Mimosa (Albizia julibrissin) pulping and papermaking properties

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ABSTRACT: This paper evaluates mimosa (*Albizia julibrissin D.*) as a substitute for traditional hardwood in fine paper manufacturing. Laboratory pulping and handsheet experiments were undertaken for plantation-grown one-, two-, three-, four-, and 20-year-old mimosa wood. Mimosa pulp yield, strength, and optical properties were comparable to sweet gum, a traditional southern hardwood. Mimosa required gentle pulping and bleaching conditions. Mimosa pulps in softwood blends indicated high potential for papermaking, with three- and four-year-old wood exhibiting the best properties.

Application: Mimosa shows high potential as a hardwood substitute for papermaking. A major advantage of mimosa over traditional hardwoods is that it can be plantation grown and can thus provide a reliable supply of uniform fiber.

Mimosa (*Albizia julibrissin D.*), a hardwood tree in the Fabaceae family, was evaluated as a viable substitute hardwood fiber source for quality writing and printing paper grades. It has been previously reported that mimosa grows quickly to harvest age with high wood yields [1,2]. Annual harvest yields for one-, two-, and three-year-old mimosa stems are 12 to 18 moisture-free metric tons per hectare in the southern United States. Mimosa has uses as an ornamental plant, as forage, and as a source of biomass energy [3–5]. It is a perennial plant with stems 6 to 12 meters high in a mature tree. When stems are harvested and plant stumps and roots are left intact, coppice growth is prolific. Mimosa plants can be established easily from seeds, and several herbicides have been found to be effective during seed germination and early plant growth [2,5]. A major advantage of mimosa over traditional hardwoods is that it can be plantation grown and could thus provide a reliable supply of uniform fiber. Furthermore, mimosa can serve as a crop alternative for farmers and as an alternative to hardwood harvesting from old-growth forests.

Laboratory pulping, bleaching, and papermaking studies were conducted on mimosa wood obtained at several harvest ages. Preliminary results and detailed experimental procedures for studies with one- and two-year-old mimosa were reported previously [1,2]. New results are presented in this paper for studies carried out on chips of one-, two-, three-, four-, and 20-year harvest-age mimosa wood [6,7].

EXPERIMENTAL

Mimosa wood was harvested from mimosa plantations at the E.V. Smith Research Center of Auburn University, located near Tallassee, Alabama. Stands of mimosa were managed so that stems could be harvested after one, two, three, and four years of growth from established plants. Stems were chipped with a field chipper. A 20-year-old mimosa tree was also chipped to provide samples from a mature tree. Except in the case of the 20-year-old plant, the thin bark layer on the mimosa stem was not removed before chipping. Chips were screened, and chips of between 3 and 7 mm thickness were collected and used for this study.

Kraft pulping was performed in programmable M/K laboratory digesters. Chips in 500-g batches were cooked in the digester under conditions of 30% sulfidity, 4.0 liquor-to-wood ratio, and 170°C. The effective alkali (EA) and cooking time were varied to obtain pulp samples with different kappa numbers. Cooks with EA charges from 14% to 20% and cooking times from 10 to 100 min were used to generate pulp samples with a broad range of pulp yields and kappa numbers for the determination of a Hatton-type kinetic model [8–10]. After cooking, the pulp samples were disintegrated in a pulper and washed in a fine-mesh screen mold. Screened pulp yield, rejects content, and screened pulp kappa number were evaluated.

Pulp samples with kappa numbers between 17 and 19 were selected for processing and property evaluation. Beater curves using a Valley beater were developed for the assessment of pulp response to mechanical treatment. Handsheets were prepared at different freeness levels and conditioned in a constant humidity/temperature room for tests of strength properties. Paper property measurements were obtained for mimosa pulps with a target freeness level of 450 mL CSF and for mimosa pulps in 50/50 blends with softwood fibers (Loblolly pine), both conditions chosen to be consistent with fine paper manufacturing.

