The wood produced can be utilized in pulp mills, as Bangladesh is facing an acute shortage of pulping raw material.

A lot of studies have been carried out on the pulping of *Acacia* species. Yamada *et al*.[6] studied kraft cooking of 9 year old *Acacia* hybrid from Sabah, Malaysia, and obtained a very good pulp yield, of 55%. Khristova *et al*.[7] studied two *Acacia seyal* varieties (*fistula* and *seyal*) grown in Sudan for pulping and papermaking with different alkaline methods. The ASAM process showed the best results in terms of pulp yield, delignification and papermaking properties. Rosli *et al*.[8] studied the influence of pulping variables (active alkali charge, sulfidity, temperature and pulping time) on the pulp yield, Kappa number and strength properties of *Acacia mangium* kraft pulp. When beaten to a freeness of 500 mL and a 50% yield, the Kraft pulp from *A. mangium* evidenced excellent physical properties. Santos *et al.*[9] investigated *Acacia melanoxylon* and its natural variability. Under the same experimental conditions of kraft pulping, the screened pulp yield ranged between 47.0-58.2% and Kappa number between 10.9-18.4, at a variation of wood density from 449 kg m^{-3} to 649 kg m^{-3}. Watanabe and Miyanishi[10] studied *Acacia mangium*, which was used for first time afforestation in 1991 in the Province of South Sumatra, Indonesia. Prior to the construction of a new pulp mill, kraft pulping characteristics of plantation-grown *Acacia mangium* were investigated in the laboratory. It was found that the pulp yield was very high and was comparable to that of *Eucalyptus globulus*. Pulpwood samples from 8-year old *Acacia mearnsii* and *Eucalyptus grandis* plantations grown in Zimbabwe were evaluated for kraft pulping, bleaching and papermaking properties by Muneri.[11] *A. mearnsii* had higher chip basic density than *E. grandis*, and required more active alkali to produce pulp. At about the same Kappa number, the *A. mearnsii* pulp had lower strength properties, but higher opacity. The pulps of both species could be bleached to an acceptable brightness. Our previous studies on *A. auriculiformis* showed pulp yields of 43%-44% and kappa number of 22-24 obtained at 20% alkali and 2.5 h of soda cooking, at 16% alkali and 2.5 h of soda-AQ cooking, and at 18% alkali and 2 h of kraft cooking.[12] The pulping properties and fibre characteristics of *Acacia mangium* clones grown in Vietnam have been reported by Griffin *et al.*[13] The kraft pulp yield at kappa 20 was very similar for diploid and tetraploid clones, while tetraploid clones produced pulp with significantly longer (883 µm) and wider (20.0 µm) fibres, compared to those of diploid clones (683 µm and 15.6 µm).

A lot of variations among different studies on *Acacia* species have been found. Moreover, studies on *Acacia* hybrid pulping are very scarce. No reports have been found on the pulping of the *Acacia* hybrid grown in Bangladesh.

In this study, the *Acacia* hybrid included into the social forestry program of Bangladesh has been characterized in terms of chemical, morphological and physical properties. The pulping and papermaking potential of this hybrid was also evaluated and compared with that of *A. auriculiformis* and *A. mangium* grown in the same forest.

EXPERIMENTAL

Material

A. auriculiformis, *A. mangium* and their hybrid were collected from the Gazipur Forest Station at the age of 8 years old. Three trees were selected for this experiment. The part 2 ft from top and bottom was selected, the branches of these trees were discarded, while the remaining portion was debarked and chipped to 0.5 x 0.5 x 2 cm size in a laboratory chipper. The chips were ground in a Wiley mill and the 40-60 mesh size was used for chemical analysis.

Physical, morphological and chemical properties

The basic wood density of the *Acacia* hybrid, *A. auriculiformis* and *A. mangium* was determined according to PAPTAC Standard A. 8P. 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 under a digital microscope (Labomed, USA). Fiber width was determined from the cross-section photograph taken in an image analyzer using specific software.

