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Scientific Article

CORRELATION OF ANATOMY WITH PHYSICAL PROPERTIES OF WOOD SPECIES FROM AN AGROFORESTRY SYSTEM

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ABSTRACT

When the premise is the best final use of wood, evaluation of anatomical variables is recommended, bearing in mind that they are correlated with the properties of this material. The present study aimed to evaluate the correlation between anatomy and the physical properties of wood from *Parapiptadenia rigida* (Benth.) Brenan, *Peltophorum dubium* (Spreng.) Taub., *Eucalyptus grandis* W. Hill × *Eucalyptus urophylla* S.T. Blake (hybrid) and *Schizolobium parahyba* (Vell.) Blake, from an agroforestry system. For this purpose, five trees of each species, aged 9 years old, were selected, and samples were collected from the diameter at 1.30 m height from the ground for analysis of the anatomical characteristics and physical properties of the wood. Anatomical variables, with the exception of fiber length and cell wall thickness, correlated with the physical properties of wood and influenced their values. The higher the cell wall fraction (0.79), vessel frequency (0.44) and ray frequency (0.92), the greater the basic density of the wood. The greater the fiber diameter (0.94), lumen diameter (0.88), vessel diameter (0.88), ray height (0.86) and ray width (0.84), the higher the moisture content of the wood.

Keywords: Anatomical elements; Moisture content; Basic density.

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CORRELAÇÃO DA ANATOMIA COM AS PROPRIEDADES FÍSICAS DA MADEIRA DE ESPÉCIES DE UM SISTEMA AGROFLORESTAL

RESUMO – Quando se tem como premissa a melhor utilização final da madeira, recomenda-se a avaliação das variáveis anatômicas, tendo em vista que elas estão correlacionadas com as propriedades desse material. O presente estudo teve como objetivo avaliar a correlação da anatomia nas propriedades físicas da madeira de *Parapiptadenia rigida* (Benth.) Brenan, *Peltophorum dubium* (Spreng.) Taub., *Eucalyptus grandis* W. Hill × *Eucalyptus urophylla* S.T. Blake (híbrido) e *Schizolobium parahyba* (Vell.) Blake, provenientes de um sistema agroflorestal. Foram selecionadas cinco árvores de cada espécie, com a idade de 9 anos, sendo coletadas amostras a 1,30 m do solo para análise das características anatômicas e das propriedades físicas da madeira. As variáveis anatômicas, com exceção do comprimento da fibra e da espessura da parede celular, correlacionaram-se com as propriedades físicas da madeira e influenciaram seus valores. Quanto maior a fração da parede celular (0,79), frequência de vaso (0,44) e frequência de raio (0,92), maior a densidade básica da madeira. Quanto maior o diâmetro da fibra (0,94), diâmetro do lume da fibra (0,88), diâmetro do vaso (0,88), altura de raio (0,86) e largura do raio (0,84), maior o teor de umidade da madeira.

Palavras-Chave: Elementos anatômicos; Teor de umidade; Densidade básica.

1. INTRODUCTION

Wood is a differentiated raw material, as it contains unique properties, with an organic, heterogeneous, porous, hygroscopic and anisotropic constitution (Eloy et al., 2020). There is a high demand for quality wood, with an increasing use of this material in different segments of the wood market, which require, in the final use of wood, knowledge of the peculiarities of each forest species used.

The need to meet this demand and at the same time preserve the environment continues to be a priority in the global sustainability movement. In this context, species that show rapid growth and the use of new forms of cultivation stand out as alternatives to supply this market (Eloy et al., 2023).

In view of this, there is a growing interest in the implementation of agroforestry systems, as there are considerable efforts to disseminate them in Brazil. Agroforestry systems involve the introduction of forestry components interacting with agricultural components in intercropping, while conserving natural resources. Although few studies have compared the productivity or quality of wood from agroforestry systems and trees from monocultures, such systems are responsible for bringing economic benefits by diversifying production on small rural properties and generating income (Caron et al., 2018).

