BASIC WOOD DENSITY, FIBER DIMENSIONS, AND WOOD CHEMICAL COMPOSITION OF FOUR *Eucalyptus* SPECIES PLANTED IN SOUTHERN BRAZIL

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ABSTRACT – In the Brazilian planted forest sector, most of the species used are from the genus *Eucalyptus*. Even though Southern Brazil has a suitable climate for species of the genus *Pinus*, the planting of frost-resistant *Eucalyptus* species has been increasing annually. The objective of this study was to evaluate the basic density, fiber dimensions, and chemical composition of *Eucalyptus benthamii*, *Eucalyptus dunnii*, *Eucalyptus saligna*, and *Eucalyptus cloeziana* woods. The trees used were from a six-year-old experimental plantation located in Canoinhas, state of Santa Catarina. For each species, three trees were selected, and discs were removed from each tree at 0%, 25%, 50%, 75%, and 100% of the commercial stem height. To evaluate the quality of the wood, the basic wood density, fiber dimensions, and chemical composition of the wood were determined by comparing the values between species and between the heights in the stem. The highest basic density was that of the wood of *E. cloeziana*; this species also had the greatest length and width of fibers. *E. dunnii* had the lowest levels of lignin and the highest levels of holocellulose. The highest lignin content was found in the wood of *E. benthamii*, *E. saligna*, and *E. cloeziana*. The relationship between wood properties and stem height was not relevant. The results highlight the tendency for higher extractives to be found at taller heights (100%), and holocellulose and lignin content are similar at all heights.

Keywords: Basic density; Fibers; Wood chemistry.

DENSIDADE BÁSICA DA MADEIRA, DIMENSÕES DAS FIBRAS E COMPOSIÇÃO QUÍMICA DA MADEIRA DE QUATRO ESPÉCIES DE Eucalyptus *PLANTADAS NO SUL DO BRASIL*

RESUMO – No setor de florestas plantadas brasileiro, a maioria das espécies utilizadas são do gênero ***Eucalyptus****. Embora o Sul do Brasil tenha clima propício para espécies do gênero* ***Pinus****, o plantio de espécies de* ***Eucalyptus*** *resistentes à geada vem aumentando anualmente. O objetivo deste estudo foi avaliar a densidade básica, as dimensões das fibras e a composição química da madeira de* ***Eucalyptus benthamii****,* ***Eucalyptus dunnii****,* ***Eucalyptus saligna*** *e* ***Eucalyptus cloeziana****. As árvores utilizadas foram provenientes de um plantio experimental de seis anos localizado em Canoinhas, estado de Santa Catarina. Para cada espécie, três árvores foram selecionadas e os discos foram removidos de cada árvore a 0%, 25%, 50%, 75% e 100% da altura do caule comercial. Para avaliar a qualidade da madeira, a densidade básica, as dimensões das fibras e a composição química foram determinadas comparando-se os valores entre as espécies e entre as alturas no*

*fuste. A maior densidade básica foi a da madeira de **E. cloeziana**; esta espécie também apresentou o maior comprimento e largura das fibras. **E. dunnii** apresentou os menores teores de lignina e os maiores teores de holocelulose. O maior teor de lignina foi encontrado na madeira de **E. benthamii**, **E. saligna** e **E. cloeziana**. A relação entre as propriedades da madeira e a altura do fuste não foi relevante. Os resultados destacam a tendência de maiores extrativos serem encontrados nas partes mais altas (100%), e os teores de holocelulose e lignina são similares em todas as alturas.*

Palavras-Chave: Densidade básica; Fibras; Química da madeira.

1. INTRODUCTION

In southern Brazil, the edaphoclimatic conditions are favorable for *Pinus* spp. plantations, with the Santa Catarina state being the second largest holder of forests of this genus. However, plantations of *Eucalyptus* spp. in southern Brazil have been increasing, and between 2009 and 2020, the area of *Eucalyptus* spp. in Santa Catarina more than doubled, from 100,140 hectares to 273,116 hectares, representing more than a third of all planted forests in that state (Indústria Brasileira de Árvores – IBÁ, 2021).

Eucalyptus spp. were introduced in Santa Catarina through the exploration of frost-resistant species, led mainly by companies in the pulp and paper sector. However, the wood of these species is also versatile and can be used to produce sawn wood in long cycles of rotations, energy, and wood panels (Oliveira and Pinto Júnior, 2021). Furthermore, wood from *Eucalyptus* spp. is harvested in short cycles of rotations of 6 to 7 years, while a similar volume of *Pinus* spp. takes 10 to 12 years to achieve (Lengowski et al., 2020).

Eucalyptus plantations in Southern Brazil show rapid growth and high productivity due to abundant rainfall, but many *Eucalyptus* species have low frost tolerance, a common climate stress in this region. The most planted tree in Brazil is the hybrid *Eucalyptus grandis* × *Eucalyptus urophylla* (Lengowski et al., 2020). However, this hybrid is not frost-resistant (Kleinpaul et al., 2010) and is not used in the expansion of *Eucalyptus* plantations in southern Brazil, for which other species are being tested.

Knowledge of wood properties, such as basic density, chemical composition, and fiber dimensions, is of great importance in determining its proper application (Vivian et al., 2015) and diversifying the timber market and silvicultural expansion. This information is also useful in targeting forest genetic breeding, which not only seeks gain in volumetric productivity, but also an improvement of wood characteristics and phytosanitary resistance (Grattapaglia, 2021).

The basic density of wood is one of the most relevant properties because it is related to most other wood properties (Gonçalez et al., 2014), and its importance is reinforced by its ease of determination (Dias et al., 2018), whereas the dimensions of the fibers are important because they are directly correlated with the properties of the paper produced (Pirralho et al., 2014). Finally, the chemical characteristics are useful for predicting and understanding the performance of wood in chemical processing, for energy production and in papermaking (Fearon et al., 2020).