Selected pulps were processed in a D_0ED bleaching sequence (chlorine dioxide, caustic extraction, and chlorine dioxide). Chlorine dioxide was applied based on kappa number (kappa factor of 0.23), with 60% of the total charge applied in the first D_0 stage and the rest applied in the second D stage. Many batches of pulp were bleached from several mimosa cooks; each bleach batch consisted of 200 g of moisture-free pulp. **Table I** shows the bleaching conditions for pulps with a kappa number of 19. Excess chlorine at the end of each D bleaching stage was removed by the addition of sodium thiosulfate followed by a thorough washing.

Mimosa chip samples were analyzed at the Forest Products Laboratory, Madison, Wisconsin. Milled samples (20-mesh accepts) were hydrolyzed with 72% (w/w) H_2SO_4 for 1 h at 30°C. Samples were diluted to 4% (w/w) H_2SO_4 with distilled water, fucose added as an internal standard, and a secondary hydrolysis performed for 1 h at 121°C. Following secondary hydrolysis, samples were immediately filtered. The filtrate and washings were collected for sugar analysis. The acid-insoluble residue (Klason lignin) was quantified gravimetrically after thorough washing. Klason lignin values were gravimetrically corrected for ash content following incubation of the lignin at 575°C for > 3 h. Sugar contents of the hydrolysates were determined by anion-exchange high-performance liquid chromatography using pulsed amperometric detection. Sugars were then quantified using an internal standard method. Results are reported as percentages of the original sample mass [11].

Pulp and paper property evaluations were done according to TAPPI standards [12]. Pulp and paper properties of mimosa are compared to those for sweet gum (*Liquidambar styraciflua L.*) pulps prepared in our lab at the same kappa numbers (18+1) cooked at 170°C with an EA of 18% [6].

PULPING, BLEACHING, PAPERMAKING, AND TESTING RESULTS

More than 50 cooks were carried out on mimosa wood samples. Generally, mimosa required approximately the same cooking conditions as those required for sweet gum. The screened pulp yield for mimosa increased with harvest age, with one- and two-year-old mimosa ranging from 41% to 43%, three- and four-year-old mimosa ranging from 40% to 47%, and 20-year-old mimosa ranging from 44% to 49%. The older mimosa had a yield close to that for sweet gum (approximately 45%), based on the target kappa number of 18.

A number of digester cooks were performed for three- and four-year-old mimosa beyond those performed to determine the target kappa number. Measurements were obtained for total pulp yield (Y) and the screened pulp kappa number (K) for a variety of effective alkali charges (EA) and cooking times. The H factor (H) was calculated from the time and temperature profiles of the cooks [13,14]. These cooks were used to determine coefficients and exponents for the empirical equations developed by Hatton [8–10] for total pulp yield and screened pulp kappa number:

$$Y = A - B[(\log H)(EA)^{n1}] \quad (1)$$

$$K = \alpha - \beta[(\log H)(EA)^{n2}] \ . \quad (2)$$

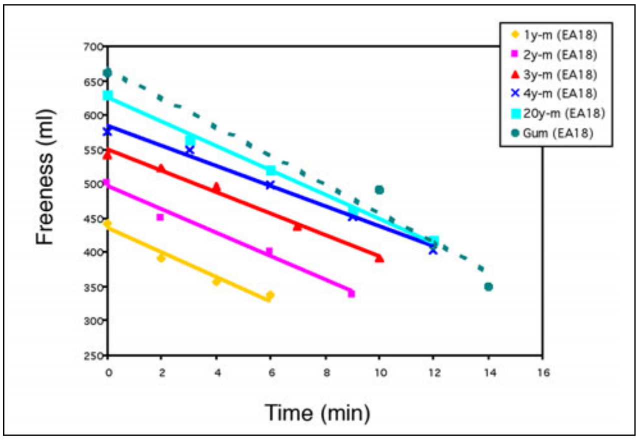
The values of the Hatton coefficients A, B, and n_1 in the total pulp yield model for four-year-old mimosa were 63.0, 0.89, and 0.70. A correlation coefficient (R^2) of 0.70 was obtained based on 10 cooks. The total pulp yield is the sum of the screened pulp yield plus the rejects content. The values of α, β, and n_2 in the kappa model for four-year-old mimosa were 69.8, 7.10, and 0.28. A correlation coefficient (R^2) of 0.97 was obtained based on 12 cooks. These empirical fits compare well with values obtained by Hatton for other species [8,9]. The total pulp yield and kappa equation coefficients for mimosa were close to those of other hardwoods such as maple and yellow birch. High correlation coefficients are perhaps an indicator of the uniformity of the mimosa raw material.