The extractives (T204 om88), 1% alkali solubility (T 212 om98), water solubility (T207 cm99), Klason lignin (T211 om83) and ash content (T211 os76) were determined in accordance with Tappi Test Methods. Holocellulose was determined by treating extractive-free wood meal with a $NaClO_2$ 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.

Pulping

Pulping was carried out in a thermostatically controlled electrically heated digester with the capacity of 5 litres. The normal charge was 250 kg of oven dried (o.d.) *Acacia* hybrid, *A. auriculiformis* and *A. mangium*. Kraft pulping conditions were as follows:

- active alkali charge was 14, 16, 18 and 20% on oven-dry (o.d.) raw material as Na_2O;
- 90 min was required to reach maximum temperature (170 °C) from room temperature;
- cooking time was 60 to 180 min at maximum temperature (170 °C);
- liquor to material ratio was 4;
- sulphidity 25%.

After digestion, the pulp was washed till 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. Three replicates of all the experiments were done and the average reading was taken. The standard deviation was analyzed using MS Excel software.

Evaluation of pulps

The pulps were beaten in a Valley beater to different freeness (°SR) 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) and tear strength (T 414 om-98) according to TAPPI Standard Test Methods.

RESULTS AND DISCUSSION

Chemical, morphological and physical properties of *Acacia* hybrid

Table 1 shows the chemical, morphological and physical properties of the *Acacia* hybrid, compared with those of *A. mangium* and *A. auriculiformis*. The cold and hot water solubility of hybrid *Acacia* was 3.8% and 6.5%, values that are close to those of other hardwood species.[14] The cold water treatment removes a part of extraneous components, such as tannins, gums, sugars, inorganic matter and colored compounds present in lignocelluloses, whereas hot water treatment removes, in addition, starches. Higher water solubility adversely affects pulp yield.[15] Acetone solubility of the *Acacia* hybrid was 4.7%, slightly lower than for *A. mangum*. The acetone soluble content also adversely affects the paper machine runnability. High extractive contents in lignocelluloses are undesirable for pulping, bleaching and papermaking, they also affect the quality of paper because of shadow marking.

The α-cellulose content in the raw material positively influences pulp yield during chemical pulping.[16] The α-cellulose content of the cellulosic raw material also determines the physical strength properties of paper.[16,17] As shown in Table 1, the α-cellulose content in *Acacia* hybrid was 45.5%, which was slightly lower than that of *Trema orientalis* – a native fast-growing species in Bangladesh.[17] Yahya *et al.*[18] found the α-cellulose content in plantation grown *Acacia* hybrid in Indonesia was 45.45%. From the chemical composition point of view, raw materials with 34% or higher cellulose content are considered as suitable for pulp and paper production. With this consideration, the α-cellulose content of the *Acacia* hybrid is quite acceptable for pulping. Lignin is an undesirable polymer for paper production and the removal of lignin during pulping requires a high amount of energy and chemicals. The lignin content is desired to be lowered, since it affects pulp yield, as well as the bleaching process, whereby higher content of lignin in wood leads to lower pulp yield and strength. Meanwhile, lower lignin content of the raw materials makes them suitable for delignification under milder pulping conditions (lower H-factor and chemical charges) to reach a desirable kappa number. Also, it requires more bleaching chemicals to whiten paper.[19] The lignin content in the *Acacia* hybrid was 29.0%, which was much higher than in *T. orientalis*.[14] Yahya *et al.*[18] reported that the lignin content in the *Acacia* hybrid was 30.91%. As compared with other two species studied here, *A. mangium* and *A. auriculformis*, the lignin content of the hybrid lies between those of the parent species.