Considering the expansion of Eucalyptus plantations in southern Brazil is recent and there is a lack of informations about wood from these plantations, the objective of this research was to evaluate the basic density, fiber dimensions, and chemical composition of the wood of *Eucalyptus benthamii* Maiden & Cambage, *Eucalyptus dunnii* Maiden, *Eucalyptus saligna* Sm., and *Eucalyptus cloeziana* F. Muell., planted in Canoinhas in the state of Santa Catarina.

2. MATERIAL AND METHODS

2.1. Wood origins and sampling

The wood specimens were obtained from the rural district of Marcílio Dias in Canoinhas, state of Santa Catarina, Brazil. The plantation is located at latitude 26°07′37″ S, longitude 050°23′41″ W, and

at an altitude of 839 m above sea level (DATUM: SIRGAS2000). According to Köppen's classification, the local climate is of the Cfb type, without a defined dry season, with cool summers and frequent frosts in winter (Alves et al., 2013).

The forest stand was a mixed experimental plantation in which the trees were planted in a 3 × 3 m spacing level in 2011. The species *E. benthamii*, *E. dunnii*, and *E. saligna* are suitable for the city of Canoinhas because they are frost-tolerant (Flores et al., 2016; Bonfatti Júnior and Lengowski, 2017), whereas *E. cloeziana* does not have satisfactory growth in the municipality (Bonfatti Júnior and Lengowski, 2017).

The sample collection was undertaken in 2017 when the plantation was six years old. From each species, three trees were randomly selected, and discs were removed at 0%, 25%, 50%, 75%, and 100% of the commercial stem height (minimum usable diameter: 6cm). Each wooden disc was divided into six wedges; a pair of opposing wedges was used to determine the basic wood density, another pair was ground to determine the chemical composition of wood, and the last pair was reduced to small fragments for the measurement of fiber dimensions.

2.2. Wood properties

The basic wood density was determined by mass weighing and indirect volume measurement method according to NBR 11941:2003 (Associação Brasileira de Normas Técnicas - ABNT, 2003) standard in two samples per disc, totalling six replicates per stem height per species.

For the fiber dimensions, small wood fragments were macerated. From the macerated tissue, the length, width, and wall fraction of 100 fibers per stem height were measured using an optical microscope following the guidelines of the International Association of Wood Anatomists – IAWA (1989), totalling 300 replicates per stem height per species.

Table 1 – Results of the determination of basic wood density and fiber dimensions into stem positions.
Tabela 1 *– Resultados da determinação da densidade básica da madeira e das dimensões das fibras nas posições do fuste.*

Total height proportion	*E. benthamii*	*E. dunnii*	*E. saligna*	*E. cloeziana*
		Basic wood density (g cm^{-3})		
0%	0.504 A (8.47)	0.538 A (9.25)	0.401 B (2.47)	0.486 A (2.67)
25%	0.475 A (1.68)	0.494 A (6.57)	0.440 A (9.19)	0.499 A (6.32)
50%	0.479 AB (7.79)	0.539 A (6.57)	0.472 B (3.17)	0.487 AB (5.71)
75%	0.476 A (3.03)	0.437 B (1.87)	0.465 AB (2.52)	0.461 AB (1.10)
100%	0.461 B (1.28)	0.437 B (0.44)	0.497 A (3.03)	0.496 A (3.00)
		Fiber length (mm)		
0%	0.918 B (9.13)	0.983 A (6.73)	0.922 B (6.38)	1.03 A (5.87)
25%	0.989 AB (7.60)	0.964 B (4.29)	0.938 B (7.21)	1.03 A (8.01)
50%	0.925 B (8.85)	0.991 A (5.54)	0.950 B (5.91)	1.05 A (7.71)
75%	0.933 B (6.45)	0.984 AB (5.24)	0.989 A (5.72)	1.02 A (8.61)
100%	0.919 B (6.20)	0.880 B (6.21)	0.886 B (7.07)	1.02 A (11.10)
		Fiber width (µm)		
0%	17.65 A (11.31)	15.97 A (16.73)	17.85 A (12.24)	17.35 A (15.81)
25%	15.75 AB (9.07)	14.50 B (13.24)	15.62 AB (13.61)	17.00 A (18.23)
50%	16.00 BC (11.60)	14.00 C (10.68)	15.12 BC (16.51)	17.87 A (16.53)
75%	15.37 B (15.18)	15.12 B (12.55)	12.25 C (19.75)	17.75 A (17.64)
100%	16.00 A (15.28)	14.00 B (12.15)	14.62 AB (11.47)	16.25 A (16.17)
		Wall fraction (%)		
0%	31.61 C (22.40)	62.01 A (25.78)	52.01 B (28.05)	59.72 A (14.71)
25%	45.14 C (25.25)	66.87 A (16.40)	55.67 B (27.15)	47.87 AB (20.00)
50%	46.13 B (18.63)	60.40 A (21.58)	63.51 A (22.78)	45.96 B (21.71)
75%	41.61 B (16.07)	61.36 A (16.51)	65.75 A (18.76)	46.46 B (23.02)
100%	41.10 B (24.44)	59.69 A (25.29)	46.76 B (22.89)	50.14 AB (27.90)

Means followed by different letters, considering the line, are different according to the Tukey test ($p<0.05$). Values in parentheses represent the coefficient of variation in percentage.
Médias seguidas de letras diferentes, considerando a linha, são diferentes de acordo com o teste de Tukey ($p<0.05$). Valores em parênteses representam o coeficiente de variação em porcentagem.

Wood samples for chemical analysis were prepared according to TAPPI T 257 sp-14 (Technical Association of Pulp and Paper Industry - TAPPI, 2014) in five samples per species. The total extractive content according to TAPPI T 204 cm-17 (TAPPI, 2017), acid-insoluble lignin content according to TAPPI T 222 om-15 (TAPPI, 2015), acid-soluble lignin content according to Goldschimid (1971), and ash content according to TAPPI T 211 om-16 (TAPPI, 2016) were determined. The total lignin content was determined by the sum of the acid insoluble and acid soluble lignin contents, and the holocellulose content was calculated by subtracting the total content of extractives and the total lignin content from 100%. Three replicates were determined, totalling nine replicates per stem height per species.

