Universidade Federal do Paraná
Setor de Ciências Agrárias
Pós-graduação em Engenharia Florestal
Revista Floresta

INFLUENCE OF ANATOMY ON THE MECHANICAL RESISTANCE OF WOODS IN AN AGROFORESTRY SYSTEM

Elder Eloy[1]*, Laura da Silva Zanchetta[1], Eduarda Bandera[1], Tauana de Souza Mangini[2], Rômulo Trevisan[1]

[1*] Universidade Federal de Santa Maria, Departamento de Engenharia Florestal, Frederico Westphalen, RS, Brasil - *eloyelder@yahoo.com.br
[1] Universidade Federal de Santa Maria, Departamento de Engenharia Florestal, Frederico Westphalen, RS, Brasil - zanchettalaura2@gmail.com, duda_bandera@outlook.com, romulo_trevisan@yahoo.com.br
[2] Universidade Federal de Santa Maria, Programa de Pós Graduação em Agronomia, Agricultura e Ambiente, Frederico Westphalen, RS, Brasil – tauanamangini@yahoo.com

Received for publication: 07/12/2021– Accepted for publication: 15/10/2022

Resumo

Influência da anatomia na resistência mecânica das madeiras de um sistema agroflorestal. O objetivo do trabalho foi avaliar a influência da anatomia na resistência mecânica de *Parapiptadenia rigida* (Benth.) Brenan, *Peltophorum dubium* (Spreng.) Taub., *Eucalyptus grandis* × *Eucalyptus urophylla* e *Schizolobium parahyba* (Vell.) Blake provenientes de um sistema agroflorestal. Para tanto, foram abatidas um total de 12 árvores com 9 anos de idade. Os corpos de prova para a avaliação das propriedades anatômicas foram retirados da região do diâmetro à altura do peito (DAP à 1,30 m do solo). Para a determinação das características mecânicas, os mesmos foram provenientes de pranchões centrais retirados a partir do DAP das toras das árvores, sendo produzidos corpos-de-prova com as dimensões de 2,5 x 2,5 x 41,0 cm para a avaliação do módulo de elasticidade, módulo de ruptura, tensão no limite proporcional e força máxima, e com as dimensões de 5 x 5 x 15 cm para a dureza Janka transversal e longitudinal e compressão normal. Quanto maiores os valores de fração da parede das fibras, da frequência dos vasos e da frequência dos raios, mais elevadas foram as propriedades mecânicas. Em contrapartida, com o aumento nas dimensões da largura das fibras, do diâmetro do lume das fibras, do diâmetro dos vasos, da altura e da largura dos raios, menores são os valores das propriedades mecânicas da madeira.
Palavras-Chave: correlação de Person; elementos anatômicos; propriedades mecânicas

Abstract

This study aimed to evaluate the influence of anatomy on the mechanical resistance of *Parapiptadenia rigida* (Benth.) Brenan, *Peltophorum dubium* (Spreng.) Taub., *Eucalyptus grandis* × *Eucalyptus urophylla*, and *Schizolobium parahyba* (Vell.) Blake from an agroforestry system. For this purpose, twelve 9-year-old trees were felled. To evaluate the anatomical properties, the specimens were taken from the diameter region at breast height (DBH at 1.30 m from the ground). To determine the mechanical characteristics, central planks from the DBH of the tree logs were removed to produce test specimens with dimensions of 2.5 × 2.5 × 41.0 cm. The modulus of elasticity, modulus of rupture, tension of the proportional limit, and maximum force were then evaluated. Conversely, test specimens with dimensions of 5 × 5 × 15 cm for were used for the transversal and longitudinal Janka hardness and perpendicular compression tests. The higher the cell wall fraction, vessel frequency, and ray frequency values, the better the mechanical properties. Conversely, with the increase in the fiber diameter, lumen diameter, vessel diameter, height, and width of rays, the values of the mechanical properties of wood are lower.
Keywords: Pearson's correlation; anatomical elements; mechanical properties

INTRODUCTION

The forests of Brazil contain hundreds of different tree species that are used for various purposes. When the technological characteristics of wood are unknown, it can present a serious problem regarding its rational use and, consequently, the expansion of forestry activity (ELOY *et al*., 2021).