The agroforestry systems were developed with specific characteristics regarding the species used, which are adapted to the location, with productive potential and interact with one another. These are constituted in temporal arrangements, which respond to planning over time, and spatial arrangements, with spacing between plants according to the objectives and functionality of the system (Schwerz et al., 2018). These systems are generally implemented with native and exotic species that have good technological characteristics to serve as a source of raw material for various purposes.

Ignorance of wood characteristics can result in serious problems regarding its rational use and, consequently, the optimization of forestry activities. To determine the best final use of wood from agroforestry systems, it is necessary to identify the properties and technological behavior of different types of material (Motta et al., 2014). To this end, there are methods developed that aim to improve the physical condition and mechanical characteristics of wood (Freitas et al., 2016).

Studies of the anatomical parameters of wood prove to be important in several applications, when we analyze the quality of wood for the most varied purposes. The dimensions and frequency of cells, for example, directly influence the physical and mechanical properties of wood (Costa et al., 2017). This can be significantly observed when drying wood, as some anatomical elements, such as the higher cell wall fraction and ray frequency, can hinder the speed of water removal from the material. On the other hand, other elements, such as fiber diameter, ray height and ray width, act in the opposite way, that is, helping this process (Zanuncio et al., 2016). With the same importance, these anatomical characteristics influence the basic density of the wood, altering the mechanical properties and, consequently, its resistance (Tanabe et al., 2016).

Therefore, the use of different species in the forestry sector must consider the quality characteristics of the wood, in addition to its other growth and productivity attributes, to meet production requirements. Thus, the present study aimed to evaluate the correlation between anatomy and the physical properties of wood from four species grown in an agroforestry system.

2. MATERIAL AND METHODS

2.1 Experimental location and sampling

The wood of the four forest species, namely *Parapiptadenia rigida* (Benth.) Brenan (angico-vermelho), *Peltophorum dubium* (Spreng.) Taub. (canafístula), *Eucalyptus grandis* × *Eucalyptus urophylla* (eucalyptus hybrid) and *Schizolobium parahyba* (Vell.) Blake (guapuruvú), was obtained from an agroforestry system characterized by having a planting spacing of 12.0 x 1.5 m (12.0 m between rows and 1.5 m between plants in the row), five trees per species being evaluated, located in the municipality of Frederico Westphalen, Rio Grande do Sul, Brazil (27°22"S, 53°25" W; 480 m altitude). According to Köppen's classification, the predominant climate of the region is Cfa, characterized as sub-humid subtemperate, with an average annual temperature of 18.8 °C and an average temperature in the coldest month of 13.3 °C (Alvares et al., 2013).

2.2 Anatomical properties of wood

To sample the trees, the average diameter of each individual was considered, and five 9-year-old specimens of each species were selected (Table 1). The test specimens for determining the anatomical characteristics were taken from the region of diameter at breast height (DBH) at 1.30 m from the ground. Subsequently, three samples were taken per tree with dimensions of 1.5 x 1.5 x 2.0 cm, oriented to obtain the transverse, longitudinal radial and longitudinal tangential anatomical planes, totaling 60 specimens.

The microtomy was performed in accordance with the IAWA's (1989) technical standard. For histological evaluation, the specimens were softened by boiling in water and subsequently tested and cut using a sliding microtome, with a thickness of 18 µm. Once the histological section of the materials was finished, double staining was carried out, with astra blue and safranin, followed by dehydration in an alcoholic series (30%, 50%, 70%, 90% and 100%), and permanent slides were mounted using Entellan® mounting medium.

Maceration was carried out in accordance with the recommendations of Franklin (1945), adopting the maceration of sticks, subjected to boiling for 45 min in an acid solution. To stain the wood cell paste, safranin was applied, followed by an alcohol series (50% and 100%) and the same mounting medium previously

Table 1. Diameter at height of 1.30 m from the ground and average height of the four forest tree species derived from an agroforestry system.

Tabela 1. Diâmetro a altura de 1,30 m do solo e altura média das árvores das quatro espécies florestais provenientes de um sistema agroflorestal.