2.3. Statistical procedures

To check for residual normality and variance homoscedasticity, the data were subjected to the Shapiro-Wilk test and Bartlett test, respectively. How these assumptions were achieved, the data were subjected to analysis of variance (ANOVA), and when significant differences were detected between species, the Tukey test was used at 5% of significance. To assess the variation in wood properties in the axial direction of the stem (bottom to top), the data were plotted in histograms. All the statistical procedures were performed using the R language, version 4.1.0 (R Core Team, 2021).

3. RESULTS

3.1. Comparison between species

The results of the basic wood density and fiber dimensions of the four evaluated *Eucalyptus* species, considering the differences between species, are shown in Table 1.

E. cloeziana had a higher density at all heights, whereas *E. benthamii* and *E. dunnii* had lower densities

Table 2 – Results of the determination of wood chemical composition.
Tabela 2 *– Resultados da determinação da composição química da madeira.*

Total height proportion	*E. benthamii*	*E. dunnii*	*E. saligna*	*E. cloeziana*
		Total extractive content (%)		
0%	4.33 A (5.34)	3.44 AB (9.68)	2.98 B (2.16)	4.27 A (11.28)
25%	2.84 AB (12.91)	1.95 C (7.11)	2.41 CB (1.01)	3.60 A (5.27)
50%	3.36 AB (1.29)	3.76 A (2.03)	3.02 B (2.55)	2.87 B (10.31)
75%	3.40 AB (9.53)	3.28 AB (7.99)	2.28 B (11.82)	4.33 A (5.66)
100%	4.67 A (2.95)	3.72 A (6.43)	5.02 A (1.39)	4.31 AB (7.36)
		Total lignin content (%)		
0%	28.12 A (1.90)	24.49 B (2.83)	28.13 A (0.95)	27.68 A (3.87)
25%	2634 A (0.20)	21.86 B (0.21)	26.80 A (6.66)	27.27 A (2.53)
50%	26.75 A (8.30)	21.62 B (3.27)	26.70 AB (1.02)	22.11 AB (1.13)
75%	26.61 A (1.73)	22.78 B (0.87)	26.98 A (2.04)	25.76 A (2.67)
100%	26.45 AB (5.53)	23.33 B (2.87)	27.42 A (0.36)	26.38 AB (0.74)
		Holocelullose content (%)		
0%	67.55 B (0.48)	72.06 A (1.47)	68.88 B (0.30)	68.04 B (0.92)
25%	70.82 B (0.44)	76.95 A (0.12)	70.78 B (2.55)	69.13 B (0.76)
50%	69.88 A (3.21)	74.62 A (1.09)	70.27 A (0.51)	75.02 A (0.75)
75%	69.99 B (1.15)	73.94 A (0.08)	70.73 B (0.42)	69.90 B (0.68)
100%	68.88 B (2.44)	72.95 B (1.31)	67.55 B (0.05)	69.30 AB (0.17)
		Ash content (%)		
0%	0.61 B (3.81)	0.82 A (2.61)	0.49 C (5.91)	0.28 D (1.76)
25%	0.53 A (12.99)	0.57 A (6.17)	0.50 A (1.33)	0.31 B (6.53)
50%	0.69 A (6.05)	0.66 A (0.52)	0.62 A (0.84)	0.40 B (5.52)
75%	0.71 A (12.86)	0.67 A (0.52)	0.70 A (6.51)	0.32 B (3.41)
100%	0.77 A (5.43)	0.82 A (4.73)	0.74 A (2.20)	0.37 B (6.29)

Means followed by different letters, considering the line, are different according to the Tukey ($p < 0.05$). Values in parentheses represent the coefficient of variation in percentage.
Médias seguidas de letras diferentes, considerando a linha, são diferentes de acordo com o teste de Tukey ($p < 0.05$). Valores em parênteses representam o coeficiente de variação em porcentagem.

at the tallest heights, and *E. saligna* had higher density at the tallest height. *E. cloeziana* had the longest fiber lengths, with the length being longer than 1 mm, whereas the fiber lengths of the other species did not show a clear trend. The fiber width exhibited the same trend as the fiber length. *E. dunnii* had fibers with the largest fraction of walls, while those of *E. benthamii* were the thinnest.

E. benthamii had the highest content of extractives, *E. dunnii* had the lowest levels of lignin and the highest levels of holocellulose and ash, and *E. cloeziana* had the lowest ash content. The highest lignin content was found in *E. benthamii*, *E. saligna*, and *E. cloeziana*, and did not differ statistically at all heights (Table 2).

3.2. Variation of wood properties in the axial direction of the stem

The four species showed different patterns in the basic density profile of wood. *E. benthammii* had the highest basic wood density at 0% and declined followed by stabilization at other heights. The highest basic wood density of *E. dunnii* was found at heights 0 and 50%, and the lowest, with no statistical differences between them, were found at heights, 25, 50, and 75%. Basic wood density of *E. saligna* showed a tendency to increase with increasing height, while *E. cloeziana* had a constant basic wood density along the stem (Figure 1).

The effect of height on the fiber dimensions is shown in Figure 2, in which Figure 2A shows the fiber length results, Figure 2B shows the fiber width results, and Figure 2C shows the wall fraction results.

