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Fiber properties of *Acacia mangium* and *Calophyllum brasiliense* woods for papermaking: a comparative study

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ABSTRACT: This study analyzed the fiber properties of 24 trees, 12 of which were *Acacia mangium* and 12 *Calophyllum brasiliense*, with the aim of evaluating the suitability of these species for paper production.We determine wood density, fiber features and fiber properties for the purpose of papermaking. In general, our results showed that both woods have medium quality for papermaking; however, *C. brasiliense* has a slight advantage by the greater number of properties classified as medium based on the reference values for fiber properties and the average values for each species. For flexibility coefficient, both species are classified as medium quality, falling within the range of 0.50 to 0.65. Wall fraction is also classified as medium quality, falling within the range of 0.50 to 0.35. Runkel ratio values group both species as good for paper (0.50 - 1.00). Slenderness ratio ranks *A. mangium* (0.62) in group III, 0.50 - 1.00, as good for paper, while *C. brasiliense* (0.43) is ranked in group II, 0.25 - 0.50, as very good for paper. According to Luce's shape factor, *C. brasiliense* is good for papermaking with a value below 0.5. Overall, both species were found to be suitable for paper manufacturing, demonstrating strong potential for this industrial application.

Propriedades das fibras das madeiras de *Acacia mangium* e *Calophyllum brasiliense* para fabricação de papel: um estudo comparativo

RESUMO: Este estudo analisou as propriedades das fibras de 24 árvores, sendo 12 de *Acacia mangium* e 12 de *Calophyllum brasiliense*, com o objetivo de avaliar a adequação dessas espécies para a produção de papel. Determinamos a densidade da madeira, as características das fibras e as propriedades das fibras. Nossos resultados mostraram que ambas as madeiras possuem qualidade média para fabricação de papel; entretanto, *C. brasiliense* leva ligeira vantagem pelo maior número de propriedades classificadas como médias com base nos valores de referência das propriedades da fibra e nos valores médios de cada espécie. Quanto ao coeficiente de flexibilidade, ambas as espécies são classificadas como de qualidade média, situando-se na faixa de 0,50 a 0,65. A fração da parede também é classificada como de qualidade média, situando-se na faixa de 0,50 a 0,35. Os valores do índice de Runkel agrupam ambas as espécies como boas para papel (0,50 - 1,00). O índice de esbeltez classifica *A. mangium* (0,62) no grupo III, 0,50 - 1,00, como boa para papel, enquanto *C. brasiliense* (0,43) é classificado no grupo II, 0,25 - 0,50, como muito boa para papel. De acordo com o fator de forma de Luce, *C. brasiliense* é boa para a fabricação de papel, com valor abaixo de 0,5. De modo geral, ambas as espécies se demonstraram adequadas para a fabricação de papel, apresentando um bom potencial para essa aplicação industrial.

Introduction

Global climate change is currently top of mind for scientists and policymakers alike. Studies indicate that a significant effort is needed to reduce greenhouse gas emissions as an important step in decreasing the planet's temperature in the long term. The pulp and paper industry also faces this challenge, mainly because they use wood. Although CO2 emissions are considered neutral by international definitions, the modernization of production systems is always desirable (Szabó et al. 2009).

The production of pulp and paper is important in the economy of many countries of the world, including the Brazilian economy. The cultivated tree sector in Brazil in 2022 generated 2.6 million direct and indirect jobs, achieved a gross revenue of R$260 billion and broke a production record by reaching 25 million tons of cellulose and 11 million tons of paper. In 2022, Brazil was the largest cellulose exporter in the world (IBÁ 2023).

The paper and cellulose industries are faced with environmental challenges, including carbon sequestration, in an effort to produce different types of high-quality paper products. This calls for improving the entire production chain with the commonly used species Eucalyptus spp. and Pinus spp., as well as the search for alternative wood species in order to offer new market options. With this in mind, our study investigated the wood of *Acacia mangium* and *Calophyllum brasiliense*.

Acacia mangium (brown salwood) is a fast-growing tropical timber and native to Australia, Indonesia and Papua, New Guinea. It is a legume species capable of improving soil fertility (Jasmani and Adnan 2017). The species is used in Asia for the production of paper and cellulose and widely exploited in Indonesia; however, owing to diseases that recently (2012-2017) affected populations of A. *mangium*, the cellulose and paper industries switched to *Eucalyptus pellita* and related hybrids (Hardiyanto et al. 2024). *Acacia mangium* is a cultivated species; its plantings have already been confirmed in all Brazilian regions in anthropogenic areas (*Acacia* 2024). The easy adaptation to humid tropical climates and the suitable properties of *Acacia mangium* fibers suggest that plantations of the species should soon spread to other regions of the world, including South America, competing with other sources of tropical wood fibers (Bajpai and Bajpai 2010).

