KRAFT PULPING AND FIBER CHARACTERISTICS OF FIVE BRAZILIAN WOODS

J. L. Gomide
Escola Superior De Florestas—U. F. V., Viçosa, Minas Gerais, Brazil

N. P. Kutscha, and *J. E. Shottafer*
Wood Technology, School of Forest Resources, University of Maine, Orono, Maine

and

L. W. Zabel
Chemical Engineering, University of Maine, Orono, Maine

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ABSTRACT

An investigation was conducted to evaluate the kraft pulping and wood fiber characteristics of the following woods grown in Brazil: Araticum, Jacaré, Açoita cavalo, and Angico vermelho. *Eucalyptus saligna* Smith., a species widely used in Brazil for pulp manufacture, was also incorporated in the study for comparative purposes.

Araticum and Açoita cavalo yielded pulps with physical characteristics that appeared superior to those of *Eucalyptus saligna*. Jacaré and Angico vermelho yielded pulps inferior to those of *Eucalyptus saligna*, but they probably could be used as pulpwoods.

The average fiber length, fiber diameter, cell lumen, and cell-wall thickness were determined for all species; but it was not possible directly to correlate fiber dimensions with pulp strength. This possibly can be explained as due, in part, to the effect of intrinsic fiber strength, which was not determined in this investigation.

An anatomical description of Araticum (*Annona sericeae*), a species never before described, is presented.

Keywords: *Annona sericeae, Piptadenia rigida, Piptadenia communis, Luchea divaricata, Eucalyptus saligna*, tropical hardwoods, fiber dimensions, strength tests.

INTRODUCTION

General background

The "Zona da Mata" region of Minas Gerais State, Brazil, comprises a mountainous area of 55,615 square kilometers (Instituto Nacional de Estatística 1937) including 12 municipalities. As its name (Forest Zone) suggests, this region was initially covered with forests. During the past century, however, coffee was planted and the steep deforested slopes have subsequently undergone erosion. As a result of the initial deforestation, the Zona da Mata now has only a little over 10% of its area covered with forests. Because of its mountainous characteristics, the Zona da Mata is not suitable for agricultural crops and the local government is trying to make that region a "forest zone" again. However, to achieve this objective, it is necessary first to study the characteristics of the native species and their possible uses, to encourage the establishment of new plantations.

Vale et al. (1972) indicated that approximately 45% of the total volume of the forests in the Zona da Mata is composed of eight species: Araticum, Copaiba, Jacaré, Cedrinho, Açoita cavalo, Angico branco, Farinha sêca, and Angico vermelho. Of the eight species, Araticum provides the largest volume per acre and Angico vermelho the smallest. Very little information can be found concerning the physical, chemical, or industrial processing properties of these eight species, and only one of them (Angico branco) has been commercially used for pulp production. Presently, there are two paper mills in the region, and both are expanding their production, but they are also facing serious problems related to availability of raw material. Although various *Eucalyptus* species are a potential source of raw material for pulp manufacture in this region, the secondary species are also a potential resource and should be investigated.

Purpose and scope of the study

This study was conducted to evaluate certain pulping properties and fiber characteristics of the following Brazilian species: Araticum (*Annona sericeae*), Angico vermelho (*Piptadenia rigida*), Jacaré (*Piptadenia communis*), and Açoita cavalo (*Luehea divaricata*). *Eucalyptus saligna* Smith., a species widely used in Brazil for pulp manufacture, was also included for comparative purposes. Following preparation by the kraft process, pulp yield, permanganate number, and freeness were determined. Characteristics of pulp handsheets and pulped fibers from each species were evaluated, and an anatomical description of Araticum, a species technically unknown, was prepared.

Literature review

As previously noted, specific information regarding the pulping of the experimental species is not available. However, a few comments may be made concerning the pertinent literature related to the experimental procedures employed in this research.

The kraft process is the dominant pulping process. The process is simple, relatively insensitive to variation in wood conditions, can be applied to a large number of species, and produces a pulp of good quality (Casey 1960; Libby 1962; Rydholm 1967). The process yields better results with tropical woods (Casey 1960), and according to Runkel (1952a) it is the only chemical process suitable for manufacture of both bleached and unbleached pulps from tropical woods. Some tropical species have extractives that condense with lignin in acid cooking liquors. In the kraft cooking liquor, however, they usually are dissolved and result in no harm to the pulp.