Stage	Chemical applied	Time (h)	Temperature (°C)
D_0	1.7% ClO_2	0.75	25
E	2.4% NaOH	1.5	65.5
D	1.1% ClO_2	3	71

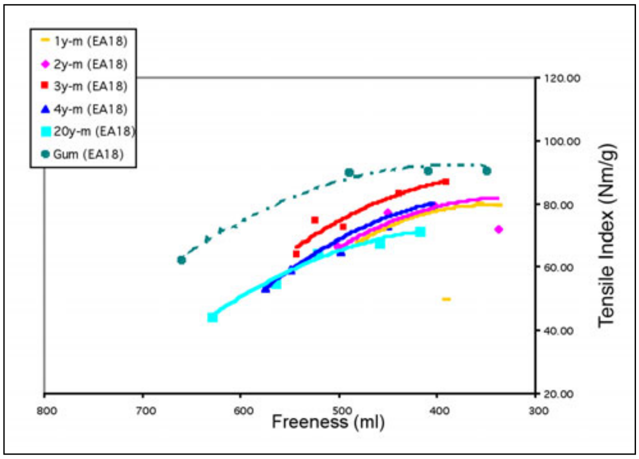
I. Bleaching conditions.

	Sweet Gum	1-year Mimosa	2-year Mimosa	3-year Mimosa	4-year Mimosa	20-year Mimosa
Fiber length (mm, length-weighted)	1.37	0.55	0.59	0.57	0.87	1.00
Fiber width (μm)	25.2	17.8	16.8	17.7	21.2	18.5
Wall thickness (μm)	8.8	5.2	4.9	5.4	6.7	6.9
Coarseness (mg/m)	0.21	0.14	0.13	0.12	0.20	0.10

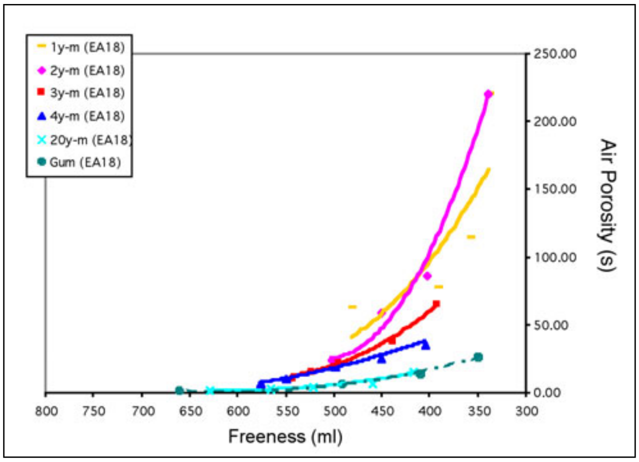
II. Comparison of fiber dimensions and coarseness for mimosa and sweet gum.



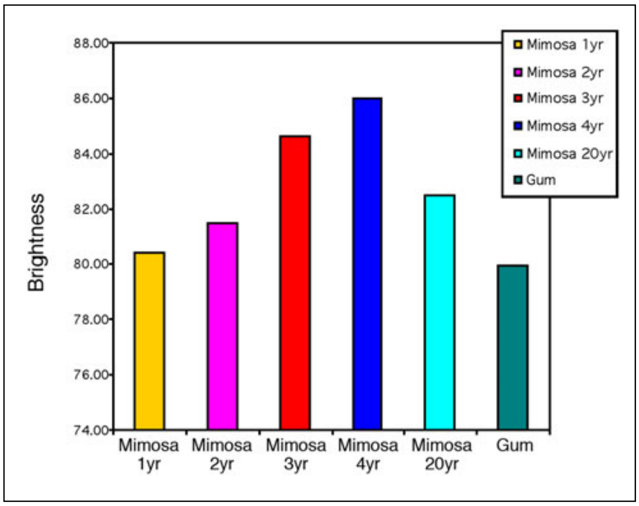
1. Beater curves.