Calophyllum brasiliense (guanandi) is a native Brazilian species, non-endemic, and occurs naturally in all regions of the country with distribution in the Amazon, Caatinga, Cerrado and Atlantic Forest (Cabral 2024). Older data already showed the wood's potential for paper production with fiber lengths from 600 to 1270 μm, but more frequently measured from 900 to 120 μm (Paula 1982, Chimelo et al. 1976). However, this wood is not typically used in papermaking. Instead, studies show many other applications of *C. brasiliense* wood, such as agricultural tools, boat building, and carpentry. In civil construction, it is used for sleepers, flooring, carpentry, furniture, interior decoration, bridge and maritime construction (above water) (Serviço Florestal Brasileiro 2024).

Wood originates from the cambium (inner bark) of trees and consists of cellulose, hemicellulose, lignin and extractives. Wood properties depend on such characteristics as growth place, climate, and soil. Trees that grow in moist, warm, sunny places grow quickly and have thick, stiff fibers, while trees that grow in dry, cold, less sunny places are slow-growing and have fine, dense fibers (Bajpai 2018).

To determine the suitability of wood quality for papermaking, several factors related to distinct fiber properties need to be assessed, including soil and climate conditions, plantation management, tree growth and development. No less important is an evaluation of wood characteristics, such as density and cellular variations that include the measurement of basic specific gravity, fiber dimensions, flexibility coefficient, wall fraction, Runkel ratio, slenderness ratio, Luce's shape factor and Mulsteph ratio (Foelkel 2009; NagarajaGanesh et al. 2022; Klock 2024). *A. mangium* is well explored in Asia, it remains an understudied species in Brazil. Although previous literature has reported on the use of *C. brasiliense* for papermaking, the present study brings contemporary data to assess its potential, thus making a novel contribution to the Brazilian forestry sector.

Therefore, in this study, we characterized and compared the wood density and fiber properties of *Acacia mangium* and *Calophyllum brasiliense* wood in order to determine the suitability of each for papermaking.

Material and Methods

Planting area

The raw material of this study, *Acacia mangium* Willd. Fabaceae (acácia) and *Calophyllum brasiliense* Cambess. Calophyllaceae (guanandi), was kindly provided from harvested crops cultivated from Reflorestadora Cicero Prado & Guanandi-CP4 Instituto Coruputuba in Pindamonhangaba, SP, Brazil. Commercial plantations of both species are situated at 22°54'31"S 45°23'11"W (elev. 560m) (Figure 1). According to the Köppen climate classification, the climate of Pindamonhangaba municipality can be classified as Cwa (humid subtropical with dry winter and hot summer). Meteorological data indicate an average annual air temperature of 18.9°C and average annual precipitation of 1,590.8 mm with almost 81% occurring between October and March (Alvares et al. 2013). The climatological water balance allows for an understanding of the water regime of the region where the area is located (Figure 1). From October to April, water supply exceeds 728.1 mm, whereas the soil water deficit, which is 3.5 mm per year, extends from June to August, peaking in July. Planting for both species (Figure 2) was established at a spacing of 3 m x 2 m without fertilization. The plantings were installed in Melanic Gleisol, or, more specifically, the association of dystrophic Tb Melanic Gleisol, clayey texture + Tb Fluvic Neosol, medium texture + Organosol, both flat relief phase (Rossi 2017).