Currently, there is a growing interest in the implementation of agroforestry systems (SAFs) as efforts for its diffusion in Brazil are considerable. SAFs are systems that involve the introduction of forestry components interacting with agricultural components. They have been developed with specific characteristics regarding the species used, temporal and spatial arrangement of the components, and purpose and functionality of the system (SCHWERZ *et al*., 2018). Therefore, these systems are generally implanted with both native and exotic species that have good technological characteristics to serve as a source of quality raw material for various purposes such as *Eucalyptus*, *Parapiptadenia*, *Peltophorum*, and *Schizolobium* (BANDERA *et al.*, 2021).

With the aim of correct wood usage, it is extremely important to know its physical, mechanical, and anatomical characteristics as these allow the determination of its technological properties. The study of wood anatomy generates information that contributes to the characterization and identification of woody plant species, in addition to providing subsidies for studies of their properties, reflections of their growth, behavior in use, and wood quality (BATTIPAGLIA *et al*., 2014). Anatomical elements such as vessels, fibers, and radial and axial parenchyma cells make wood a porous material, thereby characterizing it as a complex structure for the passage of liquid and gaseous fluids (MONTEIRO *et al*., 2017).

The variations that occur in the anatomical parameters of wood change the dimensions and frequency of the cells, thus directly affecting its physical and mechanical properties (COSTA *et al*., 2017). Mechanical strength can be determined from static bending, compression, and hardness tests, in which the mechanical parameters of the material reflect the existing relationship between the response or deformation when subjected to a stimulus or force (KOL *et al*., 2017).

Within this context, knowledge of species for agroforestry use must consider the quality characteristics of the wood and attributes to meet production and growth requirements. Thus, the present study aimed to evaluate the influence of anatomy on the mechanical resistance of wood from four species in an agroforestry system.

MATERIAL AND METHODS

Experimental location and sampling

The wood of the four forest species, *Parapiptadenia rigida* (Benth.) Brenan (Angico-vermelho), *Peltophorum dubium* (Spreng.) Taub. (Canafístula), *Eucalyptus grandis* × *Eucalyptus urophylla* (*Eucalyptus* hybrid), and *Schizolobium parahyba* (Vell.) Blake (Guapuruvú), were obtained from an SAF with a plant spacing of 12.0 × 1.5 m (12.0 m between rows and 1.5 m between plants in a row) located in the municipality of Frederico Westphalen, Rio Grande do Sul (27°22” S, 53°25” W; 480 m altitude).

According to the Köppen classification (1931), the predominant climate in the region is Cfa, characterized as subhumid subtemperate, with an average annual temperature of 18.8 °C and average temperature of the coldest month of 13.3 °C (ALVARES *et al*., 2013).

Three 9-year-old trees per species were sampled, in which the average diameter of each individual was considered (Table 1). To determine the anatomical characteristics, the specimens were taken from the region of diameter at breast height (DBH) 1.30 m from the ground. For the mechanical properties, a 2 m long log was removed from the DBH of each individual. Subsequently, central planks were produced for the preparation of test specimens.

Table 1. Average diameter at breast height (DBH) and average height (H) of the trees of the four forest species from an agroforestry system
Tabela 1. Diâmetro a altura do peito (DBH) e altura (H) média das árvores das quatro espécies florestais de um sistema agroflorestal

Species	DBH (m)	H (m)
Parapiptadenia rigida	0.17	18.01
Peltophorum dubium	0.16	19.33
Eucalyptus grandis × *Eucalyptus urophylla*	0.34	26.99
Schizolobium parahyba	0.25	21.04

Wood anatomy

For the anatomical analysis, three samples per tree with dimensions of 1.5 × 1.5 × 2.0 cm were randomly taken and oriented to obtain the transverse, radial longitudinal, and tangential longitudinal anatomical planes, resulting in 36 samples.