2. Tensile index vs. freeness.



3. Air porosity vs. freeness.



4. Brightness of mimosa handsheets from different harvest ages.

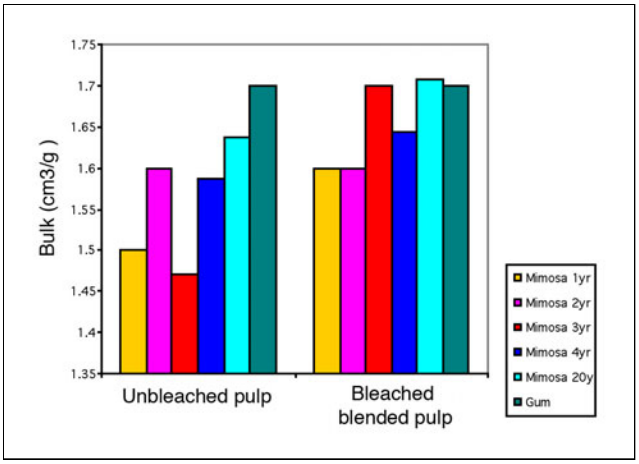
Kajaani analyses of the unbleached mimosa pulp samples are shown in **Table II**. Fiber length (length-weighted average fiber length) values of one-year-old to 20-year-old mimosa fibers ranged between 0.55 mm and 1.00 mm. Mimosa fiber length increased from one-year-old to 20-year-old wood. Mimosa fibers were found to have a fiber width of approximately 18 µm and a cell wall thickness of approximately 6 µm. These dimensions are slightly smaller than those of sweet gum fibers. Mimosa fibers exhibited low fiber coarseness, ranging from 0.1 to 0.2 mg/m, which indicates good collapsibility of the fibers.

Chemical composition analyses of mimosa wood (extractive-free basis) found lignin contents ranging from 22% to 24% and glucan contents ranging from 38% for one-year old to 46% for 20-year-old wood. Xylan content was 17%, mannan content less than 2%, and arabinan, galactan, and rhamnan contents all less than 1%. Variation in chemical composition with age was negligible.

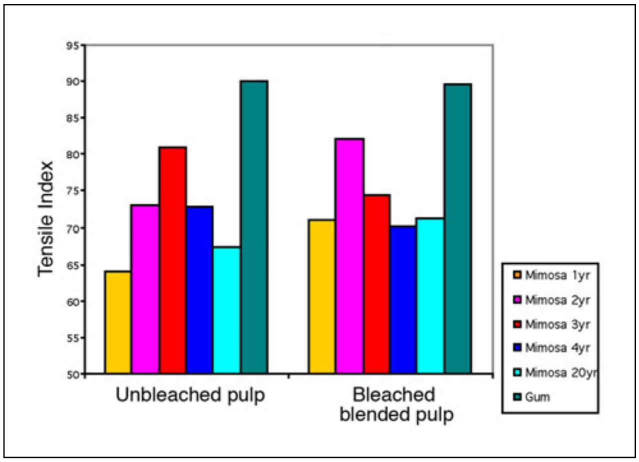
Figure 1 shows the beater curves for one-, two-, three-, four-, and 20-year-old mimosa and for sweet gum, all cooked at 170°C. Mimosa pulps had lower initial freeness levels than sweet gum, and they reached a target freeness of 450 mL CSF with little beating. The freeness increased with age of the wood.

Properties of handsheets made from these pulps changed with freeness level, with trends consistent with other wood species. As examples, **Fig. 2** shows tensile index and **Fig. 3** shows air porosity (Gurley densometer meter reading) at different freeness levels. At a freeness level of 450 mL CSF, mimosa exhibited slightly lower bulk, tensile index, burst index, and tear index, and slightly lower porosity (larger Gurley number) than sweet gum.