Pulping separates wood into its individual cell components, and to form paper these components are matted together. Therefore, the shape, length, diameter, and cell-wall thickness of the components may be expected to be of great importance to paper properties. Many investigations have been conducted to define the influence of fiber dimensions upon paper strength, but the subject has not been completely resolved. In studying tropical hardwoods, Runkel (1952b) indicated that the suitability of that wood for pulp manufacture depends on the ratio of twice the average cell-wall thickness to the average lumen diameter (Runkel ratio). This ratio should be less than unity. Peteri (1952) reported that no relationship was found between fiber length and tensile and bursting strengths. He affirmed that these two properties are greatly influenced by the "coefficient of flexibility" (ratio, as a percentage, between the cell lumen and cell diameter; l/D), where tensile strength is directly related to this coefficient. This same author did not find any relation between fiber length and tearing strength; and he concluded that if the average length of the fibers is less than a certain critical value, placed between 700 and 900 μm, it introduces a very marked harmful influence on paper strength and the above criteria cannot be applied.

In 1961 Tamolang and Wangaard, in working with hardwoods, concluded that in pulp beaten to 450 ml CSF, the breaking length value was directly related to the ratio of lumen width to cell diameter and to fiber length, and that for beaten pulp the tear strength is directly related to fiber length and to intrinsic fiber strength. Wangaard (1962) working with hardwood kraft pulps found that in unbeaten pulps the coefficient of flexibility is directly related to sheet density and tensile and burst strengths. As beating progresses, l/D continues as the predominant factor in governing sheet density, but intrinsic fiber strength assumes greater importance as a factor affecting tensile and bursting strengths. The maximum tear factor of beaten pulps was found to be predominantly and positively affected by the intrinsic fiber strength, highly and negatively affected by the Runkel ratio, and positively affected by the ratio of fiber length to cell diameter. Dadswell and Watson (1962) indicated that fiber length is the dominant factor controlling the tearing resistance, in a direct relationship, but that an increase in fiber length causes only a small improvement in burst and tensile strength. They also felt that cell-wall thickness is a most important factor in determining paper strength, stating that burst and tensile strengths are adversely affected by an increase in cell-wall thickness, but that thick-walled fibers provide some improvement in tearing resistance.

In 1966 Dinwoodie supported the earlier conclusions in his literature review (1965) by indicating that, in descending order of importance, the principal factors affecting properties of pulp are: fiber density (expressed as a ratio of cell-wall thickness to diameter), fiber length, and fiber strength. He concluded that breaking length and burst factor are determined primarily by fiber density (inverse relation), that fiber length is important (direct relation) insofar as a minimum length is required for maximum dissipation of stress, and that fiber strength (direct relation) determines the maximum strength obtainable. Tear factor, he concluded, is determined by fiber density (direct relation) and fiber length (direct relation), the former being slightly more important than the latter. Tamolang et al. (1968) studied the influence of hardwood fiber strength on pulpsheet properties and found that breaking length and burst factor increase with increasing sheet density and increasing fiber strength and that fiber length, sheet density and fiber strength were the principal factors responsible for variation in tear factor.

MATERIALS AND METHODS

Chip preparation

Four debarked bolts of each species about 2 ft in length and 4 inches in diameter were received from the Escola Superior de Florestas in Viçosa, Minas Gerais State, Brazil. Each bolt had been treated with formaldehyde and wrapped in polyethylene bags to avoid fungus growth during shipment. A disk 2 inches thick was cut from one end of each bolt for the anatomical procedure planned.

The bolts were chipped on a Carthage laboratory chipper, which limited the bolt size to 4 inches in diameter. The knife setting was adjusted to produce ⅝-inch chips. Oversize chips and sawdust were removed by screening, and the acceptable chips were then separated into two groups: ⅜-inch chips for preliminary tests and ⅝-inch chips for the pulping study. After air-drying, the chips were stored and conditioned in sealed polyethylene bags to insure a uniform moisture content.

Preliminary tests

To determine acceptable pulping conditions for each species, the ⅜-inch chips were cooked in small digesters, 5 inches long, made from 1¼-inch (ID) stainless steel pipe. The use of a larger digester was impractical because of the large number of cooks planned, therefore about 10 g of chips were processed in each digester. By using these small digesters, six cooks could be made at a time. Each species was cooked at 340 F for 2 hr, using six different active alkali concentrations (19%, 21%, 23%, 25%, 27%, 29%) and immersing the digester in a wax bath. After cooking, the chips were disintegrated in a Waring blender, and pulp pads were formed in a Buchner funnel. The pulp pads were used for permanganate number determinations. The cooking conditions for production of the pulp to be evaluated were established on the basis of the permanganate number of the pulps obtained with the small digesters. Conditions leading to a permanganate number above 10 and below 14 were selected, noting that pulps produced in the small digesters were expected to present a permanganate number 1 to 3 units higher than pulps produced in a larger laboratory digester when similar species and cooking conditions were used.

On the basis of the preliminary tests, it was concluded that all the species could be cooked under the same conditions and that this would result in pulps with permanganate numbers between 10 and 14.