Species	DBH (cm)	H (m)
Parapiptadenia rigida	17.0	18.01
Peltophorum dubium	16.0	19.33
Eucalyptus grandis × *Eucalyptus urophylla*	34.0	26.99
Schizolobium parahyba	25.0	21.04

Where: DBH = diameter at average breast height (1.30 m from the ground); H = average height.

Em que: DBH = diâmetro a altura do peito médio (1,30 m do solo); H = altura média.

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mentioned for permanent slides.

For each anatomical parameter, 75 measurements were carried out, with 25 readings determined for each of the three samples taken from each individual, following the COPANT's (1973) technical standard. Based on this standard, vessel diameter (VD), vessel frequency (VF), ray height (RH), ray width (RW) and ray frequency (RF) were evaluated. In the macerated material, fiber length (FL), fiber diameter (FD) and fiber lumen diameter (LD) were measured. Fiber cell wall thickness (CWT) was calculated using the following equation (Equation 1).

$$CWT = (FD - LD) / 2 \qquad (Eq.\ 1)$$

Where:

CWT = cell wall thickness (μm);

FD = fiber diameter (μm);

LD = lumen diameter (μm).

Fiber cell wall fraction (CWF) was calculated using the following equation (Equation 2).

$$CWF = (2 \times CWT) / FD \times 100 \qquad (Eq.\ 2)$$

Where:

CWF = cell wall fraction (%);

CWT = cell wall thickness (μm);

FD = fiber diameter (μm).

2.3 Physical properties of wood

To analyze the basic density and moisture content of the wood, circular samples were taken from the transversal section at the DBH position and used to prepare the test specimens. 25 samples of each species studied were evaluated, from the heartwood and sapwood regions, totaling 100 specimens. The determinations were carried out using the technical standard NBR 7190-1 (ABNT, 2022).

2.4 Experimental design and data analysis

The experiment was evaluated in a completely randomized design and the data were subjected to statistical analysis using the "Statistical Analysis System" Software (SAS, 2003), in which the ANOVA assumption test (F test), Shapiro-Wilk test for normality and Bartlett test for homoscedasticity of variances were carried out. In the case of significant effect variance analysis, multiple comparison of means was performed using the Tukey test. These analyses were carried out to identify similarities and divergences in wood properties between species, which are essential to discuss the relationship between anatomical elements and physical properties.

The functional relationship between the anatomical elements and the physical properties of the wood was evaluated using the Pearson correlation test, using all values of the analyzed variables. These relationships allow us to evaluate whether, in general, variations in anatomical elements influence or not the physical properties of the wood studied.

3. RESULTS

The four forest species showed differences between them in all the anatomical parameters evaluated, as well as for the physical properties of basic density and moisture content of the wood. When analyzing the test of means for anatomical properties (Table 2), it was observed that *S. parahyba* had the highest values of FD (35.1 μm), LD (27.6 μm) (Figure 1F) and VD (187.1 μm) (Figure 1B), as well as the largest dimensions of the rays, both in height (256.4 μm) and width (38.2 μm) (Figure 1D). On the other hand, the species has the lowest values for CWF (21.6%), VF (1.8 vessels mm^{-2}) (Figure 1B) and RF (14.8 rays mm^{-2}) (Figure 1D).

In general, it was observed that the species that show the highest VD values, consequently, have the lowest VF (Figure 1B and 1A, respectively). Likewise, species that have higher RH and RW values consequently have lower RF, as is the case with *S. parahyba* (Figure 1D), when compared to *P. rigida* (Figure 1C).

The species *P. dubium* showed the highest CWT (6.8 μm) and CWF (64.0 μm) values, but it was not statistically different from *P. rigida* (57.8 μm) for this variable. On the other hand, *P. dubium* had the lowest FL values (690.2 μm), and for the variable VF the lowest value was observed in *S. parahyba* (1.8 vessels mm^{-2}) (Figure 1B). The *E. grandis* × *E. urophylla* hybrid had the highest VF values

Table 2. Wood anatomical elements derived from forest species within an agroforestry system.