Microtomy was performed according to the IAWA Technical Standard (1989). For histological evaluation, the samples were softened by boiling in water and then tested and cut using a sliding microtome to a thickness of 18 µm. Once the histological cut of the materials was completed, double staining with astra blue and safranin was used. Subsequently, the samples were dehydrated in an alcoholic series (30%, 50%, 70%, 90%, and 100%), and permanent slides were mounted using a glue (Entellan).

Maceration was performed according to the recommendations of Franklin (1945), in which the sticks were macerated in a boiling acid solution for 45 min. To stain the woody cell paste, safranin, an alcoholic series (50% and 100%), and the aforementioned mounting medium for permanent slides were applied in succession.

For each anatomical parameter, 75 measurements were performed, with 25 readings for each of the three samples taken from each individual, following the COPANT Technical Standard (1973). Based on the histological sections, the vessel diameter (VD), vessel frequency (VF), ray height (RH), ray width (RW), and ray frequency (RF) were evaluated. Fiber length (FL), fiber diameter (FD), and lumen diameter (LD) were measured in the macerated material. The following equation was used to calculate the cell wall thickness (CWT) of the fibers (Equation 1):

$$CWT = (FD - LD)/2 \quad \text{(Eq. 1)}$$

where
CWT = Cell wall thickness (µm);
FD = Fiber diameter (µm);
LD = Lume diameter (µm).

The cell wall fraction (CWF) was calculated using the following equation (Equation 2):

$$CWF = (2 \times CWT)/FD \times 100 \quad \text{(Eq. 2)}$$

where
CWF = Cell wall fraction (%);
CWT = Cell wall thickness (µm);
FD = Fiber diameter (µm).

Mechanical properties of wood

To evaluate the mechanical properties of wood from the forest species, static bending, Janka hardness, and perpendicular compression tests were performed. For the static bending test, test specimens with dimensions of 2.5 × 2.5 × 41.0 cm were produced to evaluate the modulus of elasticity (MOE), modulus of rupture (MOR), tension of the proportional limit (TPL), and maximum force (MF). For the evaluation of transverse Janka hardness (JHT), longitudinal Janka hardness (JHL), and perpendicular compression with modulus of elasticity (MOE), and tension of the proportional limit (TPL), samples were produced with dimensions of 5 × 5 × 15 cm.

The samples were stored in a climate-controlled oven until they reached a moisture content of approximately 14%. A universal testing machine (Model DL-2000, Emic) was used. The samples for determining basic density were obtained from the DBH of the trees. All physical and mechanical properties were determined using the ASTM D 143-94 (2000) technical standards.

Experimental design and data analysis

The experiment was performed using a completely randomized design. Statistical analysis was performed on the data using the software "*Statistical Analysis System*" (SAS, 2003). Assumptions tests of ANOVA (F test), Shapiro–Wilk for normality, and Bartlett for homoscedasticity of variances were performed, and the data was verified to behave normally. For the significant variance analysis, multiple comparisons of means were performed using Tukey's test. These analyses were performed to identify similarities and differences in wood properties between species, which are fundamental for discussing the relationship between anatomical elements and mechanical properties.

The functional relationship between the anatomical elements and mechanical properties of the wood was evaluated using the Pearson's correlation test, using all the values of the analyzed variables. These relationships allow us to evaluate whether variations in anatomical elements influence the mechanical properties of wood.

RESULTS

According to the variance analysis, the four forest species showed significant differences among themselves in all anatomical parameters evaluated. When analyzing the mean test, *Schizolobium parahyba* resulted in the highest FD (35.1 µm), LD (27.6 µm), and VD (187.1 µm) values as well as the largest ray dimensions both in height (256.4 µm) and width (38.2 µm). Conversely, it has the lowest values for VF (1.8 vessels mm^{-2}), RF (14.8 rays mm^{-1}), and CWF (21.6%) (Table 2).

