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WOOD EVALUATION OF *Eucalyptus pellita* F.Muell. AND *Eucalyptus tereticornis* Smith AS POTENTIAL FOR PULP AND PAPER PRODUCTION[1]

AVALIAÇÃO DA MADEIRA DE *Eucalyptus pellita* F.Muell. E *Eucalyptus tereticornis* Smith COMO POTENCIAL PARA PRODUÇÃO DE POLPA E PAPEL[1]

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ABSTRACT - This paper aimed to determine the quality indexes for paper and cellulose based on the fiber features from two wood species of interest, *Eucalyptus pellita* and *E. tereticornis*. The mean annual increment (IMA) was calculated by measuring DBH and Height (25 years), a 10 cm disk from each tree was collected for density determinations and anatomical studies for cellulose and paper. Tree height, trunk diameter at 1.30 m in height (DBH), and volume per tree were higher in *E. pellita* when compared to *E. tereticornis*. The volume per hectare and average annual increment were higher in *E. tereticornis* compared to *E. pellita*. Based on the quality indexes calculated from fiber dimensions, we did not observe any variation in flexibility coefficient between the two species; however, this index was more heterogeneous with the lowest value in *E. tereticornis* pith. *Eucalyptus pellita* showed a lower wall fraction value, including a lower overall value in pith. The Runkel index was lowest in *E. pellita*; in addition, the highest value, above 1, was found in pith position in *E. tereticornis*. The slenderness index did not differ between species and it was not possible to detect which had performed better. The results indicate that *E. pellita* and *E. tereticornis* have potential for the production of paper with high mechanical resistance, such as writing, printing and packaging. The wood of both species has potential for use in producing paper and cellulose.

Key words: Wood anatomy; Wood density; Quality indexes for paper.

RESUMO - O presente trabalho teve como objetivo determinar os índices de qualidade para papel e celulose com base nas características das fibras de *Eucalyptus pellita* e *E. tereticornis*. O incremento médio anual (IMA) foi calculado com a medida do DAP e Altura (aos 25 anos), um disco de 10 cm da cada árvore foi colhido para as determinações da densidade e estudos anatômicos. A altura da árvore, o diâmetro do tronco a 1,30 m de altura (DAP) e o volume por árvore foram maiores em *E. pellita* quando comparados a *E. tereticornis*. O volume por hectare e o incremento médio anual foram maiores em *E. tereticornis* em comparação com *E. pellita*. Com base nos índices calculados a partir das dimensões das fibras, não observamos variação no coeficiente de flexibilidade entre as duas espécies; entretanto, esse índice foi mais heterogêneo com o menor valor na medula de *E. tereticornis*. *Eucalyptus pellita* apresentou menor valor de fração de parede, incluindo menor valor geral na medula. O índice de Runkel foi o mais baixo em *E. pellita*; além disso, o valor mais alto, acima de 1, foi encontrado na posição medular de *E. tereticornis*. O índice de esbeltez não diferiu entre as espécies não sendo possível detectar qual obteve melhor desempenho. Os resultados indicam que *E. pellita* e *E. tereticornis* apresentam potencial para a produção de papéis com alta resistência mecânica, como escrita, impressão e embalagem. A madeira das duas espécies tem potencial para uso na produção de papel e celulose.

Palavras-chave: Anatomia da madeira; Densidade da madeira; Índices de qualidade para papel.

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1 INTRODUCTION

Since the 1960s, pulp production in Brazil has grown at rates higher than those envisaged by other world producers. According to Indústria Brasileira de Árvores-IBÁ (2019), Brazil is the second largest producer of pulp in the world, behind only the United States, and it occupies the eighth position in world in paper production. At this rate, Brazil has experienced an average growth of 8.0% in pulp production.

For paper and cellulose production, Gomide et al. (2005) report that the most used raw material is *Eucalyptus* spp. wood, owing to high yield in short fiber cellulose and excellent physical and chemical wood properties. Traditionally, Brazil has used *Eucalyptus* wood for production of paper and cellulose, e.g., *E. grandis*, *E. saligna* and hybrid of *E. grandis* x *E. urophylla*. In São Paulo, more than 20 species of *Eucalyptus* were planted on an experimental level (Gurgel-Garrido et al., 1997) to test their potential for pulp and paper production. Here, we highlight two species for a closer examination of this potential: *Eucalyptus pellita* F. Muell and *Eucalyptus tereticornis* Smith.

Menucelli et al. (2019) studied the potential of *E. pellita* and *E. tereticornis* wood as raw materials for bioenergy based on higher heating value, and they presented some characteristics of the species. *Eucalyptus pellita* has been planted for wood in many areas of the subtropics and tropics, including Papua, New Guinea, Indonesia, India, Kenya, Congo, and Brazil (Fern et al., 2014). *Eucalyptus tereticornis* was one of the first *Eucalyptus* trees exported from Australia, and it is currently grown all over the tropics on a large scale in both India and Brazil (Brink, 2008). Foelkel (2009a) highlights the two species as used in paper and cellulose production, although they are not the most used for this purpose.