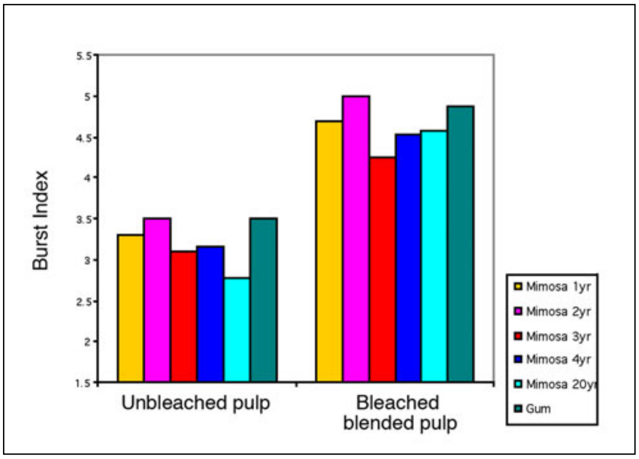
Mimosa pulps bleached with the D_0ED sequence exhibit high brightness levels varying from 80% to 86% **(Fig. 4)**. Sweet gum pulp brightness is 80% for similar charges of bleaching chemicals. Mimosa pulps had high opacity, ranging between 68% and 80%; opacity for sweet



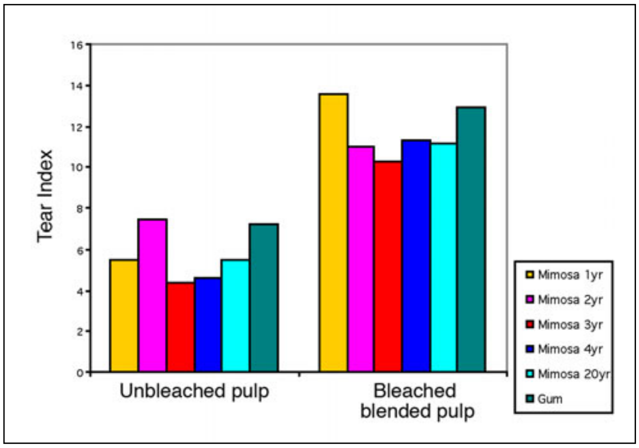
5. Bulk of mimosa handsheets from different harvest ages.



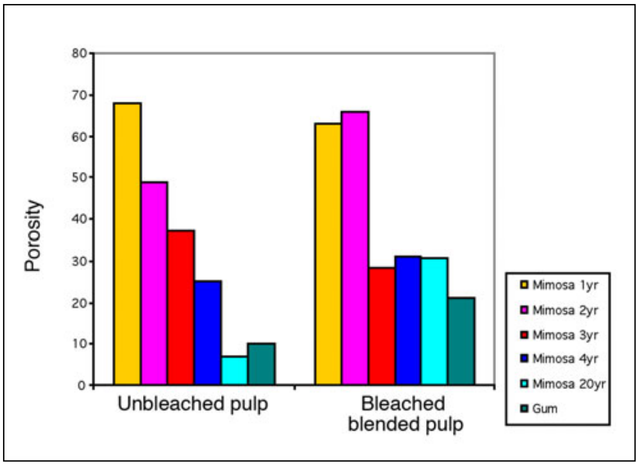
6. Tensile index of mimosa handsheets from different harvest ages.