Table 2. Anatomical analysis of the trees of the four forest species from an agroforestry system
Tabela 2. Análise anatômica das árvores das quatro espécies florestais de um sistema agroflorestal

Species	FL (µm)	FD (µm)	LD (µm)	CWT (µm)	CWF (%)
Parapiptadenia rigida	$872.6^{116.2}$ a	$13.4^{2.8}$ c	$5.7^{1.6}$ b	$3.9^{0.8}$ b	$57.8^{6.7}$ ab
Peltophorum dubium	$690.2^{134.9}$ b	$21.8^{5.9}$ b	$8.1^{4.3}$ b	$6.8^{2.0}$ a	$64.0^{13.8}$ a
Eucalyptus grandis × *Eucalyptus urophylla*	$850.1^{160.7}$ a	$12.9^{2.7}$ c	$5.9^{2.0}$ b	$3.5^{0.9}$ b	$55.2^{9.5}$ b
Schizolobium parahyba	$882.1^{178.4}$ a	$35.1^{6.1}$ a	$27.6^{5.9}$ a	$3.7^{1.1}$ b	$21.6^{6.5}$ c
Species	**VD (µm)**	**VF (vessel mm^{-2})**	**RH (µm)**	**RW (µm)**	**RF (ray mm^{-2})**
Parapiptadenia rigida	$89.1^{13.5}$ c	$6.6^{1.7}$ b	$132.9^{31.4}$ c	$19.3^{3.2}$ c	$64.8^{2.5}$ a
Peltophorum dubium	$123.9^{21.1}$ b	$4.0^{1.3}$ c	$189.5^{45.9}$ b	$25.1^{7.0}$ b	$35.4^{4.1}$ c
Eucalyptus grandis × *Eucalyptus urophylla*	$86.6^{23.5}$ c	$14.8^{2.2}$ a	$168.9^{60.8}$ b	$13.5^{3.5}$ d	$56.0^{5.8}$ b
Schizolobium parahyba	$187.1^{43.4}$ a	$1.8^{0.9}$ d	$256.4^{47.3}$ a	$38.2^{5.8}$ a	$14.8^{1.3}$ d

Where = FL = fiber length; FD = fiber diameter; LD = lume diameter; CWT = cell wall thickness; CWF = cell wall fraction; VD = vessel diameter, VF = vessel frequency; RH = ray height; RW = ray width; RF = ray frequency. Numbers raised to the exponent represent the standard deviation. The means followed by the same letter in the column compare the species and do not differ from each other, according to the Tukey test at 5% probability of error.

The highest CWT (6.8 µm) and CWF (64.0 %) values were verified for *Peltophorum dubium*, not different from *Parapiptadenia rigida*. However, the lowest FL value (690.2 µm) was observed for *Peltophorum dubium* and that of VF (1.8 vessels mm^{-2}) for *Schizolobium parahyba*. Conversely, the hybrid *Eucalyptus grandis* × *Eucalyptus urophylla* exhibited the highest VF (14.8 vessels mm^{-2}) and lowest RW (13.5 µm) values and demonstrated statistical similarities with *Parapiptadenia rigida* for all other anatomical characteristics of the fibers (Table 3).

As for the results of the mechanical properties of the wood, the four forest species showed differences among themselves for most of the evaluated properties (Table 3). The hybrid *Eucalyptus grandis* × *Eucalyptus urophylla* showed the highest values of the mechanical properties MOR, MOE, TPL, and MF, and exhibited similar MOR and MF values to *Parapiptadenia rigida* and MF value to *Peltophorum dubium*.

Table 3 - Wood mechanical properties of the four forest species from an agroforestry system
Tabela 3 – Propriedades mecânicas das quatro espécies florestais de um sistema agroflorestal

Species	Static bending				Hardness		Perpendicular compression	
	MOE (MPa)	TPL (MPa)	MOR (Mpa)	MF (N)	JHT (MPa)	JHL (MPa)	MOE (MPa)	TPL (MPa)
Parapiptadenia rigida	6113^{401} b	$36.8^{3.9}$ b	$85.3^{2.6}$ a	2430^{270} a	$81.4^{4.1}$ aB	$109.5^{3.1}$aA	$569.6^{63.8}$a	$15.4^{3.6}$a
Peltophorum dubium	6948^{553} b	$35.1^{5.1}$ b	$60.0^{5.8}$ b	2138^{261} a	$42.5^{1.4}$ bB	$47.5^{1.1}$ cA	387.5^{43}b	$9.2^{1.3}$b
Eucalyptus grandis × *Eucalyptus urophylla*	10304^{773} a	$57.4^{5.5}$ a	$89.3^{6.8}$ a	2711^{319} a	$42.3^{4.9}$ bB	$62.9^{5.0}$ bA	$345.5^{63.6}$b	$8.6^{1.4}$b
Schizolobium parahyba	3094^{600} c	$19.3^{3.5}$ c	$30.9^{5.7}$ c	952^{159} b	$11.7^{2.0}$ cB	$18.9^{4.5}$ dA	$157.7^{48.6}$c	$3.5^{1.7}$c