Tabela 2. Elementos anatômicos da madeira das espécies florestais provenientes de sistema agroflorestal.

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
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

Where: Vessel diameter (VD); Vessel frequency (VF), Ray height (RH); Ray width (RW); Ray frequency (RF); Fiber length (FL); Fiber diameter (FD), Fiber lume diameter (LD); Fiber cell wall thickness (CWT); Fiber cell wall fraction (CWF); Numbers raised to the exponent represent the standard deviation. 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.

Em que: Diâmetro de vaso (VD); Frequência dos vasos (VF); Altura de raio (RH), Largura de raio (RW); Frequência de raio (RF); Comprimento de fibra (FL); Diâmetro de fibra (FD); Diâmetro de lume de fibra (LD); Espessura da parede de fibra (CWT); Fração parede de fibra (CWF). Os números elevados ao expoente representam o desvio padrão. As médias seguidas pela mesma letra na coluna comparam as espécies e não diferem entre si, de acordo com o teste de Tukey a 5% de probabilidade de erro.

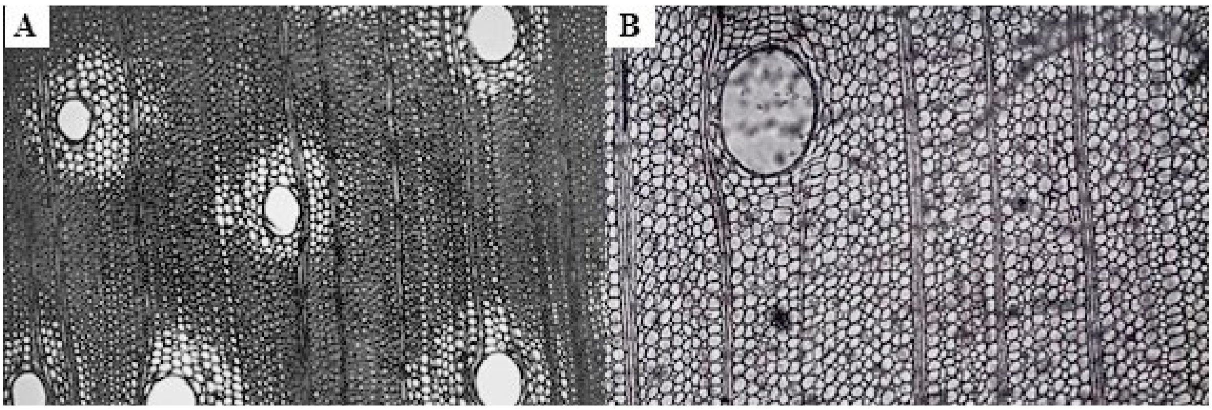

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Figure 1. Images of histological slides of the species *Parapiptadenia rigida* (A, C and E) and *Schizolobium parahyba* (B, D and F), from the agroforestry system.

Figura 1. Imagens de lâminas histológicas das espécies *Parapiptadenia rigida* (A, C e E) e *Schizolobium parahyba* (B, D e F), provenientes do sistema agroflorestal.