In general, for a species to be accepted in the pulp and paper sector, trees must undergo genetic improvement programs. Species selection depends on such factors as growth rate, as represented by mean annual increment (Reis et al., 2015) and basic wood density (Raymond and Muneri, 2001). Most breeding programs consider wood density as one of the criteria for selecting trees for pulp production, as is the case with the pulp industry, which in eucalyptus breeding programs uses this characteristic of wood in addition to related to the growth of trees (Borralho et al., 1993; Mokfienski et al., 2008; Santos et al., 2012; Miranda and Pereira, 2015).

However, it is well known that other properties must also be evaluated, such as chemical and anatomical composition of wood, as well as the formation of cellulosic pulp (Carrillo et al., 2018; Riki et al., 2019). The relationships between paper and raw material properties, namely wood chip density, have been studied by several authors (Paavilainen, 1989; Paavilainen, 2000; Downes et al., 2003; Kibblewhite et al., 2003; Santos et al., 2008a). In addition, it is known that the quality of paper is directly influenced by anatomical features of fibers and their fraction in pulp. Fibres influence paper sheet properties including tensile, stretch, burst and tear strengths (Kiaei et al., 2014). Woods with thicker-walled fibers, for example, produce a more porous and opaque paper, providing better printing capacity. On the other hand, fibers with thinner walls produce denser papers with high resistance to breakage and tension (Wiedenhoeft and Miller, 2005). A close relationship is observed between fiber and paper production. In general, shorter fibers contribute to good paper sheet formation, while longer fibers favor tear resistance (Gomide et al., 2005). Additionally, according to Alves et al. (2011), the presence of vessels favors penetration and impregnation of chips by kraft cooking liquor. However, a high vessel percentage in wood is undesirable as it directly implies lower density, which provides less productivity in the factory and greater specific consumption of material.

The most important “Fibre Derived Values” in pulping are Runkel Ratio (RR), Slenderness Ratio (SR) and Flexibility Coefficient (FC). These determine much more the potential of any species for paper production than the absolute dimensions of the fibers (Ververis et al., 2004).

The Runkel ratio is the ratio of fiber cell wall thickness to its lumen that determines the suitability of a fibrous material for pulp and paper production. If a wood has a high Runkel ratio, it means that its fiber will be stiff and less flexible and poor bonding ability. High Runkel ratio fibers produce bulkier paper than fibers with low Runkel ratio. According to Xu et al. (2006) and Enayati et al. (2009), among other authors, this ratio must be 1 to be classified as a good quality for cellulose and paper production. The flexibility coefficient is the ratio between the width of the lumen and the fiber diameter expressed as a percentage. This coefficient provides the bonding strength of individual fibers and therefore the tensile strength and bursting properties (Wangaard, 1962). The ratio between the length of fiber and its diameter determines the tear resistance of a paper (Varghese et al., 1995).

The main objective of this study was to determine some wood characteristics that affect the quality and potential of *Eucalyptus pellita* and *Eucalyptus tereticornis* of 31-years-old in homogeneous plantings for paper and cellulose purposes. Thus, it was evaluated the mean annual increment, wood density, anatomical features and some quality indexes for paper and cellulose based on fiber features. This work seeks to increase knowledge about these two species, which is currently quite scarce. Thus, it could provide plantation owners of these species with information that would allow them to choose the best destination for their timber and, as a consequence, greater added value.

2 MATERIALS AND METHODS

2.1 Species and planting area

The species were chosen because they are provenance and progeny tests of two *Eucalyptus* species with same age, planted in the same region (Gurgel Garrido et al., 1997), already genetically evaluated (Zanata et al., 2010; Macedo et al., 2013), and available for other studies. Wood samples of *Eucalyptus tereticornis* and *Eucalyptus pellita* were collected from 10 trees of each species in the municipality of Batatais, São Paulo State, Brazil, coordinates 47°31′S and 47°21′W, in elevation 880m (Zanata, 2009). The *E. pellita* plantation was established in 1986 at a spacing of 4 × 4 m with seeds from Helenvale and Cole, Australia. The *E. tereticornis* plantation was established in 1986 at a spacing of 3 × 2 m with seeds from Helenvale, Ravenshoe and Mt. Garnet, Australia. Soil in the experimental area was classified as dystroferric Red Latosol (Oxisol) and dystrophic Red-Yellow Latosol, a medium texture (Santos et al., 2018). Figure 1 presents an overview of plantings and Table 1 shows dendrometric characterization (height and diameter at breast height) of the 10 trees of with 31-year-old *E. pellita*. and *E. tereticornis*.