The fiber length did not vary in the wood samples of *E. benthamii* and *E. cloeziana*, whereas in *E. dunnii* and *E. saligna*, the smallest lengths were found at 100% height. *E. dunnii* had longer fibers at heights 0.50 and 75 %, and *E. saligna* had longer fibers at 75%

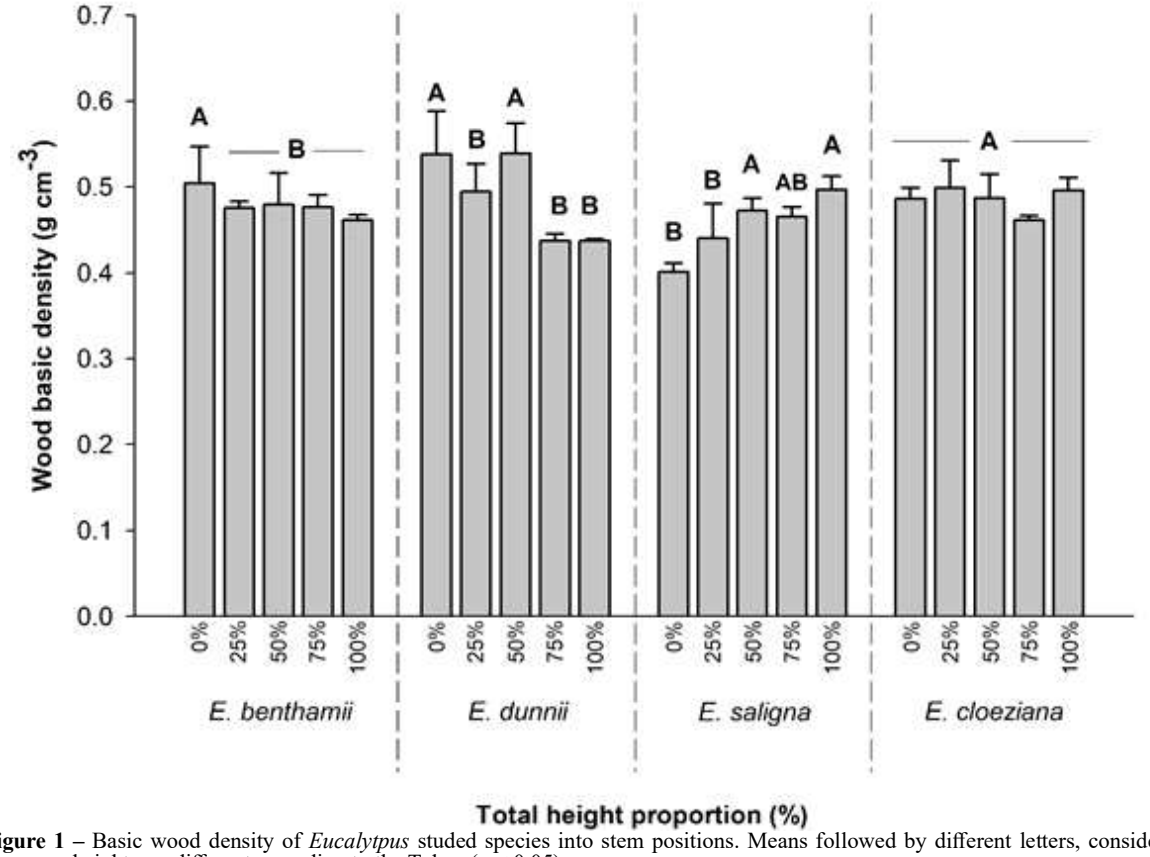

Figure 1 – Basic wood density of *Eucalytpus* studed species into stem positions. Means followed by different letters, considering the height, are different according to the Tukey ($p < 0.05$).

Figura 1 *– Densidade básica das madeiras dos* ***Eucalyptus*** *estudados nas posições do fuste. Médias seguidas por letras diferentes, considerando a altura, são diferentes de acordo com o teste de Tukey ($p < 0.05$).*