Table 1
Chemical, morphological and physical properties of *Acacia* hybrid in comparison with those of *A. auriculiformis* and *A. mangium*

Property	*Acacia* hybrid	*Acacia mangium*	*Acacia auriculiformis*
One percent alkali solubility	15.4	17.5	11.4
Hot water solubility (%)	6.5	5.9	6.5
Cold water solubility (%)	3.8	2.8	3.9
Extractive (%)	4.7	5.3	2.6
Holocellulose (%)	67.9	77.0	66.8
α-cellulose (%)	45.5	46.8	43.4
Pentosan (%)	16.7	17.2	13.2
Lignin (%)	29.0	30.3	25.2
Ash (%)	1.6	0.95	0.41
Fiber length (mm)	1.1	1.1	0.88
Density (kg/m^2)	320.3	366.3	430.0

Table 2
Kraft pulping of *Acacia* hybrid, in comparison with that of *A. auriculiformis* and *A. mangium*

Sl No.	Species	Active alkali (% as Na_2O)	Cooking time (min)	Pulp yield %			Kappa number
				Screened	Reject	Total	
1	*Acacia* hybrid	18	60	49.6	0.5	50.1	29.9
2		18	90	48.9	0.3	49.2	29.0
3		18	120	45.9	0	45.9	27.6
4		18	150	39.8	0	39.8	26.4
5		14	120	33.9	19.6	53.5	43.0
6		16	120	46.8	2.4	49.2	28.7
7		20	120	42.7	0	42.7	23.5
8	*Acacia auriculiformis*	16	90	44.6	0	44.6	20.9
9		16	120	44.3	0	44.3	19.5
10		16	150	42.9	0	42.9	18.2
11		16	180	40.9	0	40.9	17.2
12		14	120	46.1	0.7	46.8	24.7
13		18	120	42.6	0	42.6	17.3
14		20	120	44.0	0	44.0	16.4
15	*Acacia mangium*	16	90	42.0	-	42.0	21.0
16		16	120	41.0	-	41.0	19.6
17		16	150	38.7	-	38.7	19.5
18		16	180	38.0	-	38.0	19.2
19		18	90	39.9	-	39.9	20.2
20		18	120	37.4	-	37.4	18.7
21		18	150	36.0	-	36.0	18.0
22		14	120	44.9	0.2	45.1	30.7
23		14	150	43.4	0.1	43.5	27.3
24		14	180	42.8	0.1	42.9	25.1

The highest wood density was found in *A. auriculiformis*, followed by *A. mangium* and the hybrid (Table 1). The basic wood density of the *Acacia* hybrid was only 320.3 kg/m^3. This result is very low, as compared with the wood density of acacias.[20] Tanifuji *et al*.[21] showed that the wood density of the *Acacia* hybrid is lower than that of other acacias. Low wood density results in lower pulp yield.[19,22] Greaves and Borralho[23] stated that an increase in wood density and pulp yield decreased the cost of converting green roundwood into unbleached pulp per oven-dried tonne of bleached pulp produced.

The fiber length of the *Acacia* hybrid was 8.8% longer than that of *A. auriculiformis* and similar to that of *A. mangium* (Table 1). A hybrid producing longer fibres is expected to produce stronger paper.[22]

Pulping

Table 2 shows the kraft pulping data of the *Acacia* hybrid, compared with those for *A. auriculiformis* and *A. mangium*. Pulping was carried out by varying the active alkali charge and cooking time at 170 °C. The pulp yield and kappa number decreased with increasing active alkali charge and cooking time. The *Acacia* hybrid chips did not delignify sufficiently at 14% active alkali charge for 120 min of cooking (Sl No 5) and remained almost undercooked. Under these conditions, kappa number and the screened pulp yield were only 43.0 and 33.9%, respectively, with a reject of 19.6%. The screened pulp yield suddenly increased to 46.8% and kappa number and the reject decreased to 28.7 and 2.4%, respectively, with increasing active alkali charge to 16% in 120 min of cooking (Sl No. 6). Upon a further increase of the active alkali charge to 18% in 120 min of cooking, the screened pulp yield slightly decreased to 45.9% with no reject and kappa number decreased by 1.1 points (Sl No. 3). Yamada *et al*.,[6] showed that it was not necessary to cook acacia using an active alkali charge beyond 13%, as at this level, kappa number of the produced pulp dropped below 20. It is also observed from Table 2 that the pulp yield of the *Acacia* hybrid was much higher than those of *A. auriculiformis* and *A. mangium*. *A. auriculiformis* and *A. mangium* delignified more easily than the *Acacia* hybrid. At 16% active alkali charge in 120 min of cooking, *A. auriculiformis* cooked to a kappa number of 19.5.