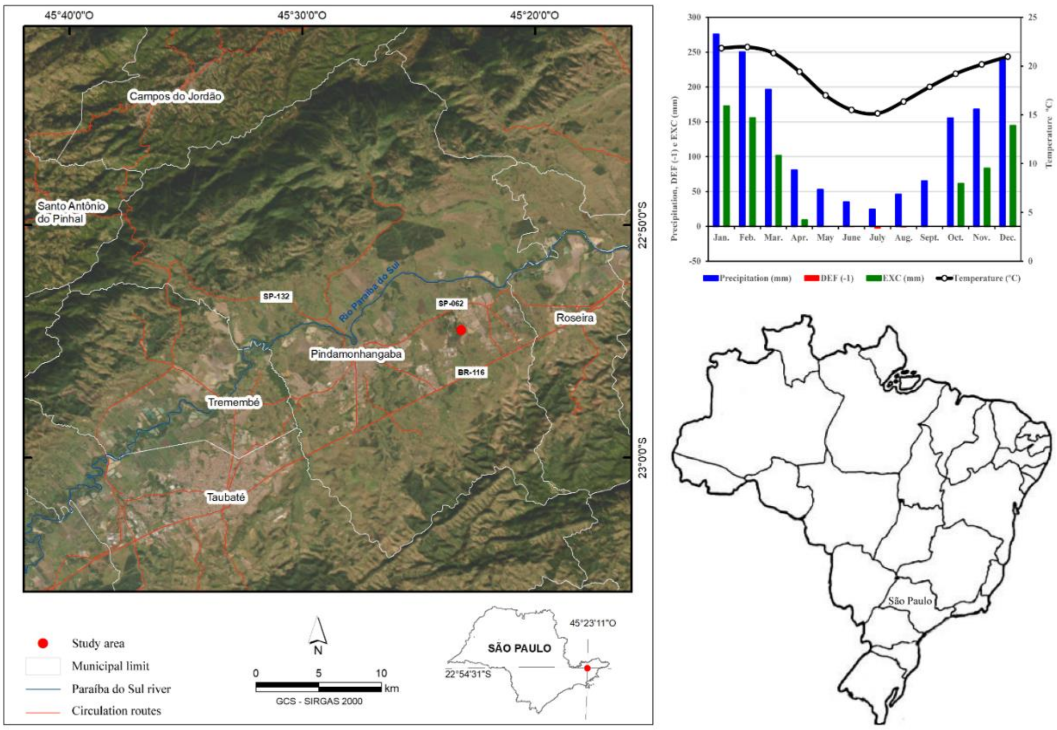

Figure 1. Location in the municipality of Pindamonhangaba (red circle) in São Paulo State, Brazil. Average monthly precipitation, water deficit DEF (-1), water surplus (EXC), and mean temperature (line).

Figure 2. Overview of *Acacia mangium* and *Calophyllum brasiliense* plantations in the municipality of Pindamonhangaba, São Paulo State.

Sampling

We determined height, DBH (diameter at breast height - 1.30 m from the ground) in 12 trees of each species, totaling 24 trees. The average DBH and tree height were (24 cm, 22 m) in *Acacia mangium* and (16.5 cm, 13 m) in *Calophyllum brasiliense*, respectively. Then, we felled the selected trees, and from each tree, a log, 1 meter in length, was cut at the region immediately below breast height. From logs, a central plank (5 cm thick) was cut, and from these planks, we used a tenon saw to cut battens (4cm x 4cm) close to the bark (Figure 3) in order to determine wood basic density, fiber features, and, consequently, assess the properties for paper and cellulose.

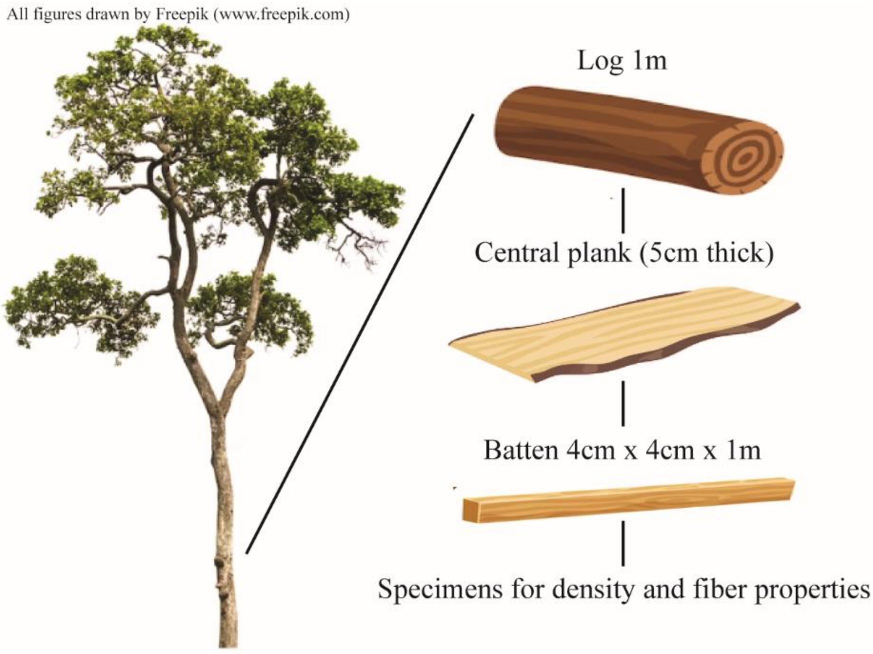

Figure 3. Schematic illustration of sampling for wood density and fiber properties.

Basic density

Basic density was determined by finding the ratio between dry mass and saturated volume. The specimens (5 cm x 3 cm x 2 cm) were immersed in water and were considered saturated when they presented constant mass during monitoring in the laboratory. Subsequently, the specimens were dried in an oven at 105°C ± 2°C to obtain the dry mass. Saturation volume was obtained by the hydrostatic balance method. Wood basic density was calculated by determining the relationship between dry mass and saturated volume in accordance with the Brazilian standard ABNT NBR 7190-3 (ABNT 2022), as

$$\rho bas = \frac{Dm}{Sv} \quad (1)$$

where ρbas = basic density (kg.m^{-3}), Dm = Dry mass (kg) and Sv = saturated volume (m^{-3}).

Fiber analyses

We cut small pieces of wood from each sample for maceration using Franklin's method (Berlyn and Miksche 1976). Wood fragments were stained with aqueous safranin 1% and mounted temporarily in a solution of water and glycerin (1:1). Measurements followed the recommendations of the IAWA committee (1989). Quantitative data were based on at least 25 measurements for each feature from each tree, thus fulfilling statistical requirements for the minimum number of measurements. Anatomical measurements were obtained using an Olympus CX 31 microscope equipped with a camera (Olympus E330 EVOLT) and computer image analysis software (Image-Pro 6.3).