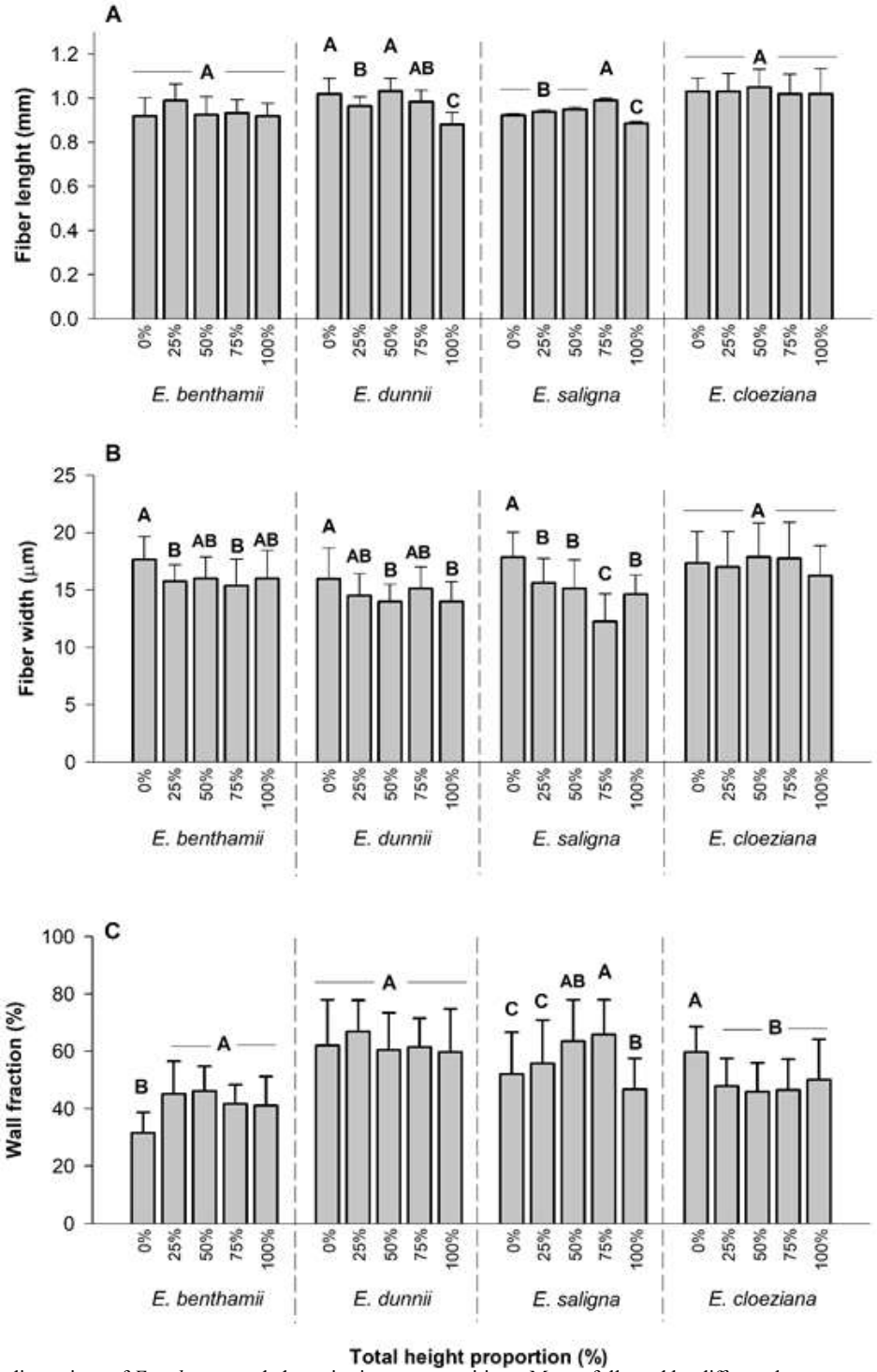

Figure 2 – Fiber dimensions of *Eucalytpus* studed species into stem positions. Means followed by different letters, considering the height, are different according to the Tukey test ($p < 0.05$).

Figura 2 *– Dimensões das fibras das madeiras dos* ***Eucalyptus*** *estudados nas posições do fuste. Médias seguidas por letras diferentes, considerando a altura, são diferentes de acordo com o teste de Tukey ($p < 0.05$).*

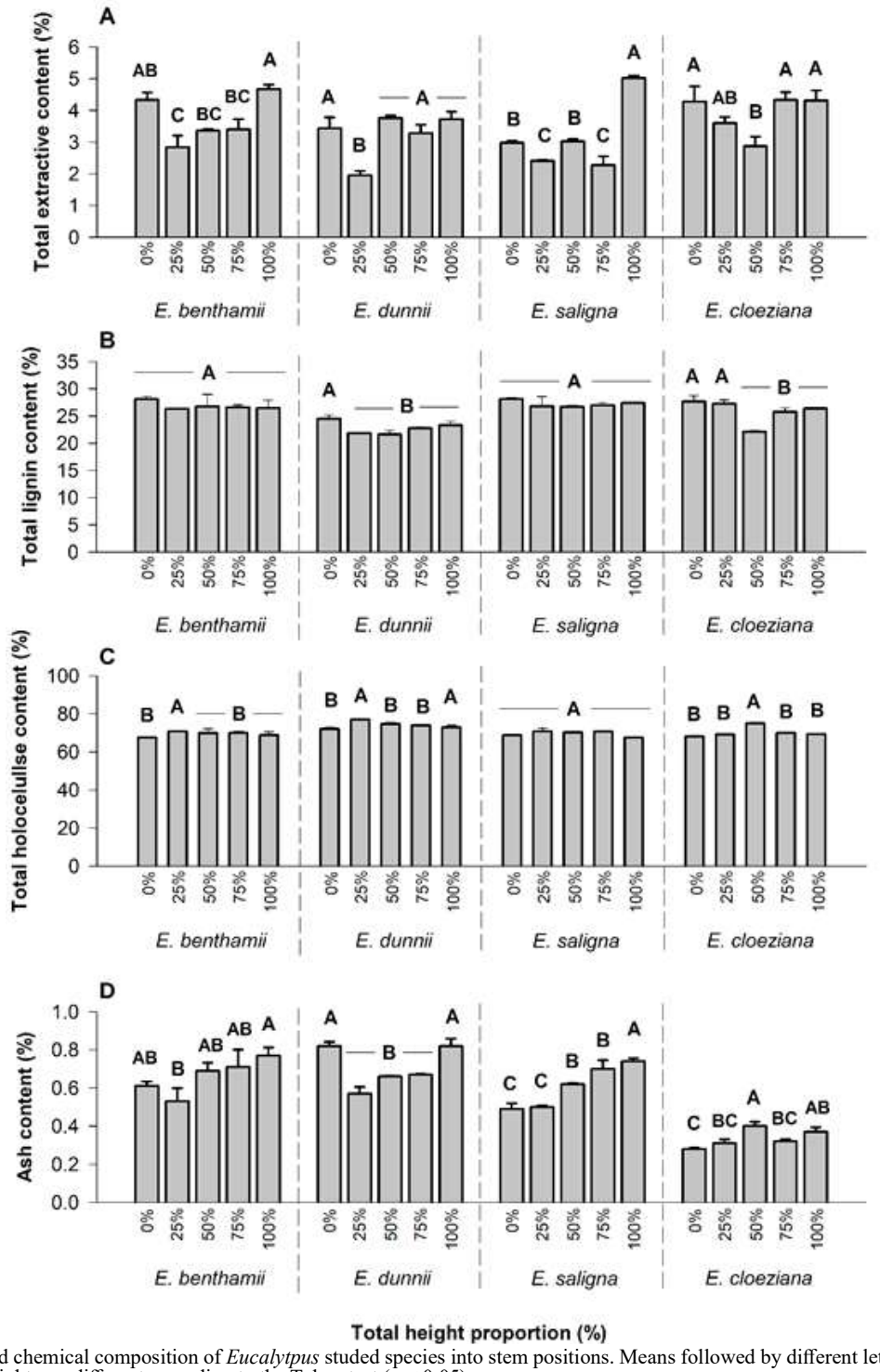

Figure 3 – Wood chemical composition of *Eucalytpus* studed species into stem positions. Means followed by different letters, considering the height, are different according to the Tukey test ($p < 0.05$).