7. Burst index of mimosa handsheets from different harvest ages.



8. Tear index of mimosa handsheets from different harvest ages.

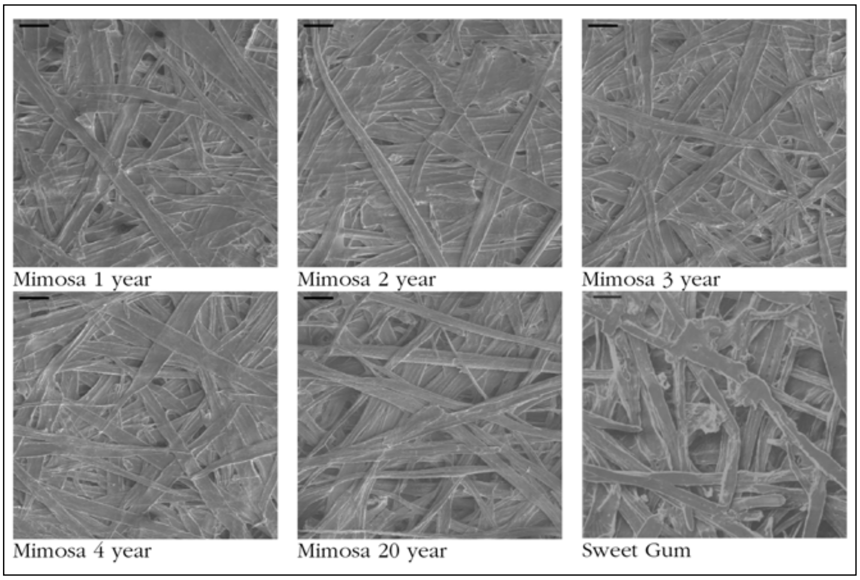


9. Porosity of mimosa handsheets from different harvest ages.

gum pulp was around 66%.

Figures 5 through **9** show property measurements for handsheets made from the unbleached pulps and bleached pulps in 50/50 blends with bleached softwood fibers. Comparisons were made at similar freeness levels (about 450 mL). Unbleached mimosa sheets had slightly lower bulk, burst index, and tear index than sweet gum, while bleached blended sheets had strength properties similar to those of sweet gum sheets. These figures show that, as expected, strength properties, especially burst and tear index, were higher for the 50/50 softwood/hardwood pulp blends. The mimosa blends have values similar to the sweet gum blends for all properties except tensile strength.

Scanning electron microscopy (SEM) images were obtained for mimosa handsheets from pulp samples that had not been bleached or beaten (**Fig. 10**). Fiber dimen-



10. SEM images of mimosa handsheets. The black bar in each picture is a 50-μm scale.

sions are consistent with those obtained through Kajaani analysis, and the images reveal the collapsibility of the fibers.

CONCLUSIONS AND FUTURE WORK

Mimosa was easily pulped and bleached, and pulp yields were similar to traditional hardwoods. The Hatton empirical kinetic equations developed for mimosa indicate a predictable response to pulping conditions. Mimosa pulp had low initial freeness and was easier to refine to 450 mL CSF, which indicates a potential energy saving from reduced requirements for pulp refiner operation. Mimosa pulp samples had higher brightness and opacity values than sweet gum pulp samples when they were processed under similar bleaching conditions and chemical charges.

Mimosa fiber dimensions were smaller and property values lower than those for typical hardwoods, and mimosa paper strength properties were slightly lower than those for sweet gum. However, this study shows that in 50% softwood blends, the mimosa sheets were similar to sweet gum (hardwood) sheets; this blend is typical for manufacturing of printable paper grades. Three- and four-year-old mimosa had slightly better pulp and paper properties than one- and two-year-old mimosa. **TJ**

INSIGHTS FROM THE AUTHORS

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In recent years, industry fiber supply needs and hardwood harvest concerns have generated a greater interest in plantation-grown hardwood fiber sources. Mimosa is a fast-growing woody biomass and forage plant which shows great potential as a new hardwood fiber source.

This study builds on previous work with mimosa to characterize more fully its response to pulping conditions and the properties of mimosa pulp. High and consistent harvest and pulp yields were observed over a wide range of harvest ages (1–20 years). Properties were found to be similar to those of sweet gum, a southern hardwood in wide commercial use today.

Mimosa is similar to nonwood fiber sources in that it can be harvested frequently (annually). However, since mimosa is a woody plant, it has fewer of the pulp processing drawbacks often associated with nonwoods. Mimosa is a perennial so it does not have to be replanted or reseeded; wood is harvested and new stems grow from established plants.

The next step in this work will be to establish mimosa plantations of modest size to evaluate pilot- and full-scale agricultural practices and perform pulping trials.

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