Fiber properties for pulp and paper

From values of length (L), diameter (D), lumen diameter (d) and fiber wall thickness (w), we calculated the following ratios for pulp and paper: Flexibility coefficient (FC, Eq. 2), Wall proportion (WP, Eq. 3), Runkel ratio (RR, Eq. 4), Slenderness ratio (SR, Eq. 5), Luce's shape factor (LSF, Eq. 6), and Mulsteph ratio (MR, Eq. 7 (Silva and Evangelista 2021). The ranges and indicators for each property are presented with reference values in Table 1.

$$FC = \frac{d}{D} \quad (2)$$

$$WP = \frac{2 \cdot W}{D} \cdot 100 \quad (3)$$

$$RR = \frac{2 \cdot W}{d} \quad (4)$$

$$SR = \frac{L}{D} \quad (5)$$

$$LSF = \frac{D^2 - d^2}{D^2 + d^2} \quad (6)$$

$$MR = \frac{D^2 - d^2}{D^2} \quad (7)$$

Table 1. Ranges and indicators for papermaking based on fiber properties.

Properties	Definitions
Flexibility coefficient	Less than 0.30 (very thick): Fibers do not collapse. Very little contact surface. Poor fiber – fiber union. From 0.30 to 0.50 (thick): Very little collapse of fibers. Little contact surface. Poor fiber-fiber union. From 0.50 to 0.65 (medium): Partial collapse of fibers with elliptical cross section. Good fiber – fiber union. From 0.65 to 0.8 (thin): Same properties as those noted above. Greater than 0.80 (very thin): Fiber's collapse. Good contact surface. Good fiber-fiber union (UFPR 2024).
Wall fraction	Greater than 0.70 (very thick): Very high stiffness. From 0.70 to 0.50 (thick): High stiffness. From 0.5 to 0.35 (medium): Medium stiffness. From 0.35 to 0.20 (thin): Low stiffness. Less than 0.20 (very thin): Very low stiffness (UFPR 2024). Higher values of this index correlate with increased rigidity and resistance to collapse of fibers (Foelkel 2009).
Runkel ratio	Group I, less than 0.25: Excellent for paper. Group II, 0.25 - 0.50: Very good for paper. Group III, 0.50 - 1.00: Good for paper. Group IV, 1.00 - 2.00: Regular for paper. Group V, greater than 2.00: Bad for paper (UFPR 2024).
Slenderness ratio	Group I, less than 0.25: Excellent for paper. Group II, 0.25 - 0.50: Very good for paper. Group III, 0.50 - 1.00: Good for paper. Group IV, 1.00 - 2.00: Regular for paper. Group V, greater than 2.00: Bad for paper (Klock 2024).
Luce's shape factor	Luce's shape factor is directly related to paper sheet density. Values less than 0.5 are considered good for paper and pulp making (NagarajaGanesh et al. 2022).
Mulsteph ratio	Values lower than 0.5 are indicated because they are related to a smaller relative area of the cell wall, indicating thin walls (Akgul and Tozluoglu 2009).

Data analyses

We initially undertook descriptive statistical analysis and used Box Plot graphics to detect outliers. Thus, values 1.5 times higher than the 3rd quartile and values 1.5 times lower than the 1st quartile were excluded from the analysis. Normality tests were performed to check the distribution of data, and when a normal distribution was not observed, data were square root-transformed. Then, the t test was used to identify pairs of significantly different means. Pearson's correlation test was applied to basic density, fiber features and properties for pulp and paper. Statistical analyses were performed using R software (R Core Team 2019).

Results and Discussion

We present the means for each variable in each tree and the means of the 12 trees in both species (Table 2). In the comparison between fiber features and properties for pulp and paper based on fiber dimensions, we observed significant differences, but only for fiber length and slenderness ratio (Figure 4).

These results were based on the reference values for fiber properties (Table 1) and an analysis of average values for each species (Table 2). For the flexibility coefficient, both species are classified as medium quality, falling within the range of 0.50 to 0.65. Wall fraction is also classified as medium quality, falling within the range of 0.50 to 0.35. Runkel ratio values group both species as good for paper (0.50 - 1.00). Slenderness ratio ranks *A. mangium* (0.62) in group III, 0.50 - 1.00, as good for paper, while *C. brasiliense* (0.43) is ranked in group II, 0.25 - 0.50, as very good for paper. According to Luce's shape factor, *C. brasiliense* is good for papermaking with a value below 0.5, whereas Mulsteph ratio finds neither species to be suited to papermaking since they are both above the reference value of 0.5.

We only considered the Pearson's correlation coefficient of wood density with fiber features and fiber properties for papermaking since papermaking properties are calculated on the basis of fiber dimensions, so high correlations are expected between such variables.