Figura 3 *– Composição química das madeiras dos* ***Eucalyptus*** *estudados nas posições do fuste. Médias seguidas por letras diferentes, considerando a altura, são diferentes de acordo com o teste de Tukey ($p < 0.05$).*

height. Fiber width tended to decrease with increasing height in *E. benthamii*, *E. dunnii*, and *E. saligna*, whereas the fiber widths of *E. cloeziana* did not vary in relation to the axial position of the stem. The wall fraction of *E. dunnii* was maintained at all heights, whereas in *E. saligna*, the wall fraction tended to increase with increasing height. *E. benthamii* and *E. cloeziana* exhibited contrasting results; in the former species, the smallest wall fraction was found at the base of the stem, while in the latter, the largest wall fraction was found at the stem base.

Figure 3 shows the results of the chemical composition of the wood, Figure 3A shows the total extractive content, Figure 3B shows the total lignin content, Figure 3C shows the holocellulose content, and the ash content is shown in Figure 4D.

The highest total content of extractives was found at 100% height; however, in *E. saligna*, this value was statistically different from the value found in the base, whereas in the other three species they did not vary. The total lignin content did not vary with height in the wood samples of *E. benthamii* and *E. saligna*, whereas in *E. dunnii* and *E. cloeziana*, the lowest levels of total lignin were found at the tallest heights. The holocellulose content did not vary in *E. saligna*, but in *E. benthamii* and *E. cloeziana*, the highest values were found at intermediate heights of 25 and 50%, respectively. In *E. dunnii*, the highest content was found at 25 and 100% heights. *E. saligna* and *E. cloeziana* showed a tendency to have higher ash content with increasing stem height. *E. dunnii* had the highest levels at heights 0 and 100%, and *E. benthamii* did not show a clear trend of variation in the ash content, with the lowest content found at the height of 25% and the highest at the height of 100%. The ash contents at heights 0.50 and 75% heights were statistically equal to the highest values found for that species.

4. DISCUSSION

4.1. Comparison between species

The basic density values found were within the typical values of wood of *Eucalyptus* species cultivated in Brazil for pulp and paper production (0.43 and 0.55 g cm^{-3}) (Gomide et al., 2005). Fast-growing trees are expected to have low basic density, as was the case of the value found (0.38 g cm^{-3}) for five-year-old *E. grandis* wood from the state of Rio Grande do Sul, Brazil, by Cremonez et al. (2019). The four species in the present study presented satisfactory values for wood applications in which higher basic wood densities are favourable, such as to produce cellulosic pulp and energy (Brand, 2010; Smook, 2016).

Considering the fiber dimensions, all wood samples were suitable for producing paper. The differences found in length are not relevant to the paper properties, as the cellulosic pulp produced from hardwoods is considered as short-fiber pulp (Smook, 2016). However, the wood of *E. benthamii* is more suitable to produce printing and writing paper as it has a lower wall fraction (Santos and Sansígolo, 2007), while the wood of other species is more suitable for producing tissue papers for absorbent purposes, as fibers with a higher wall fraction absorb more liquid (Santos and Sansígolo, 2007).

To produce pulp, the lignin is removed by chemicals for fiber individualization; therefore, the lignin content directly affects the process because this compound makes pulping difficult (Lengowski et al., 2020). However, the presence of lignin and total extractives is favorable for energy production, whereas ash is undesirable for any use (Wastowski, 2018). Despite having the highest ash content, wood of *E. dunnii* is the most suitable for producing cellulosic pulp because it has a higher holocellulose content and a lower lignin content. The highest levels of lignin were found in *E. benthamii*, *E. saligna*, and *E. cloeziana*, among which the most suitable for energy production was *E. cloeziana*, which had the lowest ash content.

4.2. Variation of wood properties in the axial direction of the stem

The idiosyncrasy of a decrease/stabilization at 0–25% height, followed by an increase at 25–75% height, and a decrease/stabilization in the final portion of the commercial height constitutes a common model. This pattern of longitudinal variation of the basic wood density of trees of the *Eucalyptus* genus has been frequently reported in the literature (Alzate et al., 2005; Sette Junior et al., 2012; Gonçalez et al., 2014). In the present study, only *E. dunnii* fit into this model, contrasting the findings of Lopes et al. (2011) that there were no significant differences in basic wood density at different heights on the stems of *E. dunnii* trees.

The basic density of *E. benthamii* was higher at the base than at the other heights, which is in line with the findings of Benin et al. (2017). *E. saligna*, on the other hand, showed an increase in basic density up to the apex, a pattern similar to that described by Alzate et al. (2005), whereas *E. cloeziana* did not show differences between heights. This homogeneity of the basic density along the stem of *E. cloeziana* was earlier reported by Sturion et al. (1987). It has been suggested that higher density is associated with the mechanical requirements to support the stem and canopy of the trees (Sette Junior et al., 2012), and that the four species studied have different responses according to their mechanical requirements.

Earlier studies on the effect of stem height on the length of wood fibers from species of the genus *Eucalyptus* have found varied patterns; the length increased at greater tree heights (Gonçalez et al., 2014), decreased with increasing height (Valente et al., 1992; Rocha et al., 2004; Jorge et al., 2000), as well as did not vary with tree height (Taylor, 1973). Therefore, it is difficult to characterize the pattern of fiber length along the stem in *Eucalyptus* spp. This was the case for fiber width and wall fraction as well; no standard pattern was found for these variables because anatomical variations along the stem for *Eucalyptus* species are not consistent (Wilkes, 1988).