Where: MOE = module of elasticity; MOR = module of rupture; TPL = tension of the proportional limit; MF = maximum force; JHT = transverse Janka hardness; JHL = longitudinal Janka hardness. The averages followed by the same lowercase letter in the column compare the species and do not differ, according to the Tukey test at 5% probability of error. The means followed by the same capital letter on the line compare the JHT and JHL and do not differ, according to the Tukey test at 5% probability of error.

Parapiptadenia rigida had the highest values of hardness JHT and JHL, and perpendicular compression MOE and TPL. As *Schizolobium parahyba* presented the lowest CWF and VF values (Table 2), it also had the lowest values for all mechanical properties of wood (Table 3).

Table 4 lists the basic density values of the four forest species. *Parapiptadenia rigida* (0.652 g cm^{-3}) showed the highest average, followed by *Eucalyptus grandis* × *Eucalyptus urophylla* (0.509 g cm^{-3}) and *Peltophorum dubium* (0.488 g cm^{-3}), and lastly by *Schizolobium parahyba* (0.277 g cm^{-3}).

Table 4. Basic density (ρb) of the wood of the four forest species from an agroforestry system
Tabela 4. Massa específica básica (ρ_b) da madeira das quatro espécies florestais de um sistema agroflorestal

Species	ρ_b (g cm^{-3})
Parapiptadenia rigida	$0.652^{0.03}$ a
Peltophorum dubium	$0.488^{0.02}$ b
Eucalyptus grandis × *Eucalyptus urophylla*	$0.509^{0.03}$ b
Schizolobium parahyba	$0.277^{0.02}$ c

The evaluation of the correlation between anatomical and mechanical properties allows the verification of the influence of one parameter over the other. Pearson's correlation analysis revealed that the anatomy of wood influenced most of the mechanical properties of the studied species (Table 5). There was an exception between FL and CWT, which showed no correlation.

Table 5 – Pearson's correlation between the wood anatomy and the mechanical properties of the species from an agroforestry system
Tabela 5 – Correlações de Pearson entre a anatomia e as propriedades mecânicas da madeira de espécies de sistema agroflorestal

Anatomy variable	Mechanical properties							
	Static bending				Hardness		Perpendicular compression	
	MOE	TPL	MOR	MF	JHT	JHL	MOE	TPL
FL	-0.06^{ns}	0.01 ^{ns}	0.01^{ns}	-0.07^{ns}	0.05 ^{ns}	0.14 ^{ns}	0.07 ^{ns}	-0.03 ^{ns}
FD	-0.70*	-0.72*	-0.87*	-0.84*	-0.76*	-0.78*	-0.65*	-0.71*
LD	-0.70*	-0.68*	-0.85*	-0.84*	-0.75*	-0.71*	-0.67*	-0.71*
Cwt	0.03^{ns}	-0.05^{ns}	0.01^{ns}	0.07^{ns}	-0.01 ^{ns}	-0.15 ^{ns}	0.06 ^{ns}	0.02 ^{ns}
Cwf	0.64*	0.59*	0.77*	0.77*	0.66*	0.59*	0.61*	0.64*
VD	-0.64*	-0.70*	-0.82*	-0.79*	-0.76*	-0.76*	-0.67*	-0.70*
VF	0.80*	0.85*	0.72*	0.69*	0.29 ^{ns}	0.38 ^{ns}	0.22 ^{ns}	0.22 ^{ns}
RH	-0.48*	-0.54*	-0.74*	-0.71*	-0.84*	-0.82*	-0.73*	-0.81*
RW	-0.78*	-0.80*	-0.84*	-0.85*	-0.62*	-0.64*	-0.50*	-0.57*
RF	0.59*	0.66*	0.86*	0.81*	0.84*	0.84*	0.70*	0.80*