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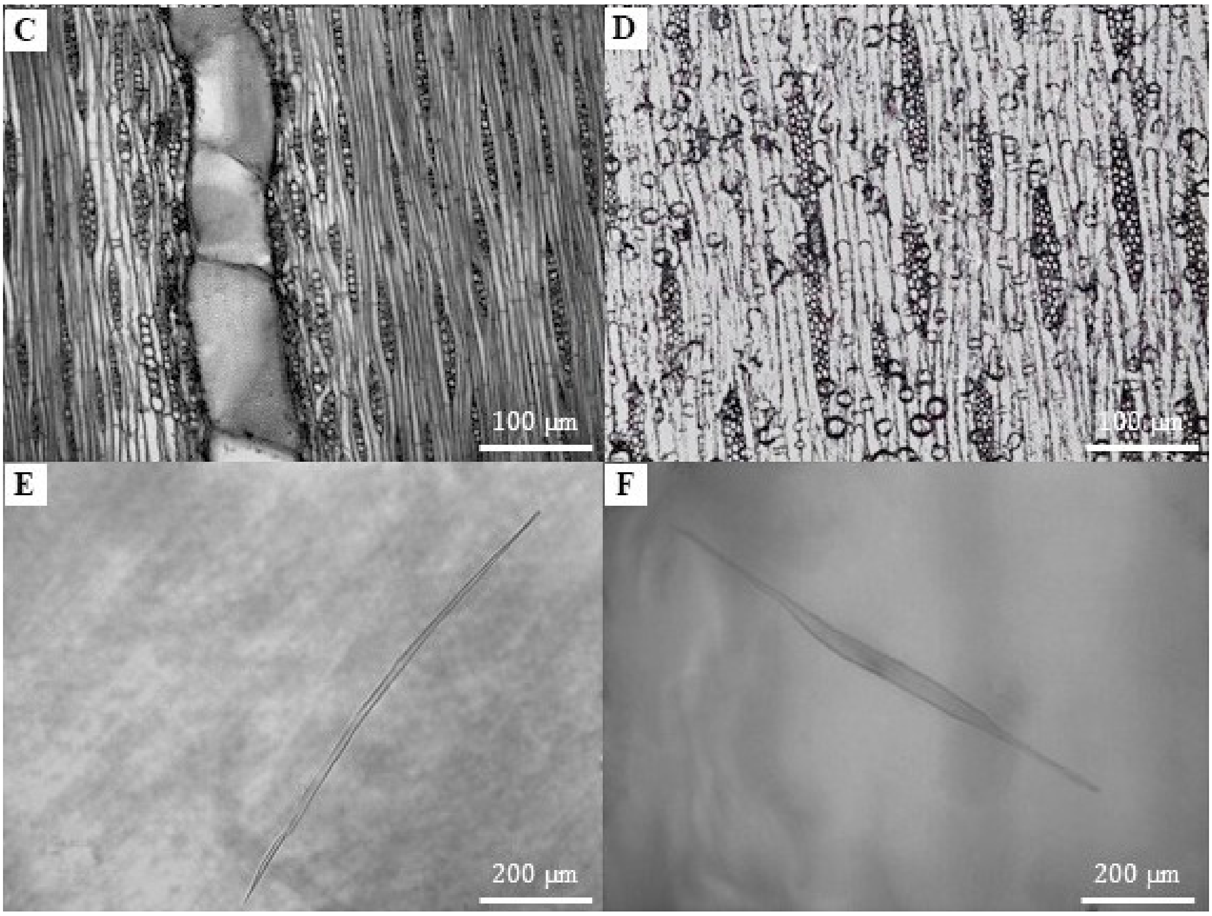

Figure 1. Images of histological slides of the species *Parapiptadenia rigida* (A, C and E) and *Schizolobium parahyba* (B, D and F), from the agroforestry system.

Figura 1. Imagens de lâminas histológicas das espécies *Parapiptadenia rigida* (A, C e E) e *Schizolobium parahyba* (B, D e F), provenientes do sistema agroflorestal.

(14.8 vessels mm^{-2}) and lowest RW values (13.5 µm), when compared with the other species, demonstrating statistical similarities with the species *P. rigida* for all anatomical characteristics of the fibers and VD (Table 2).

When analyzing the test of means for physical properties, it was found that the four forest species differed statistically, with the basic density of *P. rigida* wood (0.652 g cm^{-3}) having the highest average value when compared with those of the others, followed by *E. grandis* × *E. urophylla* (0.509 g cm^{-3}) and *P. dubium* (0.488 g cm^{-3}), which did not differ from each other and, later, by *S. parahyba* (0.277 g cm^{-3}). As for moisture content, it can be reported that the species *S. parahyba* (192.2%) had the highest average value, followed by *P. dubium* (127.9%), *E. grandis* × *E. urophylla* (85.4%) and *P. rigida* (66.6%), which obtained the lowest value (Table 3).

From the Pearson's correlation analysis, it was possible to observe that wood anatomy influenced most of the physical properties of the species studied, with the exception of FL and CWT, which did showed no correlation (Table 4).