The higher concentration of total extractives at the tallest height is related to the accelerated physiological activity of the tree in that portion due to the proximity to the leaves that are responsible for photosynthesis (Taiz et al., 2014). The higher content of extractives found at the base of the stem may be related to the conversion of sapwood into heartwood, in which extractives are formed and deposited in the wood (Silva and Trugilho, 2007).

It is expected that the lignin content will increase with the age of the tree and the holocellulose content will decrease until they stabilize (Valente et al., 1992; Silva et al., 2005). It can be considered that *E. saligna* trees had already reached this stabilization and trees of the other species were close to this, as there were few discs that differed significantly, both in terms of the lignin content and the holocellulose content.

The variation in ash content is not commonly a research topic of wood chemistry studies, which is more commonly used to evaluate the general presence of ash and its effects on wood properties. In the present study, the highest ash content was found at the tallest height, being statistically equal to the 0% height position in *E. benthamii* and *E. dunnii*. In general, the variation in ash content was not similar to that of any of the other wood chemical constituents studied.

5. CONCLUSIONS

The wood with the highest basic density was found in *E. cloeziana*, and those with the lowest density was found in *E. benthamii* and *E. dunnii*.

The length of the fibers of *E. cloeziana* was the largest, being the only one that exceeded 1 mm, and fibers of greater width were also found in *E. cloeziana*; however only fibers at 50% and 70% tree heights were in fact significantly superior. The fibers with the highest wall fraction were those of *E. dunnii*.

Chemical composition analysis showed that *E. dunnii* wood was more suitable for pulping with the lowest lignin content and the highest holocellulose content. *E. benthamii*, *E. saligna*, and *E. cloeziana* had higher lignin contents.

The relationship between *Eucalyptus* wood properties and stem height was considered weak. In terms of basic wood density, each species exhibited a different pattern.

Considering the fiber length, *E. benthamii* and *E. cloeziana* showed no variation in this variable along the stem; despite the different variations, *E. dunnii* and *E. saligna* had the smallest lengths at the tallest height. It was not possible to determine any consistent behavior for the fiber width and wall fraction.

For extractives, it can be stated there is a tendency for a higher concentration of them at the tallest height of the tree (100%), and the content of total lignin and holocellulose tend to be similar at any height of the tree.

AUTHOR CONTRIBUTIONS

Eraldo Antonio Bonfatti Júnior designed the research Project, wrote the paper obtained and discussed the statistical, experimental, and estimated data. Elaine Cristina Lengowski wrote the paper and supported the data analysis. Bruna Mulinari Cabral, Thiago Wendling Gonçalves de Oliveira, Jeinna Michelly Rodrigues de Barros, and Rudson Silva

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6. REFERENCES

Alves CA, Stape JL, Sentelhas PC, Gonçalves JLM, Sparovek G. Köppen's climate classification map for Brazil. Meteorologische Zeitschrift. 2013;22(6):711-717. DOI: 10.1127/0941-2948/2013/0507

Alzate ACB, Tomazello Filho M, Piedade SMS. Variação longitudinal da densidade básica da madeira de clones de *Eucalyptus grandis* Hill ex Maiden, *E. saligna* Sm. e *E. grandis* x *urophylla*. Scientia Forestalis. 2005;68:87-95.

Associação Brasileira de Normas Técnicas – ABNT. NBR: 11941: determinação da densidade básica. Rio de Janeiro: 2003.

Benin CC, Watzlawick LF, Hillig E. Propriedades físicas e mecânicas da madeira de *Eucalyptus benthamii* sob efeito do espaçamento de plantio. Ciência Florestal, 2017;27(4):1375-1384. DOI: 10.5902/1980509830219

Bonfatti Júnior EA, Lengowski EC. Crescimento e sobrevivência de quatro espécies de *Eucalyptus* spp. em Canoinhas SC. Revista do Instituto Florestal, 2017;29(1):121-127. DOI: 10.24278/2178-5031.201729107

Brand MA. Energia da biomassa florestal. Rio de Janeiro: Interciência; 2010. ISBN 8571932441.

Cremonez VG, Bonfatti Júnior EA, Andrade AS, Silva EL, Klitzke RJ, Klock U. Wood basic density effect of *Eucalyptus grandis* in the paper making. Matéria, 2019;24(3):e-12420. DOI: 10.1590/S1517-707620190003.0735

Dias ACC, Marchesan R, Almeida VC, Monteiro TC, Moraes CB. Relação entre a densidade básica e as retrações em madeira de teca. Ciência da Madeira. 2018;9(1):37-44. DOI: 10.12953/2177-6830/rcm.v9n1p37-44

Fearon O, Kuitunen S, Ruuttunen K, Alopaeus V, Vuorinen T. Detailed modeling of kraft pulping chemistry: Delignification. Industrial & Engineering Chemistry Research. 2020;59(29):12977-12985. DOI: 10.1021/acs.iecr.0c02110

Flores T, Alvares CA, Souza V, Stape JL, editors. *Eucalyptus* in Brazil – Climatic Zoning and Identification Guide. Piracicaba: IPEF; 2016. ISBN 9788589142076.

Goldschimid O. Ultraviolet spectra. In: Sarkanen, KV, Ludwig, CH, editors. Lignins: occurrence, formation, structure, and reactions. New York: John Wiley & Sons; 1971. p. 241-266. ISBN 9780471754220.

Gomide JL, Colodette JL, Oliveira RC, Silva CM. Caracterização tecnológica, para a produção de celulose, da nova geração de clones de *Eucalyptus* do Brasil. Revista Árvore. 2005;29(1): 129-137. DOI: 10.1590/S0100-67622005000100014

Gonçalez JC, Santos GL, Silva Júnior FG, Martins IS, Costa JA. Relações entre dimensões de fibras e de densidade da madeira ao longo do tronco de Eucalyptus urograndis. Scientia Forestalis. 2014;42(101):81:89.