Figure 1 shows the pulp yield – kappa number relationship for the *Acacia* hybrid, *A. auriculiformis* and *A. mangium* pulps. It is clear from the figure that the pulp yield at higher kappa number was higher for the hybrid than for *A. auriculiformis* and *A. mangium*. However, the hybrid could not delignify as well as *A. auriculiformis* and *A. mangium*. At kappa number 20, the pulp yield of *A. auriculiformis* was 3% higher than that of acacia hybrid and *A. mangium*. This can be explained by the different syringyl to guaiacyl ratio of lignin. Nimz[24] reported that β-O-4 linkages in guaiacyl units are hydrolyzed at a slower rate than syringyl units. A straight line correlation between the delignification rate and the ratio of syringyl to guaiacyl propane units was also obtained by Chang and Sarkanen.[25] Since the syringyl content of a typical hardwood can vary from 20 to 60%,[26] a higher rate of delignification is most likely due to higher syringyl contents in the native lignin of *A. auriculiformis*. Nevertheless, the pulp yield from these acacias grown in Bangladesh is much lower than those reported by other studies on acacias in other countries.[9,27] Still, the results obtained here are very similar to those of our previous study.[12]

Evaluation of papermaking properties

Acacia hybrid pulp, with kappa number 27.6 (Sl No. 3), *A. auriculiformis* pulp, with kappa number 19.5 (Sl No 9) and *A. mangium*, with kappa number 19.6 (Sl No. 16), were evaluated for papermaking properties and the results are shown in Figures 2-4. The pulps were beaten in a Valley beater and handsheets were prepared. The purpose of beating pulp is to improve the conformability of individual fibers in sheet consolidation, increasing the bonding surface between fibers in the fibrous network, and thus enhancing sheet strength. The effects can be brought about through mechanical treatment (*e.g.*, beating), the main purpose of which is to flexibilize the fibre wall structure by external and internal (delamination) fibrillation.

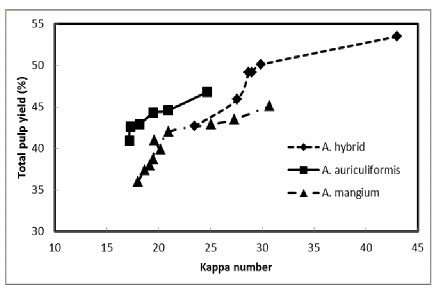

Figure 1: Pulp yield and kappa number relationship

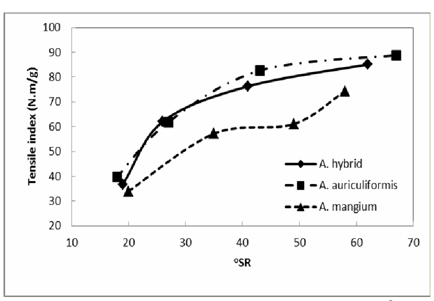

Figure 2: Evolution of tensile index with °SR for *Acacia* hybrid pulp, in comparison with *A. auriculiformis* and *A. mangium*