Pearson's correlation analysis demonstrated an inversely proportional correlation of the anatomical variables with the basic density for the variables FD, LD, VD, RH and RW, and a directly proportional correlation with the variables CWF, VF and RF. On the other hand, for moisture content, an inversely proportional correlation was observed with the anatomical variables CWF, VF and RF, and a directly proportional correlation was observed with the variables FD, LD, VD, RH and RW (Table 4).

Table 3. Basic density (ρb) and moisture content (MC) of wood derived from forest species within an agroforestry system.

Tabela 3. Densidade básica (ρb) e teor de umidade (MC) da madeira de espécies florestais proveniente de sistema agroflorestal.

Species	ρb (g cm^{-3})	MC (%)
Parapiptadenia rigida	$0.652^{0.03}$ a	$66.6^{1.1}$ d
Peltophorum dubium	$0.488^{0.02}$ b	$127.9^{5.3}$ b
Eucalyptus grandis × *Eucalyptus urophylla*	$0.509^{0.03}$ b	$85.4^{2.1}$ c
Schizolobium parahyba	$0.277^{0.02}$ c	$192.2^{18.9}$ a

Where: Means followed by different letters in the column compare the species and differ from each other, according to Tukey's test at 5% probability of error. Numbers raised to the exponent represent the standard deviation.

Em que: As médias seguidas por letras diferentes na coluna comparam as espécies e diferem entre si, de acordo com o teste de Tukey a 5% de probabilidade de erro. Números elevados ao expoente representam o desvio padrão.

Table 4. Pearson's correlation between the wood anatomy and physical properties derived from forest species within an agroforestry system.

Tabela 4. Pearson's correlation between the wood anatomy and physical properties derived from forest species within an agroforestry system.

Anatomy variable	Physical properties	
	ρb	MC
Fiber length (FL)	-0.06 ^{ns}	0.02 ^{ns}
Fiber diameter (FD)	-0.88*	0.94*
Fiber lume diameter (LD)	-0.88*	0.88*
Fiber cell wall thickness (CWT)	0.03 ^{ns}	0.11 ^{ns}
Fiber cell wall fraction (CWF)	0.79*	-0.74*
Vessel diameter (VD)	-0.85*	0.88*
Vessel frequency (VF)	0.44*	-0.65*
Ray height (RH)	-0.88*	0.86*
Ray width (RW)	-0.76*	0.84*
Ray frequency (RF)	0.92*	-0.95*

Where: ρb = basic density; MC = moisture content; * = Significant Pearson's correlation; ^{ns} = Non-significant Pearson's correlation.

Em que: ρb = densidade básica; MC = teor de umidade; * = Correlação de Pearson significativa; ^{ns} = Correlação de Pearson não significativa

4. DISCUSSION

To evaluate the influence of one parameter on another in the correlation analysis, as in the case of the anatomical and physical properties of wood, it is essential that the species studied show heterogeneity among themselves. This is an important characteristic, because heterogeneous materials are mandatory to more accurately evaluate the influence of anatomical parameters on the physical properties of wood (Eloy et al., 2023). This is justified by the fact that the different species studied have different anatomical parameters and, consequently, their physical properties differ.

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The dimensions, as well as the frequency and distribution of anatomical elements, directly affect the physical and mechanical properties of wood (França et al., 2015), as well as the drying process (Zanuncio et al., 2016). Therefore, it is important to deepen the research on these relationships and carry out the study separately for species that have heterogeneous characteristics.

When analyzing the anatomical properties of the species studied, it was found that *S. parahyba* had the highest values of VD, RH, RW, FL, FD and LD compared to the others (Table 2). In general, values close to those found in the literature for *S. parahyba* were observed, as reported by Nisgoski et al. (2012), who found an average VD of 202.20 µm and VF of 2.02 vessels mm^{-2} in 15-year-old trees. This variation was also found in the genus *Eucalyptus* by Pillai et al. (2013), who highlighted that this characteristic is associated with the difference between genetic materials and the environmental conditions under which the trees grow.