Grattapaglia D. Genômica aplicada à genética e melhoramento de *Eucalyptus* na Embrapa: 25 anos de avanços e as perspectivas para o futuro. In: Oliveira EB, Pinto Júnior JE, editors. O eucalipto e a Embrapa. Brasília: Embrapa; 2021. p. 203-267. ISBN 9786587380049.

Indústria Brasileira de Árvores – IBÁ. Relatório Anual 2021. Brasília: IBÁ; 2021. [cited 2022 March 22]. Available from: https://www.iba.org/datafiles/publicacoes/relatorios/relatorioiba2021-compactado.pdf

International Association of Wood Anatomists. List of microscopic features for hardwood identification. IAWA Bulletin. 1989;10(3):219-332.

Jorge F, Quilhó T, Pereira H. Variability of fibre length in wood and bark in *Eucalyptus globulus*. IAWA Journal. 2000;21(1):41-58. DOI: 10.1163/22941932-90000235.

Kleinpaul IS, Schumacher MV, Vieira M, Navroski MC. Plantio misto de *Eucalyptus urograndis* e *Acacia mearnsii* em sistema agroflorestal: I – Produção de Biomassa. Ciência Florestal. 2010;20(4):621:627. DOI: 10.5902/198050982420

Lengowski EC, Bonfatti Júnior EA, Vatras B,

Moreira Neto PB, Barros JMR, Nisgoski S. Properties of wood from frost-tolerant *Eucalyptus* planted in Brazil. Wood and Fiber Science. 2020;52(4):431-435. DOI: 10.22382/wfs-2020-041

Lopes CSD, Nolasco AM, Tomazello Filho M, Dias CTS, Pansini A. Estudo da massa específica básica e da variação dimensional da madeira de três espécies de eucalipto para a indústria moveleira. Ciência Florestal. 2011;21(2):315-322. DOI: 10.5902/198050983235

Oliveira EB, Pinto Júnior, JE, editors. O eucalipto e a Embrapa. Brasília: Embrapa; 2021. ISBN 9786587380049.

Pirralho M, Flores D, Sousa VB, Quilhó T, Knapic S, Pereira H. Evaluation on paper making potential of nine *Eucalyptus* species based on wood anatomical features. Industrial Crops and Products. 2014;54:327-334. DOI: 10.1016/j.indcrop.2014.01.040

Rocha FT, Florsheim SMB, Couto HTZ. Variação das dimensões dos elementos anatômicos da madeira de árvores de *Eucalyptus grandis* Hill ex Maiden aos sete anos. Revista do Instituto Florestal. 2004;16(1):43-55.

R Core Team. R: A language and environment for statistical computing. Viena, VI: R Foundation for Statistical Computing; 2021.

Santos SD, Sansígolo, CA. Influência da densidade básica da madeira de clones de *Eucalyptus grandis* x *Eucalyptus urophylla* na qualidade da polpa branqueada. Ciência Florestal. 2007;17(1):53-63. DOI: 10.5902/198050981935

Sette Júnior CR, Oliveira IR, Tomazello Filho M, Yamaji FM, Laclau JP. Efeito da idade e posição de amostragem na densidade e características anatômicas da madeira de *Eucalyptus grandis*. Revista Árvore. 2012;36(6)1183-1190. DOI: 10.1590/S0100-67622012000600019

Silva JC, Matos JLM, Oliveira JTS, Evangelista WV. Influência da idade e da posição ao longo do tronco na composição química da madeira de *Eucalyptus grandis* Hill ex. Maiden. Árvore. 2005;29(3):455-460.

Silva DA, Trugilho PF. Comportamento dimensional da madeira de cerne e alburno utilizando-se a metodologia de análise de imagem submetida a diferentes temperaturas. Cerne. 2003; 9(1):56-65. DOI: 10.1590/S0100-67622005000300013

Smook, G. Handbook for pulp and paper technologists. 4. ed. Atlanta: TAPPI Press; 2016. ISBN: 0969462859.

Sturion JA, Pereira JC, Albino JC, Morita M. Variação da densidade básica da madeira de doze espécies de *Eucalyptus* plantadas em Uberaba. Boletim de Pesquisa Florestal. 1987;14:28-38.

Taiz L, Zeiger E, Møller IM, Murphy A. Plant Physiology and Development. 6. ed. Sunderland: Sinauer; 2014. ISBN: 9781605352558.

Taylor FW. Anatomical wood properties of South-African grown *Eucalyptus grandis*. South African Forestry Journal. 1973;84:20-24.

Technical Association of Pulp and Paper Industry – TAPPI. TAPPI T 204 cm-17: Solvent extractives of wood and pulp. Atlanta: 2017.

Technical Association of Pulp and Paper Industry – TAPPI. TAPPI T 211 om-16: Ash in wood, pulp, paper, and paperboard: combustion at 525°C. Atlanta: 2016.

Technical Association of Pulp and Paper Industry – TAPPI. TAPPI T 222 om-15: Acid-insoluble lignin in wood and pulp. Atlanta: 2015.

Technical Association of Pulp and Paper Industry – TAPPI. TAPPI T 257 sp-14: Sampling and preparing wood for analysis. Atlanta: 2014.

Valente CA, Souza APM, Furtado FP, Carvalho AP. Improvement program for *Eucalyptus globulus* at Portucel: technological component. Appita. 1992; 45(6):403-407.

Vivian MA, Segura TES, Bonfatti Júnior EA, Sarto C, Schmidt F, Silva Júnior FG, et al. Qualidade das madeiras de *Pinus taeda* e *Pinus sylvestris* para a produção de polpa celulósica kraft. Scientia Forestalis. 2015;43(105):183-191.

Wastowski DA. Química da Madeira. Rio de Janeiro: Interciência; 2018. ISBN 9788571934078.

Wilkes J. Variations in wood anatomy within species of Eucalyptus. IAWA Journal. 1988; 9(1):13-23.