Cooking conditions

As a result of the preliminary tests conducted in the small digesters with a target permanganate number between 10 and 14 for all cooks, the following conditions were selected for the production of pulps for the yield study, permanganate number determination, physical properties evaluation, and fiber measurements:

Active alkali—25% as Na_2O
Sulfidity—25% as Na_2O
Liquor to wood ratio—6:1 (ml per oven-dry g of wood)
Maximum temperature—340 F
Time at maximum temperature—2 hr
Time to temperature—½ hr

The Jacaré cooked as outlined above resulted in a pulp with a permanganate number of 15.7. To obtain a permanganate number between 10 and 14, this species was cooked for 2¾ hr at maximum temperature. All other cooking conditions for Jacaré were as described above.

Pulp preparation

A 3-lb capacity (oven-dry wood) digester, indirectly steam heated, was used for all cooks. Two cooks, labeled A and B, were made for each species using the same conditions for both cooks as established above.

Pulp preparation consisted, briefly, of washing the cooked chips, disintegrating them with a Morden slush maker, determining the yield, screening the pulp on a laboratory-size Bird vibratory screen with openings 0.008 to 0.010 inch wide, determining the percentage of rejects, and dewatering the pulp to approximately 20% consistency. A sample of pulp was removed, a pulp pad of about 20 g was made, dried on a hot plate, and stored in a polyethylene bag for fiber measurements.

The amount of pulp produced by a cook was determined by slurrying the total cook at about 3% consistency, and determining the consistency of a sample. The oven-dry weight of pulp in the total cook was calculated from the weight of the slurry and the consistency of the sample. The yield was then calculated from the oven-dry weight of chips charged to the digester and the oven-dry weight of the pulp produced.

The beater study was conducted according to TAPPI Standard T200 ts-66. Samples were drawn from the laboratory beater at time intervals of 0, 10, 20, 30, 40, 50, and 60 min.

Fiber measurements

The experimental pulps were used to determine the average fiber dimensions for each species. By using pulp instead of macerated wood, the average fiber length in each pulp type could be determined by measuring broken and unbroken fibers, and the average fiber length for each species of wood could be estimated by the unbroken fibers alone.

Fiber measurements were made essentially according to Isenberg (1967) and included fiber length, fiber diameter, cell lumen width, and cell-wall thickness. The length of broken and unbroken fibers was measured, using 100× magnification, until 200 unbroken fibers were measured. Broken fiber segments less than 180 μm were not measured, since such short pieces are likely to be lost in the white water during the pulping or papermaking process (Hale 1969). One hundred measurements were made of fiber width, cell lumen diameter, and wall thickness using 400× magnification. These measurements were made at the midpoint of the fibers.

Pulp testing

The pulp analysis consisted of measuring the permanganate number, yield percentage, and reject percentage. Pulp permanganate numbers were determined according to TAPPI Standard T214 m-50. Handsheets were made in accordance with TAPPI

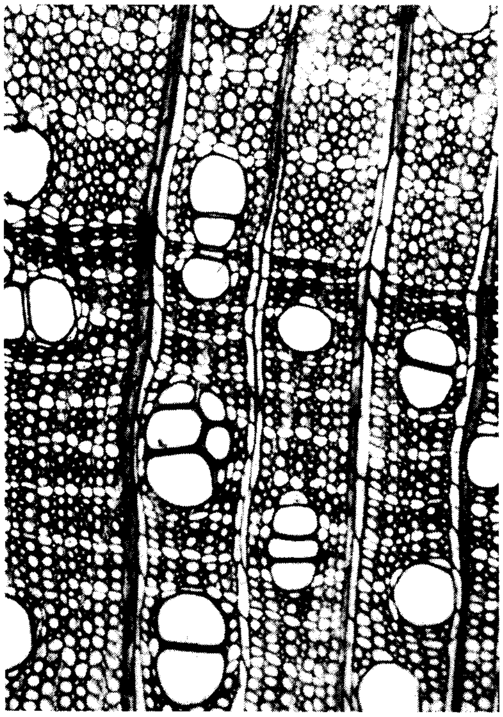

FIG. 1. Cross section of Araticum. (75×)