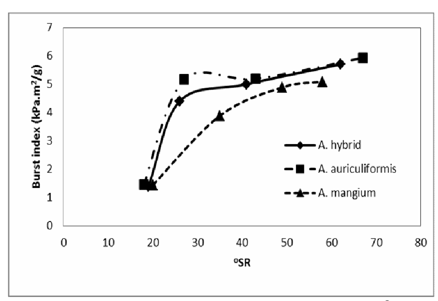

Figure 3: Evolution of burst index with °SR for *Acacia* hybrid pulp, in comparison with *A. auriculiformis* and *A. mangium*

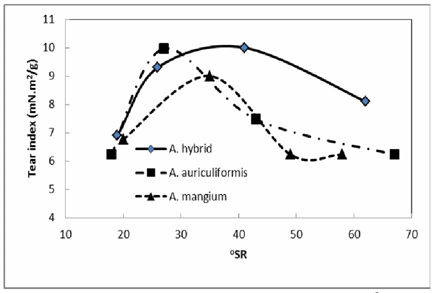

Figure 4: Evolution of tear index with °SR for *Acacia* hybrid pulp, in comparison with *A. auriculiformis* and *A. mangium*

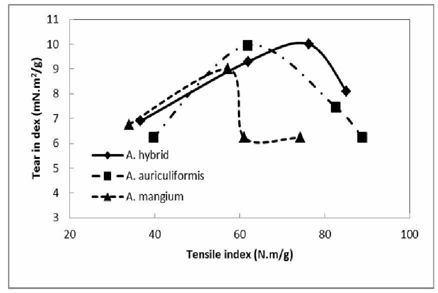

Figure 5: Tensile – tear relationship for *Acacia* hybrid pulp, in comparison with *A. auriculiformis* and *A. mangium*

At the initial stage of beating, the tensile and burst index of both beaten and unbeaten pulps were almost similar. The tensile index of unbeaten *Acacia* hybrid pulp was 36.7 N.m/g at the SR value of 18. After prolonged beating to a SR value of 62, the tensile index increased to 85.1 N.m/g, which was close to the value for *A. auriculiformis* pulp and better than that for *A. mangium* pulp. The tensile index of the *Acacia* hybrid pulp was about 31% higher than that of *A. mangium* at a °SR value of 40 (Fig. 2). The burst index of these pulps presented the same trend. The tensile and burst indexes of the *Acacia* hybrid pulp were weaker than those of the pulp prepared by Yamada from *Acacia* hybrid and almost similar to those of *A. auriculiformis* and *A. mangium*.[6]

The *Acacia* hybrid had a slightly better tear index over that of *A. auriculiformis*, particularly in the higher drainage resistance range (Fig. 4), which is probably due to its relatively short fibers (Table 1). Also, the *Acacia* hybrid pulp had about 12% higher tear index, compared to that of *A. mangium* pulp (Fig. 4). The tensile – tear relationship is an important parameter, which indicates to what extent inter-fiber bonding strength affects tear resistance at a given beating level, as it is responsible for the resistance of the fibers against being pulled out of the fibrous sheet structure. A plot of tear *vs.* tensile index is given in Figure 5 and it shows that the maximum tear index of the *Acacia* hybrid was at a tensile index of 76.3 N.m/g, while it was 61.9 N.m/g for *A. auriculiformis* and 57.2 N.m/g for *A. mangium*. At these two peak levels, the tear index values are almost similar (10 mN.m^2/g).

CONCLUSION

Acacia hybrid grown in Bangladesh is characterized with higher α-cellulose and lignin and lower wood density compared to *A. auriculiformis*. Acacia hybrid exhibited higher pulp yield, but delignification degree was lower compared to *A. auriculiformis*. The tensile index of unbeaten pulp acacia hybrid was 36.7 N.m/g at the SR value of 18. After prolong beating to SR value 62 N.m/g, tensile index increased to 85.1 N.m/g, which was close to *A. auriculiformis* pulp and better than *A. mangium* pulp. Acacia hybrid pulp showed the maximum tensile-tear ratio among these three species of acacias.

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