For *Acacia mangium*, we observed average positive correlations between density and fiber wall thickness (0.48), Mulsteph ratio (0.43), wall fraction (0.42) and Luce's shape factor (0.43), but a low correlation between density and Runkel ratio (0.37). For *Calophyllum brasiliense*, we observed average positive correlations of density with Mulsteph ratio (0.54), wall fraction (0.43) and Luce's shape factor (0.40), but low correlation of density with Runkel ratio (0.31) (Figure 5).

Table 2. Fiber features and properties for pulp and paper based on fiber dimensions of *Acacia mangium* (1) and *Calophyllum brasiliense* (2) wood at 15 and 16 years, respectively.

sp.	Tree	ρbas (kg.m^{-3})	FL (μm)	FD (μm)	FLD (μm)	FWT (μm)	FC	WF	RR	SR	LSF	MR
1	1	516	1292	17.99	10.29	4.36	0.53	0.47	0.93	0.71	0.56	0.71
	2	470	1038	19.97	12.25	4.00	0.56	0.44	0.93	0.64	0.54	0.63
	3	543	1085	19.71	9.83	4.84	0.46	0.54	1.24	0.62	0.64	0.78
	4	614	1042	22.84	14.44	4.36	0.53	0.47	0.95	0.58	0.57	0.72
	5	600	1210	20.61	11.06	4.25	0.53	0.47	0.90	0.68	0.56	0.71
	6	453	1121	24.66	17.60	4.04	0.64	0.36	0.59	0.51	0.42	0.59
	7	516	1238	23.20	14.62	4.96	0.53	0.47	0.91	0.60	0.56	0.72
	8	477	1206	18.49	11.27	4.40	0.48	0.52	1.11	0.72	0.62	0.76
	9	515	1136	19.92	11.06	4.93	0.57	0.43	0.78	0.51	0.51	0.68
	10	562	1292	18.29	8.98	4.47	0.52	0.48	0.98	0.70	0.58	0.73
	11	509	1094	19.14	11.43	4.34	0.56	0.44	0.82	0.56	0.52	0.68
	12	635	1276	19.09	11.49	4.55	0.56	0.44	0.82	0.63	0.52	0.68
	Mean	534	1169	20.32	12.03	4.46	0.54	0.46	0.91	0.62	0.55	0.70
2	1	485	810	18.84	10.12	4.11	0.57	0.43	0.78	0.41	0.51	0.67
	2	614	851	17.18	9.18	3.86	0.62	0.38	0.79	0.44	0.45	0.60
	3	563	901	18.14	8.46	4.94	0.49	0.51	1.11	0.45	0.61	0.75
	4	545	792	18.69	9.96	4.20	0.63	0.37	0.62	0.32	0.44	0.60
	5	536	787	18.45	9.95	4.78	0.52	0.48	1.02	0.37	0.57	0.72
	6	459	842	22.46	14.39	3.53	0.71	0.29	0.42	0.36	0.33	0.49
	7	541	786	21.38	11.47	4.29	0.62	0.38	0.66	0.34	0.45	0.61
	8	516	874	17.17	8.38	3.61	0.61	0.39	0.66	0.47	0.46	0.62
	9	548	997	22.96	13.09	4.43	0.55	0.45	0.83	0.49	0.53	0.69
	10	548	945	18.92	9.98	4.66	0.49	0.51	1.12	0.52	0.61	0.75
	11	545	986	20.23	11.56	3.86	0.59	0.41	0.72	0.55	0.48	0.65
	12	562	762	21.00	11.89	3.80	0.59	0.41	0.74	0.43	0.48	0.64
	Mean	538	861	19.62	10.70	4.17	0.58	0.42	0.79	0.43	0.49	0.65

ρb = basic specific gravity; FL = fiber length; FD = fiber diameter; FLD = fiber lumen diameter; FWT = fiber wall thickness; FC = flexibility coefficient; WF = wall fraction (stiffness coefficient); RI = Runkel ratio; SR = slenderness ratio; LSF = Luce's shape factor (Boiler index); MR = Mulsteph ratio.

This study investigated the fiber properties of *Acacia mangium* and *Calophyllum brasiliense* wood for papermaking. In general, our results showed that both woods have medium quality for papermaking, but *C. brasiliense* has a slight advantage over *Acacia mangium* because it presents a greater number of properties classified as medium.

In general, papers have specific characteristics according to purpose. For example, in printing and writing papers, smoothness, opacity, formation, volume, porosity, printability, resistance, and dimensional stability are desirable. Associated features include a higher percentage of short and narrow fibers with relative rigidity and good refinability and the capacity to hold together without collapsing, thus constituting a well-structured network with good connection between fibers and low content of vessel elements. In sanitary papers (tissue), the desired properties are softness, tactile softness, absorption, sensation of soft and bulky paper with resistance and low content of fines. Associated features include fiber rigidity with a low degree of collapsibility in order to resist embossing and creping, narrow fibers, low hemicellulose content and relative resistance to refining, low parenchyma cell content and low connection between fibers in order to maintain a loose network and porosity (Foelkel 1997). For proper assessment of such characteristics, we must consider the relationships between wood density and fiber dimensions, which, consequently, determine suitable properties for papermaking.