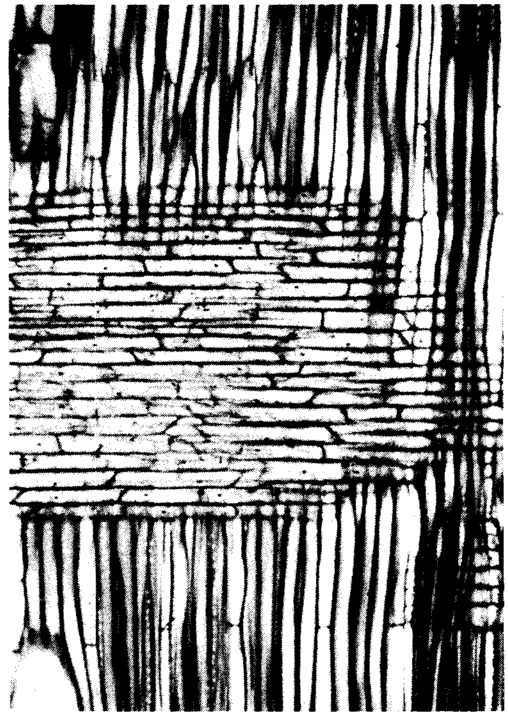

FIG. 2. Radial section of Araticum. (75×)

Standard T205 m-58. Each group of handsheets was tested for basis weight, caliper, bulk, density, bursting strength, tensile strength, and tearing strength, according to TAPPI Standard T220 m-60.

The complete procedure, including cooking, pulp preparation, pulp analysis, beating, handsheet making, and pulp testing was repeated, thus obtaining two individual testing results, designated A and B, for each species.

Anatomical studies

The 2-inch thick disks cut from the ends of the bolts were subdivided into ½-inch cubes and boiled in water with a reflux condenser to soften them for sectioning. Sodium carbonate was used as an additional softening agent for Jacaré and Angico vermelho. The softened cubes were stored in 50% alcohol and then sectioned with a sliding microtome. Cross, radial, and tangential sections were cut 15 μm thick and stained with 2% ferric ammonium sulfate, 1% hematoxylin solution, and aniline-safranin (Gomide 1972).

The sections were studied to provide an understanding of the anatomical makeup of each species. The slides of Araticum were also used to establish an anatomical description of this species, since none was available from the literature or through personal communication.

RESULTS AND DISCUSSION

Anatomical description of Araticum

Common name. Araticum, Araticum miudo.

Scientific name. Ramalho (1971) indicated that the species used in this study had been classified, by comparative methods, as *Annona sericeae* Dunal. Annonaceae. According to him this species is practically unknown, probably because of the existence of many similar species and to a current lack of commercial importance, Kukachka (1972) indicated that this species is technically unknown and that this may also be said for the great majority of the Annonaceae. The anatomical description of this species was made with assistance from the following references: Hess (1946), Kribs (1968), Panshin and de Zeeuw (1970).

General characteristics. Sapwood pale yellow to yellow grayish. Luster medium. Without characteristic odor or taste. Specific gravity (green volume) 0.55. Moderately hard. Texture medium to coarse. Straight grain. Growth rings distinct. Vessels visible without lens on all surfaces; solitary and in radial groups of 2–3 or in small clusters; evenly distributed or more numerous in latewood; diffuse-porous. Rays visible without lens on cross and radial sections but not on tangential section. Apotracheal banded parenchyma readily visible on cross section with lens. Ripple marks absent. Gum ducts absent.

Minute anatomy. (Figs. 1–3) *Vessels*—Very few (average 10 per mm^2), solitary and in radial groups of 2–3 or in small clusters, evenly distributed or more numerous in the latewood. Vessel elements of variable size: length 150–550 μm, average 350 μm; diameter 50–270 μm. average 150 μm; with simple perforation plates; with or without ligulate extensions. Intervessel pitting alternate, numerous, hexagonal to rounded, 9–10 μm in diameter; pit apertures linear, 4–5 μm long, sometimes coalescent. *Rays*—Widely to normally spaced, 3–6 per mm; homocellular and heterocellular Type III; procumbent cells with average dimensions 200 x 35 μm; mostly 3 cells wide, occasionally 1, 2, or 4 cells wide; maximum height 30–80 cells high up to 2150 μm high. *Parenchyma*—Longitudinal parenchyma abundant, in numerous uniseriate or biseriate lines in radial section. Apotracheal banded to diffuse-in-aggregate in cross section. *Fibers*—Libriform with simple or inconspicuously bordered pits; wide diameter and thin-walled or narrow diameter and thick-walled; non-septate. Fiber length 0.62–2.44 mm, average 1.53 mm; fiber diameter 10.10–86.50 μm, average 29.89 μm; lumen diameter 2.50–78.80 μm, average 20.30 μm; cell-wall thickness 2.50–9.50 μm, average 4.75 μm.

FIG. 3. Tangential section of Araticum. (75×)

Uses. This wood has not been used for any purpose of commercial importance, but this investigation indicates that it produces a pulp with good qualities.

Permanganate number

The permanganate numbers of the pulps produced with the larger digester and used for strength evaluations are given in Table 1. All the species were cooked under the same conditions except Jacaré, which had to be cooked for 2¾ hr instead of 2 hr to obtain a permanganate number between 10 and 14.