Where: MOE = module of elasticity; MOR = module of rupture; TPL: tension at the proportional limit; MF = maximum force; JHT = transverse Janka hardness; JHL = longitudinal Janka hardness; FL = fiber length; FD = fiber diameter; LD = lume diameter; CWT = cell wall thickness; CWF = cell wall fraction; VD = vessel diameter, VF = vessel frequency; RH = ray height; RW = ray width; RF = ray frequency; * = Significant Pearson's correlation; ^{ns} = Pearson's correlation not significant.

Pearson's correlation analysis showed an inversely proportional correlation between the FL, LD, VD, RH, and RW variables and mechanical properties (Table 5). The mechanical properties that most correlated with the anatomical properties were the MOR and MF. The anatomical properties that presented the highest correlation with MOR and MF were FD (-0.87), LD (-0.85), RW (-0.84), and RF (0.86).

DISCUSSION

The dimensions, frequency, and distribution of anatomical elements directly affect the physical and mechanical properties of wood (FRANÇA *et al*., 2015). In addition, heterogeneity is an important feature because heterogeneous materials are mandatory for a more accurate assessment of the influence of anatomical parameters on the mechanical characteristics of wood (ZANUNCIO *et al*., 2016).

Anatomical analysis indicates values close to those found in the literature for *Schizolobium parahyba*. being reported by Nisgoski *et al*. (2012) reported an average VD value of 202.20 µm and FV value of 2.02 vessels mm^{-2} for a 15-year-old *Schizolobium parahyba* wood. This small variation is explained by Pillai *et al.* (2013), who studied the genus *Eucalyptus* and reported that it is associated with the difference between genetic materials and environmental conditions.

Fibers are very important characteristics to be evaluated because their dimensions directly influence the machining of wood. Thus, long fibers are more resistant, allowing greater intertwining and favoring increased resistance (BENITES *et al*., 2015). Notably, however, the resistance of wood is a function of not only the fiber size but also the proportion of the chemical constituents of the cells (hemicellulose, cellulose, and lignin) as well as the amount of extractives present in the fire (COSTA *et al*., 2017).

In addition to the FL, the study of the width also becomes relevant as fibers with greater widths have great potential for collapse and ease of refining (PEDRAZZI *et al*., 2013). However, CWT is related to the flexibility of the fibers, and thinner walls decrease the mechanical resistance of the material, which in turn increases the collapse capacity; that is, they allow greater flexibility (NISGOSKI *et al*., 2012).

Thus, the highest CWF values of *Parapiptadenia rigida* and *Peltophorum dubium* are associated with the basic density because they are directly proportional. It results in higher values of mechanical properties, making the material more resistant (SETTE JR *et al*., 2012).

Furthermore, the study of the dimensional values of vessels is extremely important in wood as they conduct liquids throughout the entire tree. Consequently, changes in these dimensions influence some properties of the wood (SETTE JR *et al*., 2012). Thus, a high proportion of empty spaces occupied by vessels leads to lower basic density (LIMA *et al*., 2014).

Therefore, products with high basic density values are suitable for use that require greater mechanical resistance (FRANÇA *et al*., 2015). The higher these values, the better the mechanical properties (VALENTE *et al*., 2013). These authors also reported that basic density is inversely correlated with LD and FD, which corroborates the results of this study.

The lowest values of *Schizolobium parahyba* for all evaluated mechanical properties are associated with CWF, which is directly related to the aging of the vascular cambium. With the formation of new cells, the walls of the oldest cells tended to become increasingly thicker until they stabilized when they reached the adult stage. This behavior influences the basic density of wood and improves its physical and mechanical properties (TANABE *et al*., 2016).

Another characteristic also associated with wood specific mass values is LD; the higher the LD values, the greater the number of empty spaces in the wood, thereby decreasing the basic density and values of the mechanical properties.