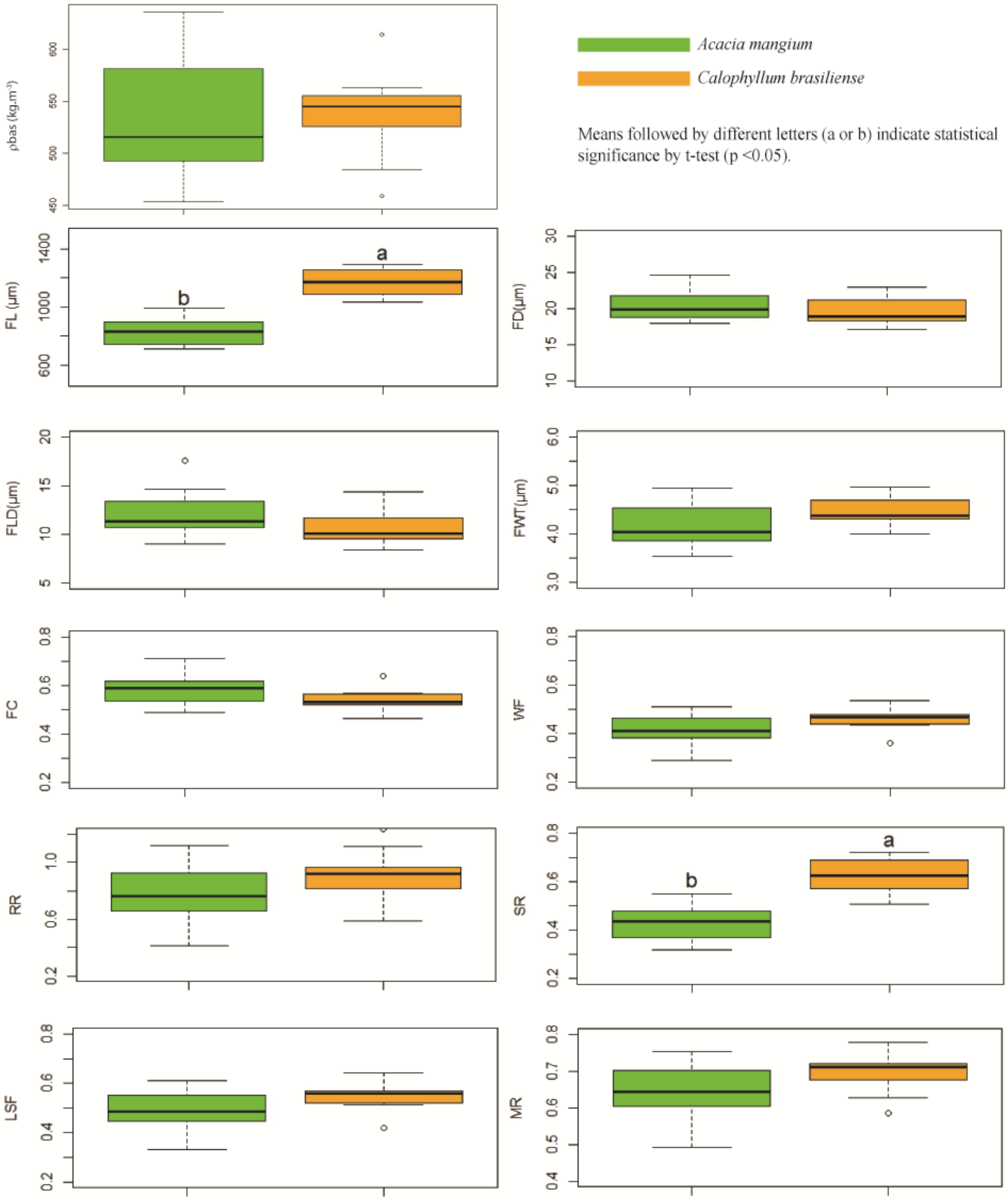

Figure 4. Comparison between fiber features and properties for pulp and paper based on fiber dimensions of *Acacia mangium* and *Calophyllum brasiliense* wood at 15 and 16 years, respectively. ρbas = basic density; FL = fiber length; FD = fiber diameter; FLD = fiber lumen diameter; FWT = fiber wall thickness; FC = flexibility coefficient; WF = wall fraction (stiffness coefficient); RI = Runkel ratio; SR = slenderness ratio; LSF = Luce's shape factor (Boiler index); MI = Mulsteph ratio.