Therefore, *S. parahyba* was characterized by the highest porosity among the species studied, with a VD of 187.1 µm (Table 2 and Figure 1B). This parameter directly influenced the lowest basic density of wood (0.277 g cm^{-3}) (Table 3), and consequently, these variables correlated inversely proportionally (-0.85) (Table 4). On the other hand, this species had the highest average moisture content (192.2%) among those studied, which contributed to a directly proportional correlation with VD (0.88) (Table 4).

This was motivated by the fact that the greater the number of empty spaces in the xylem, the greater the proportion of spaces for water storage in the cellular lumens, increasing the moisture content of the wood. On the other hand, this greater amount of empty spaces limits the occurrence of a greater proportion of cell wall, which results in a lower basic density of the wood (Zanuncio et al., 2016).

The highest VF values, equal to 14.8 vessels mm^{-2} (Table 2), were found for *E. grandis* × *E. urophylla*, corroborating what was reported by Lima et al. (2019), who obtained an average value of 14.9 vessels mm^{-2}. In general, it was observed that the higher the VF, the lower the VD (Figures 1A and 1B), directly influencing the lower values of wood moisture content. This demonstrates an inversely proportional correlation (-0.65) between VF and wood moisture content (Table 4).

This characteristic directly influences drying, which occurs more slowly (Eloy et al., 2021). These authors reported that the maximum moisture content in wood was associated with the empty spaces of cellular lumens, which facilitate water transport and promote drying (Zanuncio et al., 2016). Thus, the higher the VD, the higher the speed at which water is removed from the wood and, on the other hand, the higher the VF per mm^{-2}, the lower the drying rate (Eloy et al., 2021). Therefore, in practice, species that have higher lumen diameter dry faster, as the removal of water from the wood is facilitated, that is, the wood of *S. parahyba* dries faster than that of *E. grandis* × *E. urophylla*.

When we analyze the dimensions of the fibers, we can infer that the highest CWF values found for the species *P. rigida*, *P. dubium* and *E. grandis* × *E. urophylla* are associated with the basic density, since they are directly proportional (Table 4). This relationship results in the highest values for this physical property, as well as for all other mechanical properties, making the material more resistant (Eloy et al., 2023). On the other hand, lower CWF values result in a lower basic density of the wood (Lima et al., 2014), corroborating the results found for *S. parahyba*, which were lower average CWF values (21.6%) (Table 2) and, consequently, lower basic density values (0.277 g cm^{-3}) (Table 3).

For the FD and LD variables of the fibers, an evident variation is observed when we analyze Figures 1E and 1F, corresponding to the species *P. rigida* and *S. parahyba*. Different dimensions of the fibers were found, with *S. parahyba* having the highest values of these variables (Table 2); consequently, there was an inversely proportional correlation with the basic density of the wood (-0.88) (Table 4). These results corroborate those reported by Valente et al. (2013), who observed an inverse correlation of basic density with LD. Thus, a high proportion of empty spaces results in a lower basic density (Lima et al., 2014). On the other hand, directly proportional relationships between FD and LD were observed with wood moisture content of 0.94 and 0.88, respectively (Table 4).

Regarding the dimensions of the rays, we observed a correlation with the physical properties of the wood (Table 4), since they are formed by radial parenchyma cells that have relatively thin cell walls, in most cases non-lignified, and relatively large lumens (Burger and Richter, 1991). Species with lower RH and RW values are characterized by a higher basic density, such as *P. rigida*, which had the lowest RH (132.9 µm) and RW (19.3 µm) (Table 2 and Figure 1C) and, consequently, the highest basic density value (0.652 g cm^{-3}) (Table 3). The higher the values of these anatomical properties, the higher the moisture content, due to the fact that the cells have larger lumens with large empty spaces, as is the case with *S. parahyba* (Figure 1D).

However, for the RF variable, the physical properties vary in the opposite way, as the species that have higher RF values will show lower RH and RW. This can be observed in a very evident way for the species *P. rigida* Figure 1C) and *S. parahyba* (Figure 1D), which have very different anatomical characteristics (Table 2).