Figure 1. Overview of 31-year-old plantations in the Floresta Estadual de Batatais. a. *Eucalyptus pellita*. b. *Eucalyptus tereticornis*.

Figura 1. Visão geral das plantações de 31 anos na Floresta Estadual de Batatais. a. *Eucalyptus pellita*. b. *Eucalyptus tereticornis*.

2.2 Mean annual increment

Wood density was determined on samples from diameter at breast height by the ratio between the oven-dry mass and the green volume of samples (Glass and Zelinka, 2010).

$$\text{Volume} = 0.0000785398163 * \text{DBH}^2 * \text{H} \quad Eq.1$$

where DBH = diameter at breast height, 1.3 m from the ground, and H = height.

Then, the volume per hectare was calculated according to the spacing (4 x 4 m) in *E. pellita* and (3 x 2 m) in *E. tereticornis* by multiplying the number of plants by the average tree volume, and, finally, mean annual increment was calculated by dividing volume per hectare by planting age at the time of measurement (25 years, 1986-2011).

2.3 Sampling for wood density and anatomical ratios for pulp and paper

In 2017, selected trees were felled, and discs 10 cm in thickness were removed from the base of each tree to obtain specimens for wood density, anatomy and quality indexes for pulp and paper. Three radial positions were established: the nearest part of trunk center, which was designated as pith, a middle position, and a position close to the bark, which was designated as bark.

2.4 Apparent density (D_{12})

Apparent density was determined in acclimatized specimens by the ratio of their mass and volume at the current moisture content (MC). We used the model proposed by Kollmann and Côté (1968) to obtain the value to nominal 12 % equilibrium moisture content (EMC) (D_{12}) (see Eq. 2 and 3). The density of the model used at any moisture content ($D_{u\%}$, ranging from 0 to 25 % MC) is relative to the density at 0 % MC (D_0). Then, D_{12} was calculated from D_0 using the following two equations:

$$D_{u\%} = D_0\,(1 + 0.01_{u\%})\left(1 - \frac{0.0084_{u\%}D_0}{1 + 0.28D_0}\right) Eq.2$$

$$D_{12\%} = \frac{1.12D_0 + 0.2007D_0^2}{1 + 0.28D_0} \qquad Eq.3$$

2.5 Anatomical analyses

We cut small portions of wood from each sample for maceration using Franklin's method (Berlyn and Miksche, 1976). Wood fragments were stained with aqueous safranin and mounted temporarily in a solution of water and glycerin (1:1). Samples of 2 cm^3 were softened in boiling water and glycerin (4:1) for 1-2 hours. From these samples, transverse and longitudinal sections 20µm in thickness were obtained with a sliding microtome. Sections were bleached with sodium hypochlorite (60%), washed thoroughly in water, and stained with 1% safranin (Johansen, 1940). Measurements followed the recommendations of the IAWA Committee (1989). Quantitative data are based on at least 25 measurements for each characteristic from each tree, thus fulfilling statistical requirements for the minimum number of measurements.

2.6 Anatomical ratios for pulp and paper

From values of length (L), diameter (D), lumen diameter (d) and fiber wall thickness (w), we calculated the following ratios for pulp and paper: Flexibility coefficient (FC), Wall proportion (WP), Runkel ratio (RR), and Slenderness ratio (SR) (Pirralho et al., 2014):

$$\text{Flexibility coefficient} = \frac{d}{\text{D}} \text{ x } 100 \qquad Eq.4$$

$$\text{Wall proportion} = \frac{2w}{D} x\ 100 \qquad Eq.5$$

$$\text{Runkel ratio} = \frac{2w}{d} \qquad Eq.6$$

$$\text{Slenderness ratio} = \frac{L}{D} \qquad Eq.7$$

2.7 Data analyses

We initially undertook descriptive statistical analyses and used Box Plot graphics to detect outliers. Thus, values 1.5 times higher than the 3rd quartile and values 1.5 times lower than the 1st quartile were excluded from the analysis. Normality tests were performed to check the distribution of data, and when a normal distribution was not observed, data were square root-transformed. For radial variation, a parametric analysis of variance (one-way analysis of variance (ANOVA)) was performed. When a significant difference was observed, Tukey's test was used to identify pairs of significantly different means. For comparing between two species, a *t* test was used.

3 RESULTS

Tree height, trunk diameter at 1.30 m in height (DBH), and volume per tree were higher in *E. pellita* when compared to *E. tereticornis*. The volume per hectare and average annual increment were higher in *E. tereticornis* compared to *E. pellita* (Table 2).

In *E. pellita*, wood density close to the bark and in intermediate position did not differ and was higher than wood density close to the pith. In *E. tereticornis*, density increased from the pith to the bark. *Eucalyptus pellita* presents a denser wood than *E. tereticornis* (Table 3).