Schizolobium parahyba stood out in terms of compression values, showing the lowest values. According to Verbist *et al*. (2020), denser wood has a higher compression value than those with lower basic density. In terms of hardness, the longitudinal direction resulted in the highest values when compared to the transverse direction for all analyzed species, which was due to the parallel or perpendicular orientation of the fibers (COSTA *et al*., 2017).

Pearson's correlation analysis showed an inversely proportional correlation between the FD, LD, VD, RH, and RW variables and the mechanical properties. Thus, it is recommended to evaluate anatomical variables, considering that they are strongly correlated with the mechanical properties of the wood, for best wood usage of the studied species.

CONCLUSIONS

- Anatomical variables, with the exception of fiber length and cell wall thickness, correlated with the mechanical properties of the wood and influenced their values.
- The greater the cell wall fraction, vessel frequency, and ray frequency, the greater the mechanical resistance of the wood.
- The greater the fiber diameter, lumen diameter, vessel diameter, ray height, and ray width, the lower the mechanical resistance of the wood.

REFERENCES

ALVARES, C. A.; STAPE, J. L.; SENTELHAS, P. C.; MORAES, G.; LEONARDO, J.; SPAROVEK, G. Köppen's climate classification map for Brazil, **Meteorologische Zeitschrift**, Áustria, v. 6, p. 711–728, 2013.

ASTM. American Society. For testing and materials. Standard methods of testing small clear specimens of timber: ASTM D 143-94. Philadelphia, 2000.

BANDERA, E.; ELOY, E.; TREVISAN, R.; MANGINI, T. S.; ZANCHETTA, L. S. CANDATEN, L.; AZEVEDO, N. E. P.; SANTOS, Y. C. T Effect of thermal modification on the technological properties of wood from species in an agroforestry system. **Revista Brasileira de Ciências Agrárias**, Recife, v.16, n.3, p. 1-7, 2021.

BATTIPAGLIA, G.; MICCO, V.; SASS-KLAASSEN; TOGNETTI, R.; MÄKELA, A. WSE symposium: Wood growth under environmental changes: the need for a multidisciplinary approach. **Tree physiology**, Oxford, v.34, n.8, p.787-791, 2014.

BENITES, P. K. R. M.; GOUVEA, A. F. G.; CARVALHO, A. M. M. L.; SILVA, F. C. Caracterização anatômica das fibras de oito espécies florestais do cerrado de Mato Grosso do Sul para a produção de papel. **Ciência da Madeira**, Pelotas, v.6, n.2, p.88-93, 2015.

COPANT. Comissão Panamericana de Normas Técnicas. Descrição macroscópica, microscópica e geral da madeira: esquema I de recomendação. Colômbia. 1973.

COSTA, L. J.; LOPES, C. B. DA S.; REIS, M. F. DE C.; CÂNDIDO, W. L.; FARIA, B. D. F. H. DE; PAULA, M. O. DE. Caracterização anatômica e descrição físico-química e mecânica da madeira de *Mimosa schomburgkii*. **Floresta**, Paraná, v.47, n.4, p.383-390, 2017.

ELOY, E.; TREVISAN, R.; PIECHA, T. S.; FONTOURA, M. R.; COSTA, H. W. D.; CARON, B. O. Anatomy and drying of wood of four species from an agroforestry system, **Floresta**, Curitiba, v. 51, n. 4, p. 910-917, 2021.

FRANÇA, T. S. F. A.; ARANTES, M. D. C.; PAES, J. B.; VIDAURRE, G. B.; OLIVEIRA, J. T. S.; BARAÚNA, E. E. P. Características anatômicas e propriedades físico-mecânicas das madeiras de duas espécies de mogno africano. **Cerne**, Lavras, v. 212, n. 4, p. 633-640, 2015.

FRANKLIN, G. L. Preparation of thin sections of synthetic resins and wood: resin composites, and a new macerating method for wood. Nature, 1945.

IAWA. International Association of Wood Anatomists. List of microscopic features for hardwood identification. Iawa Bulletin, Leiden, v.10, n.3, p.219-332, 1989.

KOL, H. S.; KESKIN, A. S.; VAYDOGAN, K. G. Effect of heat treatment on the mechanical properties and dimensional stability of beech wood. **Journal Of Advanced Technology Sciences**. Correia, v. 6, p. 820-830, 2017.