Araticum and Angico vermelho yielded permanganate numbers quite similar to those of *Eucalyptus saligna.* This suggests that for commercial pulp production, they probably can be cooked under the same conditions as *Eucalyptus saligna.* Açoita cavalo presented a relatively high permanganate number, but one still in the desired range of 10 to 14.

TABLE 1. *Permanganate number, yield and rejects of the experimental pulps used for strength evaluation procedure*

Species	Cook	Permanganate number	Yield %	Rejects %
Araticum	A	11.9	42.1	0.69
	B	12.3	42.4	0.25
	Average	12.1	42.3	0.47
Angico vermelho	A	12.4	44.8	1.43
	B	13.2	45.9	0.11
	Average	12.8	45.3	0.77
Jacaré	A	13.5	49.0	0.04
	B	13.8	48.6	0.04
	Average	13.6	48.8	0.04
Açoita cavalo	A	14.0	39.2	0.05
	B	14.0	39.4	0.02
	Average	14.0	39.3	0.03
Eucalyptus saligna	A	12.3	43.4	0.03
	B	12.2	42.8	0.03
	Average	12.2	43.1	0.03

Pulp yield

Table 1 shows the total yield, based on the oven-dry weight of the wood for each species, together with the percentage of rejects obtained during screening. Açoita cavalo produced the lowest yield, although the permanganate number was in the established upper limit. Araticum and Angico vermelho showed a yield similar to the control species (*Eucalyptus saligna*). Jacaré presented the highest yield, although it was cooked for a longer time.

Jacaré, Açoita cavalo, and *Eucalyptus saligna* presented similarly low percentages of rejects (Table 1). Araticum yielded a much higher amount of rejects, though not abnormally high, while Angico vermelho produced the highest percentage of rejects.

Freeness

The various levels of freeness, reported as Canadian Standard Freeness, as well as density obtained for each species at different beating times, are plotted (Figs. 4, 5). All the species, except Araticum, yielded freeness levels similar to *Eucalyptus saligna.* Araticum had a high freeness, and this may be desirable for some applications. Araticum was apparently the most sensitive to beating.

Although all the pulps were beaten for 60 min, all of them, except Açoita cavalo, presented freeness levels higher than 300 ml at that time. This suggests that all the pulps should have been beaten longer or, in

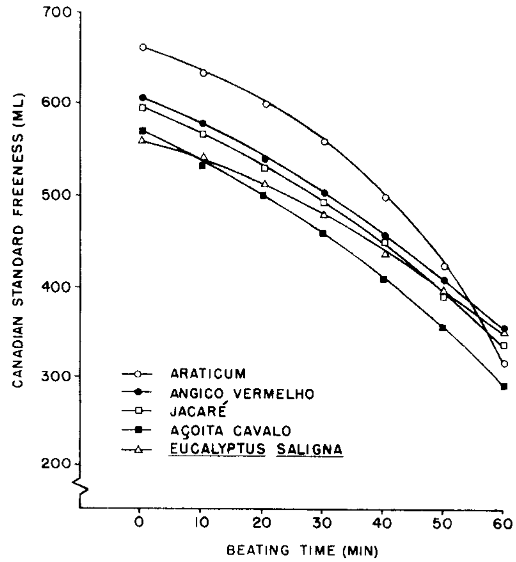

FIG. 4. Relationship of Canadian Standard Freeness values and beating time for experimental pulp types.

general, until a freeness of about 100 ml was reached. This greater freeness range would have permitted the determination of the maximum attainable strength for all of the pulps. As indicated in Fig. 6, only Açoita cavalo reached its maximum.

Fiber measurements

Average fiber dimensions for each species, including the length of whole fibers, fiber diameter, lumen diameter, and cell-wall thickness are presented in Table 2. The Runkel ratio, coefficient of flexibility, and average fiber length in the pulps, after screening and before beating, together with strength properties of handsheets at 350 ml CSF are shown in Table 3. Araticum, Açoita cavalo, and Angico vermelho exhibited longer average fibers than *Eucalyptus saligna.* Araticum and Açoita cavalo had a wider average fiber and a larger lumen diameter than *Eucalyptus saligna.* Araticum was the only species with thicker walls than *Eucalyptus saligna.*

It has been generally accepted that fiber flexibility has a direct effect upon burst and tensile strengths (Peteri 1952; Tamolang