The study of wood anatomy proves to be important in several applications in the area of wood technology. Eloy et al. (2021), working with forest species, reported that the FD and LD variables of the fiber directly influenced the drying of the wood. This occurred most notably for the species *S. parahyba*, for which high correlations were observed, especially in the initial periods of the process, consequently showing a greater speed of water removal from the wood. For *P. rigida* and *E. grandis* × *E. urophylla*, which had lower values of these variables, drying was slower.

This variation is related to the water removal behavior of the wood, which initially occurs freely leaving the cell lumens, and at the end of the drying period the water impregnated in the cell wall is removed (Zanuncio et al., 2016). Thus, materials with higher CWF values make it difficult for water to pass through and reduce drying speed, as well as having a smaller proportion of cell lumens, which retain less moisture when saturated (Kollmann and Côté, 1968).

Similarly, Mangini et al. (2023) observed an inversely proportional behavior between the basic density and the initial moisture content of agroforestry systems species, highlighting that this variation comes from the relationship between mass and volume of the material, since, with a percentage of water above 30% (Fiber Saturation Point - FSP), the wood only changes its mass, which directly interferes with the density of the individuals.

The same authors, working with the drying of agroforestry systems species, highlighted that during the first 30 days of drying in the open air, the loss of moisture was faster and more accentuated and, consequently, the drying rates were higher. This characteristic was also observed by Braz et al. (2015), when drying Teak (*Tectona grandis*) and Black wattle (*Acacia mangium*) wood outdoors, where the greatest loss of moisture, for both species, occurred in the first weeks.

This variation occurs due to the presence of free water in the wood cavities, above the FSP, being maintained by weak capillary forces, which facilitates evaporation and results in high losses in the first weeks of drying (Monteiro et al., 2018; Nascimento et al., 2019). However, below the FSP, evaporation occurs more slowly and gradually, as hygroscopic water is found at this stage of drying, located in the cell walls and linked by hydrogen bonds to the polar cellulose molecules (Moretti et al., 2020). Thus, the removal process is made difficult, combined with the need for energy to break this bond, as it results from the combination of moisture diffusion through the walls and lumens of the cells (Jesus et al., 2016).

Other authors related the anatomical characteristics to the mechanical properties of wood. For Sette Junior et al. (2012), a higher CWF increases the basic density of the wood and, consequently, improves its mechanical properties, making the wood more resistant (Tanabe et al., 2016). Therefore, products with high basic density values are suitable for uses that require greater mechanical resistance, directly influencing the machining of wood (Bandera et al., 2021). On the other hand, the higher the cell lumen values, the greater the amount of empty space in the wood, reducing the basic density, as well as the values of mechanical properties (Eloy et al., 2023).

5. CONCLUSION

In relation to the conditions studied in this work, it can be concluded that:

The anatomical variables, with the exception of fiber length and cell wall thickness, correlate with the physical properties of the wood and influenced their values. The greater the cell wall fraction, vessel frequency and ray frequency, the greater the basic density and the lower the moisture content of the wood. The greater the fiber diameter of the lumen diameter, vessel diameter, ray height and ray width, the lower the basic density and the higher the moisture content of the wood studied.

To increase interest in the implementation of agroforestry systems based on the analysis of the quality of the wood produced and improve the final use in a more efficient and sustainable way, it is recommended to evaluate the anatomical variables, as they are strongly correlated with the physical properties of the wood. These assessments are relevant to more accurately analyze water removal in the drying process and the mechanical resistance of the wood.

AUTHOR CONTRIBUTIONS

Writing - Original Draft, Conceptualization, Methodology, Validation, Investigation and Supervision: Elder Eloy, Tauana de Souza Mangini and Claiton Nardini. Conceptualization, Methodology and Investigation: Braulio Otomar Caron, Rômulo Trevisan and Alec Duwe dos Santos. Writing – Review and Editing: Elder Eloy, Tauana de Souza Mangini, Claiton Nardini, Braulio Otomar Caron, Rômulo Trevisan and Alec Duwe dos Santos.

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