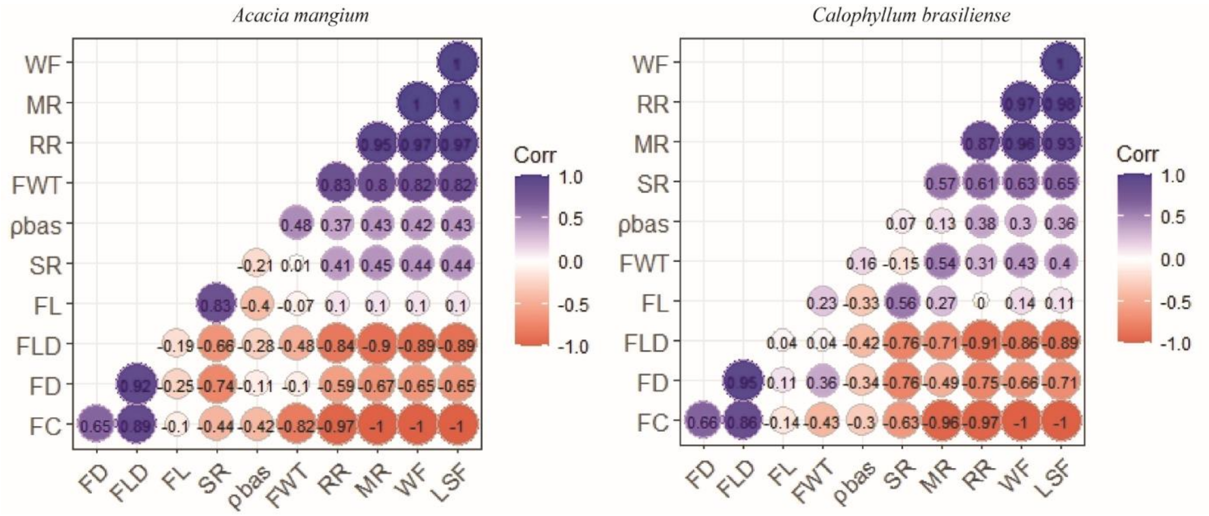

Figure 5. Pearson's Correlation Coefficient between basic density, fiber features and properties for pulp and paper of *Acacia mangium* and *Calophyllum brasiliense* wood at 15 and 16 years, respectively. ρbas = basic density; FL = fiber length; FD = fiber diameter; FLD = fiber lumen diameter; FWT = fiber wall thickness; FC = flexibility coefficient; WF = wall fraction (stiffness coefficient); RI = Runkel ratio; SR = slenderness ratio; LSF = Luce's shape factor (Boiler index); MI = Mulsteph ratio.

The average basic density of *A. mangium* and *C. brasiliense* was 534 ($kg.m^{-3}$) and 538 ($kg.m^{-3}$), respectively, values considered medium for both species (Andrade and Jankowsky 2015). Pulps from lower basic density wood are ideal for the production of printing and writing paper because, in general, low density is related to fibers with thinner walls; otherwise, pulps from denser woods are ideal for absorbent paper, owing to fibers with thicker walls (Santos and Sansígolo 2007, Mokfienski et al. 2008). Based on wood density values, it is suggested that neither *A. mangium* nor *C. brasiliense* possesses properties entirely suited to the production of printing and writing paper.

Both species are classified as medium quality according to the flexibility coefficient (0.50 to 0.65). This property is derived from the ratio of fiber lumen diameter to fiber diameter which, in turn, determines the elasticity or rigidity of cell (NagarajaGanesh et al. 2022). Fibers with good flexibility values are suitable for production of paper with high mechanical resistance, such as writing, printing and packaging (Saikia et al. 1997). The higher the flexibility coefficient, the more malleable and flexible this fiber will be, which results in a greater connection between fibers, consequently increasing the tensile strength and bursting resistance of the paper (Foelkel et al. 1978). Therefore, it is understood that the fibers of *A. mangium* and *C. brasiliense* will present medium resistance to traction and paper bursting.

In the present study, wall fraction is also classified as medium quality for these species (0.50 to 0.35). This property is used to find the wood best suited to pulp manufacturing in terms of formability and energy requirements (NagarajaGanesh et al. 2022). Paper with poor flexibility originating from fibers with very high wall proportion values tends to have lower tensile and burst strength (Boschetti et al. 2015). We found no statistical difference in this property between the two tree species evaluated. However, it is reported that high wall proportion correlates with increasing rigidity and resistance to collapse of fibers (Foelkel 2009). In the present study, a higher value was found in *A. mangium* (0.46) when compared to *C. brasiliense* (0.42), but obviously all properties must be analyzed together to select the best material for papermaking.

Runkel ratio values group species as among those good for paper between 0.50 and 1.00; in the present study, the RR value for *A. mangium* was 0.91 and 0.79 for *C. brasiliense*. These high RR values mean stiffer and less flexible fiber (Ogunjobi et al. 2014) with resultant weaker binding capacity, providing bulkier paper (Xu et al. 2006, Enayati et al. 2009). On the other hand, lower RR means more porous papers (Kiaei et al. 2014). Furthermore, fibers with Runkel ratio lower positively influence the breaking, tensile, and bending strength of paper (Ma et al. 2011). Although included in the same quality group, the value of *A. mangium* suggested lower-quality material for papermaking compared with *C. brasiliense*.