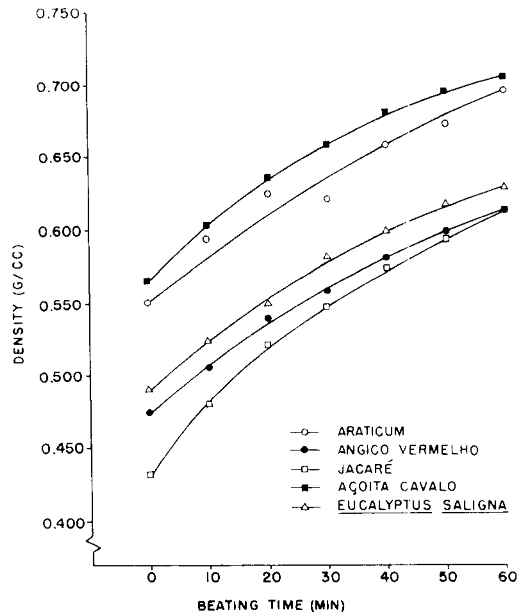

FIG. 5. Relationship of density and beating time for five experimental pulp types.

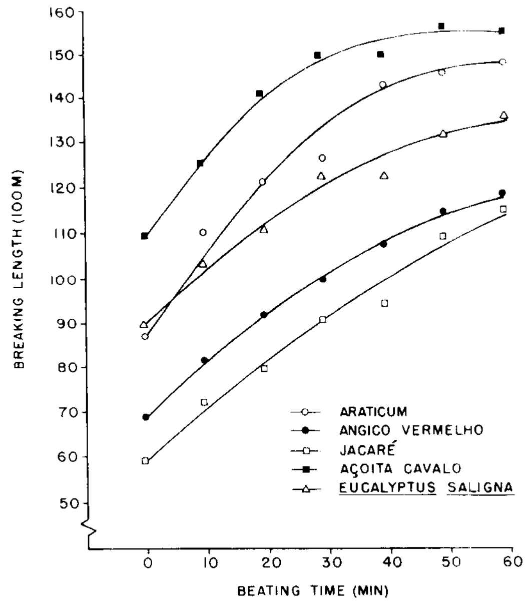

FIG. 6. Relationship of breaking length values and beating time for five experimental pulp types.

and Wangaard 1961; Wangaard 1962, Chase et al. 1971). In Table 3 it is evident that the pulp with the highest and therefore the best coefficient of flexibility is Araticum, followed in decreasing order by Açoita cavalo, Jacaré, *Eucalyptus saligna*, and Angico vermelho. The Runkel ratio is believed to have an inverse relationship with tensile and bursting strengths. Table 3 shows that Araticum gave the lowest and therefore the best Runkel ratio, and Angico vermelho the highest Runkel ratio.

If the influence of fiber length, coefficient of flexibility, and Runkel ratio are considered together and it is assumed the influence of the coefficient of flexibility and Runkel ratio may be more important than fiber length, some general predictions about pulp strength could be made. Araticum would be expected to give the strongest pulp, followed in descending order by Açoita cavalo, Jacaré, *Eucalyptus saligna* and finally Angico vermelho. However, the intrinsic fiber strength also has an important

TABLE [illegible]. Fiber dimensions for five experimental [illegible] pulp species

Species	Length of whole fibers Average (mm)	Length of whole fibers Standard deviation	Fiber diameter Average (μm)	Fiber diameter Standard deviation	Lumen diameter Average (μm)	Lumen diameter Standard deviation	Cell wall thickness Average (μm)	Cell wall thickness Standard deviation
Araticum	1.53	0.376	29.89	9.227	20.33	10.577	4.75	1.526
Angico vermelho	1.13	0.257	14.80	3.436	6.80	3.891	3.97	1.117
Jacaré	0.77	0.201	18.18	3.579	10.93	4.548	3.54	1.172
Acoita cavalo	1.59	0.392	24.13	4.190	15.88	4.524	4.16	1.213
Eucalyptus saligna	0.90	0.257	19.77	3.655	11.09	5.257	4.31	1.823

TABLE 3. *Pulp-handsheet strength properties and fiber characteristics for five experimental wood pulp species* [1]

Species	Breaking length (100 M)	Burst factor	Tear factor	Fiber length average (mm)	Coefficient of flexibility[2]	Runkel ratio[3]
Araticum	147	77.5	103	1.38	68.0	0.47
Angico vermelho	118	67.0	99.0	1.03	45.9	1.17
Jacaré	113	52.0	78.5	0.74	60.1	0.65
Açoita cavalo	155	95.0	125	1.35	65.8	0.52
Eucalyptus saligna	134	68.0	111	0.83	56.0	0.78

[1] Strength properties at 350 ml CSF

[2] Coefficient of flexibility = $\frac{\text{Lumen diameter}}{\text{Fiber width}} \times 100$

[3] Runkel ratio = $\frac{2\ (\text{Cell-wall thickness})}{\text{Lumen diameter}}$

influence on pulp strength (Wangaard 1962; Dinwoodie 1966; Rydholm 1967; Tamolang et al. 1968). This should be taken into account when making general comparisons between different pulps. As is noted later in this paper, this expected strength array for the species did not appear valid. This can possibly be accounted for by the fact that the influence of intrinsic fiber strength was not considered in this study. Another factor that may also have affected the relationship between fiber characteristics and pulp strength is the different permanganate number values obtained for each species.