KÖPPEN, William. 1931. Climatologia. México, Fundo de Cultura Econômica.

LIMA, R. S.; COELHO, J. C. F.; SILVA, J. C.; ARAÚJO, J. A.; CALDERON, C. M. A. Influência da anatomia nas propriedades físicas da madeira de *Iryanthera grandis* Ducke. **Enciclopédia Biosfera**, Jandaia, v.10, n.19, p.1188-1198, 2014.

MONTEIRO, T. C.; LIMA, J. T.; HEIN, P. R. G.; SILVA, J. R. M.; TRUGILHO, P. F.; ANDRADE, E. B. Efeito dos elementos anatômicos da madeira na secagem das toras de *Eucalyptus* e *Corymbia*. **Scientia Forestalis**, Piracicaba, v.45. n.115, p.493-505, 2017.

NISGOSKI, S.; MUÑIZ, G. I. B.; TRIANOSKI, R.; MATOS, J. L. M.; VENSON, I. Características anatômicas da madeira e índices de resistência do papel de *Schizolobium parahyba* (Vell.) Blake proveniente de plantio experimental. **Scientia Forestalis**, Piracicaba, v.40, n.94, p.203-211, 2012.

PEDRAZZI, C.; COLODETTE, J. L.; OLIVEIRA, R. C.; WILLE, V. K. Avaliação morfológica das fibras de polpas Kraft de Eucalipto com diferentes conteúdos de Xilanas. **Scientia Forestalis**, Pìracicaba, v.41, n.100, p.515-522, 2013.

PILLAI, P. H. C.; PANDALAI, R. C.; DHAMODARAN, T. K.; SANKARAN, K. V. Effect of silvicultural practices on fibre properties of Eucalyptus wood from short-rotation plantations. **New Forests**, Sydney, v.44, n.4, p.521-532, 2013.

SAS. Statistical Analysis System. Getting Started with the SAS Learning Edition. Care, North Carolina: SAS Institute Inc, 2003.

SCHWERZ, F.; MEDEIROS, S. L. P.; ELLI, E. F.; ELOY, E.; SGARBOSSA, J.; CARON, B.O. Plant growth, radiation use efficiency and yield of sugarcane cultivated in agroforestry systems: An alternative for threatened ecosystems. **Anais da Academia Brasileira de Ciências**, Rio de Janeiro, v.90, n.4, p.3265-3283, 2018.

SETTE JR, C. R.; OLIVEIRA, I. R.; FILHO, M. T.; YAMAJI, F. M.; LACLAU, J. P. Efeito da idade e posição de amostragem na densidade e características anatômicas da madeira de *Eucalyptus grandis*. **Árvore**, Viçosa, v.36, n.6, p.1183-1190, 2012.

TANABE, J.; ISHIGURI, F.; NAKAYAMA, M.; OHSHIMA, J.; IIZUKA, K.; YOKOTA, S. Properties of juvenile and mature wood and their effects on the bending properties of lumber in *Pinus taeda* growing in Tochigi. **Forest Products Journal**, LaGrange, v.66, n.7-8, p.428-432, 2016.

VALENTE, B. M. R. T.; EVANGELISTA, W. V.; SILVA, J. C.; LUCIA, R. M. D. Variabilidade radial e longitudinal das propriedades físicas e anatômicas da madeira de Angico-vermelho. **Scientia Forestalis**, Piracicaba, v.41, n.100, p.485-496, 2013.

VERBIST, M.; BRANCO, J. M.; NUNES, L. Characterization of the mechanical performance in compression perpendicular to the grain of insect-deteriorated timber. **Buildings**, São Paulo, v.10, n.1, p.1-14, 2020.

ZANUNCIO, A. J. V.; CARVALHO, A. G.; DAMÁSIO, R. A. P.; OLIVEIRA, B. S.; CARNEIRO, A. C. O.; COLODETTE, J. L. Relationship between the anatomy and drying in *Eucalyptus grandis* x *Eucalyptus urophylla* wood. **Árvore**, Viçosa, v.40, n.4, p.723-729, 2016.