Slenderness ratio interferes with paper density (Agnihotri et al. 2010) and is associated with the strength of paper such that high values provide resistance against sheet breakage and bursting (NagarajaGanesh et al. 2022). Fibers with slenderness value greater than 0.33 alone are considered suitable for making paper (Sharma et al. 2013), whereas fibers with values lower than 0.70 are essential for the quality of cellulosic pulp (Young 1981). According to definitions used in Brazil, slenderness ratio ranks *A. mangium* (0.62) in group

III, 0.50 - 1.00, as good for paper, while *C. brasiliense* (0.43) is ranked in group II, 0.25 - 0.50, as very good for paper. Therefore, based on slenderness ratio, *C. brasiliense* has better fiber quality for papermaking.

Luce's shape factor, another property used in the selection of specimens regarding fiber quality, is directly related to final paper sheet density (NagarajaGanesh et al. 2022). LSF is an important fiber index derived from fiber diameter and lumen diameter. LSF values less than 0.5 are considered good for paper- and pulpmaking. In general, the properties associated with the degree of fiber binding tend to increase with fiber length (Baldin et al. 2017). Additionally, LSF refers to the force required to achieve lumen collapse and is proportional to the fiber shape factor (Almeida et al. 2022). According to the values of our study of *A. mangium* (0.55) and *C. brasiliense* (0.49), only the latter species is at the limit of considered good for papermaking, having an LSF value below 0.5.

The Mulsteph ratio is related to the collapse capacity that fibers can present since it is a ratio of the relative area of the cell wall over the entire fiber (Pego et al. 2019). Ratios that present values lower than 0.5 are considered desirable for the production of paper and cellulose because they are related to the smaller relative area of the cell wall, indicating thin walls (Akgul and Tozluoglu 2009). Both woods investigated here were above the reference value 0.5; therefore, based on MR, neither of the two wood species is suitable for papermaking.

Wood density is considered one of the most informative properties, and it is influenced by anatomical characteristics, largely fibers, since, in proportional terms, fibers are the cells that occur most in wood (Wiedenhoeft and Eberhardt 2021). Therefore, correlations between density and fiber properties, which derive from fiber dimensions, are expected for papermaking. The positive relationship between density and fiber wall thickness is more obvious to understand since thicker walls contribute more mass and, consequently, provide greater density. Otherwise, the correlations between density and fiber properties can be best explained according to which fiber feature has the greatest weight in the calculation of each property, as well as by the radial and axial variations of the wood (Ohshima et al. 2005, Carrillo et al. 2015).

The wood of *Acacia mangium* differs from that of *Eucalyptus* spp. in that *A. mangium* presented fibers with thinner walls approximately at the same perimeter of the fiber, which resulted in lower roughness and a greater degree of fiber collapse compared to fibers from *Eucalyptus* spp. Additionally, *A. mangium* fibers had fewer defects. These results, along with others in the present study, indicated that pulps containing thin-walled fibers, such as *A. mangium* pulp, are interesting sources for the production of high-quality printing papers (Mohlin et al. 2006). *A. mangium* also presents an excellent source of short fiber for papermaking. Its short and thin-walled fibers are recommended for low-volume production, high opacity and smooth sheets (Bajpai and Bajpai 2010).

As for *C. brasiliense*, we did not find recent studies on the suitability of wood for paper and cellulose. However, Paula (1982) and Chimelo et al. (1976) did report that *C. brasiliense* wood showed potential for paper production. Although studies on *Liquidambar styraciflua* and *Hevea brasiliensis* yielded results comparable to those observed for *C. brasiliense*, they highlighted the suitability and strong potential of these species for cellulose pulp production (Vivian et al., 2023; Faria et al., 2019).

Therefore, the information from the present study could serve as a starting point for renewed interest in *C. brasiliense* wood for papermaking, noting the success of species already established for that purpose, namely *Eucalyptus* spp. and *Pinus* spp. In any case, wood density, fiber dimensions of both species and the derived properties are acceptable and show that the two woods have medium suitability to produce cellulose and paper.

Conclusions

In general, our results showed that both woods have medium quality for papermaking, with *C. brasiliense* having a slight advantage by its greater number of properties classified as medium based on the reference values for fiber properties and the average values for each species. For the flexibility coefficient, both species are classified as medium quality, falling within the range of 0.50 to 0.65. Wall fraction is also classified as medium quality, falling within the range of 0.50 to 0.35. Runkel ratio values group the two species as good for paper (0.50 - 1.00). Slenderness ratio ranks *A. mangium* (0.62) in group III, 0.50 - 1.00, as good for paper, while *C. brasiliense* (0.43) is ranked in group II, 0.25 - 0.50, as very good for paper. According to Luce's shape factor, *C. brasiliense* is good for papermaking with a value below 0.5, while according to the Mulsteph ratio, neither species is suggested for papermaking as each one is above the reference value of 0.5. Thus, even though ratios do not show a constant throughline, both species are suitable for use in papermaking with the caveat that trees of different ages can provide better quality material, and production costs must always be a consideration in wood choice for a particular purpose.

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