Handsheet strength evaluation

Density. The density values obtained with each experimental pulp type at the different beating time levels indicated that Açoita cavalo yielded the highest densities, followed by Araticum, *Eucalyptus saligna*, Angico vermelho, and Jacaré (Fig. 5). Although it is not possible to establish a specific or unique relationship between handsheet density and handsheet strength, those with higher density could be expected to present higher tensile and burst strength values. It should be noted that low density is actually desirable for the manufacture of certain types of paper.

Breaking length. Tensile strength, expressed as breaking length, is shown as a function of beating time in Fig. 6. For all the pulp types, the curves followed the typical pattern of strength development with increasing beating time. To evaluate the breaking length results of the test species, an analysis of variance, employing a split-plot design with subsamples, was used. This analysis of variance indicated a significant interaction between species and beating time and therefore it was questionable to attempt to establish, statistically, the significance of differences between the breaking length values of the five species. However, some conclusions may possibly be drawn from Fig. 6.

Duncan's multiple range test was employed to determine the significance of differences in breaking length values at the various beating times, for each pulp type. In general, the beating time intervals of 10 min were found to be too short. The samples probably should have been withdrawn from the beater at 20–30-min intervals. Figure 6 indicates that by increasing the beating time beyond 60 min, higher breaking length values could probably be expected for the three weaker species. The breaking length data indicate that these tropical hardwoods produce very strong kraft pulps. The maximum breaking length attained, by beating, by Açoita cavalo and by Araticum approaches that obtainable by northern softwoods and materially exceeds that of typical northern hardwoods.

In Table 3 the average fiber length, coefficient of flexibility, and Runkel ratio of the pulps are presented for all tested species, together with the strength properties shown in Figs. 6, 7, and 8, at a freeness of 350 ml. Based on the fiber characteristics, Araticum was expected to yield the highest breaking length values, followed in descending order by Açoita cavalo, Jacaré, *Eucalyptus saligna*, and Angico vermelho. However, this was not the case, as shown in Fig. 6, which indicates that other important factors must be contributing to the strength characteristics. Probably one of the more important of these factors, and one that was not determined in this study, is the inherent strength of the fiber itself. This might explain, in part, the reason why Araticum fibers, which have a higher coefficient of flexibility and lower Runkel ratio than Açoita cavalo, do not produce a stronger pulp. The same reasoning might be applied to Jacaré which, while having better coefficient of flexibility and Runkel ratio values than *Eucalyptus saligna*, exhibited a lower pulp strength.

Burst factor. To analyze the burst factor values an analysis of variance, again employing a split-plot design with subsamples, was performed and the results showed a significant interaction between beating time and species. A statistical analysis, therefore, between the burst factor means of the five species was not performed. Figure 7, however, permits some conclusions to be drawn. Açoita cavalo appears to be much stronger than the other species tested, while Araticum was the second strongest species in regard to burst strength. *Eucalyptus saligna* and Angico vermelho showed similar bursting strength values, although the former was slightly stronger than the latter. Jacaré developed the lowest bursting strength.

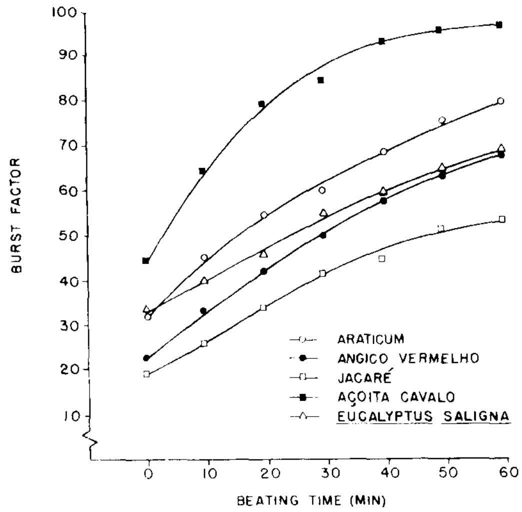

FIG. 7. Relationship of burst factor values and beating time for five experimental pulp types.

A Duncan's multiple range test was employed to analyze the effect of beating time upon burst factor values. All species revealed significant differences in burst factor means at the various levels of beating except Jacaré and Açoita cavalo, which exhibited no significant difference between burst factor means at beating times of 50 and 60 min. Figure 7 indicates that 60 min of beating time were apparently not sufficient for most of the species to reach their maximum bursting strengths. These species probably should have been beaten for 120–180 min. Although there are significant differences evident in bursting strength at 10-min intervals, samples could probably be drawn from the beater at 20–30-min intervals if the total beating time were increased to 120–180 min.

In all probability, the same analysis developed in relating fiber characteristics to breaking length can be applied to the bursting strength results. Again, intrinsic fiber strength may have played a significant role in determining burst factor results.

Tear factor. Figure 8 illustrates the relationship between tear factor and beating time for all the species. Here again a significant interaction between beating time and species was detected with an analysis of

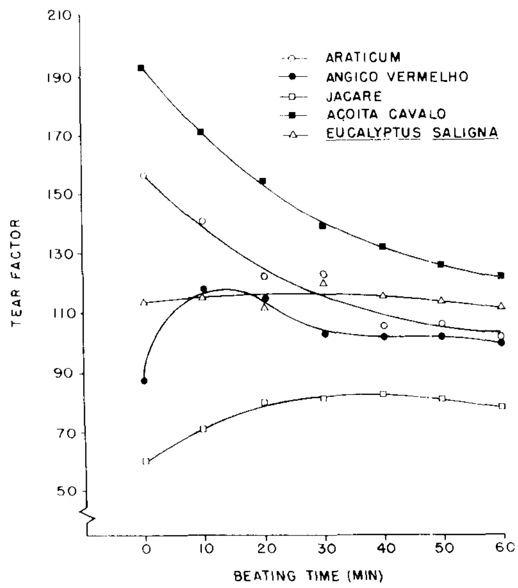

FIG. 8. Relationship of tear factor values and beating time for five experimental pulp types.

variance, using split-plot design with subsamples. No statistical comparisons between the species were attempted.

A Duncan's multiple range test was employed to analyze the influence of beating time upon tear factor for all five species. The results of this test showed that there was no significant effect of beating time upon tearing strength of *Eucalyptus saligna* pulp, even when comparing the unbeaten pulp (0 min) with the pulp beaten for 60 min. The effect of beating time upon pulp made from Jacaré was also similar to the effect upon pulp of *Eucalyptus saligna*.

Tear strength is expected to present an inverse relationship to beating time, and Açoita cavalo and Araticum produced values that tended to follow this pattern. *Eucalyptus saligna* and Jacaré, however, did not show a significant decrease in tearing strength with increasing beating time. Angico vermelho was the only species that presented an initial increase in tear factor followed by a decrease. However, the decrease in tear factor values for Angico vermelho was not as pronounced as might be expected. These results again indicate that the beating time possibly was too short (Fig. 8). Although the beating time apparently was insufficient to obtain conclusive results, some inferences may be drawn on the basis of the results obtained. Açoita cavalo exhibited the highest tearing strength. Araticum showed greater tearing strength than *Eucalyptus saligna* when beaten for less than 30 min, and beyond this limit *Eucalyptus saligna* presented the greater tearing strength. Angico vermelho showed a lower tear factor than *Eucalyptus saligna* and Jacaré developed the poorest tearing strength of all the test species.

Cell-wall thickness and fiber length commonly have an important and positive effect on tearing strength, but no specific relationship could be established between these fiber dimensions and tear factor, as shown in Tables 2 and 3. This might possibly be explained by the undetermined effect of intrinsic fiber strength.

CONCLUSIONS

On the basis of this study the following conclusions may be drawn:

1. Although beating time has been judged insufficient, this study indicates that in descending order of pulp quality, Açoita cavalo was the best species, followed by Araticum, *Eucalyptus saligna*, Angico vermelho, and Jacaré.
2. Although Angico vermelho and Jacaré apparently produce poorer pulps than *Eucalyptus saligna*, they can probably be used as pulpwoods.
3. In the pulp permanganate range from 10 to 14, Jacaré presented the highest yield percentage, followed by Angico vermelho, *Eucalyptus saligna*, Araticum, and Açoita cavalo.
4. Jacaré, which produces a good yield, may be suitable for production of pulp where low density is desired.
5. If the Minas Gerais State government for Zona da Mata wishes to encourage the planting of local species, Araticum is recommended because of its good pulping properties and because it is the

native species that has the highest volume per acre.

6. Although Açoita cavalo has a lower volume per acre than Araticum, it is also recommended for reforestation by native species in the Zona da Mata because of its very good pulp characteristics.
7. The cooking conditions used in this investigation produced good pulp and provide a starting point to determine the optimum cooking conditions for each species.
8. This study indicates that the woods evaluated are in general more difficult to beat than North American hardwoods.

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