In *E. pellita*, wider diameter vessels occurred close to the bark and were narrower, but with no statistical difference in intermediate and pith positions. In *E. tereticornis*, vessel diameter increased from pith to bark. *Eucalyptus tereticornis* has wider vessels than *E. pellita*. Vessel density showed the same behavior in both species, decreasing from pith to bark. *Eucalyptus pellita* has a higher vessel density than *E. tereticornis* (Table 3). In *E. pellita*, higher rays occurred close to the pith and in intermediate position.

In contrast, in *E. tereticornis*, higher rays were reported in intermediate and bark positions. *Eucalyptus tereticornis* has higher rays than *E. pellita*. Wider rays occurred in intermediate position in *E. pellita*. *Eucalyptus tereticornis* has wider rays in the bark when compared to *E. pellita*. In *Eucalyptus pellita*, a higher ray frequency occurred in intermediate position. Most frequent rays occurred in intermediate and pith positions in *E. tereticornis*. Higher ray frequency was observed in *E. pellita* when compared to *E. tereticornis* (Table 3).

In *E. pellita*, longer fibers occurred close to the bark. In *E. tereticornis*, fiber length did not differ radially. *Eucalyptus tereticornis* has longer fibers than *E. pellita*. Fibers with thicker walls occurred in intermediate and bark positions in *E. pellita*. In *E. tereticornis*, fiber wall thickness did not differ radially. *Eucalyptus tereticornis* has thicker-walled fibers than *E. pellita* (Table 3).

In *E. pellita*, flexibility coefficient was higher near the pith and did not differ in the other two positions. In *E. tereticornis*, a higher flexibility coefficient value was observed close to the bark. No difference was observed between the two species. The wall fraction was higher in the two most external positions in *E. pellita* and showed no variation in *E. tereticornis*. Higher wall fraction was observed in *E. tereticornis* when compared to *E. pellita*. The Runkel index was higher in the two most external positions in *E. pellita*. In *E. tereticornis*, the Runkel index value close to the pith differed from that close to the bark. *Eucalyptus tereticornis* showed a higher Runkel index value than that of *E. pellita*. The slenderness ratio did not vary radially in, or between, the two species (Table 3).

Table 1. Dendrometric data of ten 31-year-old *Eucalyptus pellita* and *Eucalyptus tereticornis* trees used for wood density and anatomy determination.

Tabela 1. Dados dendrométricos de dez árvores de *Eucalyptus pellita* e *Eucalyptus tereticornis* com 31 anos de idade usados para determinação da densidade e anatomia da madeira.

	Eucalyptus pellita		*Eucalyptus tereticornis*	
Tree	Height (m)	DBH (cm)	Height (m)	DBH (cm)
1	22.70	24.00	20.50	19.50
2	17.30	18.50	17.70	16.00
3	17.70	21.00	14.20	14.00
4	15.30	25.00	20.70	16.00
5	20.40	36.00	17.00	15.00
6	15.70	21.00	19.10	16.50
7	12.70	30.00	25.10	21.00
8	16.00	24.50	24.57	25.00
9	16.40	22.50	19.50	16.00
10	12.70	23.50	23.32	18.00
Mean	16.69	24.60	20.17	17.70

Table 2. Silvicultural data and mean annual increment in 25-year-old *Eucalyptus pellita* and *Eucalyptus tereticornis*.

Tabela 2. Dados silviculturais e incremento médio anual em *Eucalyptus pellita* e *Eucalyptus tereticornis* com 25 anos.

	Eucalyptus pellita	*Eucalyptus tereticornis*
Height (m)	2 (20.45a) 30	1.5 (19.3b) 33
DBH (cm)	1 (26.32a) 60	1 (16.29b) 40
Tree volume (m³)	0.621a	0.242b
Volume per hectare (m³.ha^{-1})	234.38	403.33
Mean annual increment (m³.ha^{-1}.year^{-1})	9.37	16.13

Table 3. Radial variation and comparison among wood density, anatomical features and quality indices for paper and cellulose in 31-year-old *Eucalyptus pellita* and *Eucalyptus tereticornis* wood.

Tabela 3. Variação radial e comparação entre densidade da madeira, características anatômicas e índices de qualidade para papel e celulose na madeira de *Eucalyptus pellita* e *Eucalyptus tereticornis* aos 31 anos.

	Radial variation						Means between three radial positions	
		Eucalyptus pellita			*Eucalyptus tereticornis*		*Eucalyptus pellita*	*Eucalyptus tereticornis*
	Pith	Inter	Bark	Pith	Inter	Bark	Mean	Mean
ρ 12% (g.cm^{-3})	0.812b	0.987a	1017a	0.677c	0.823b	0.899a	0.939A	0.800B
VD (μm)	73b	76b	104a	76c	87b	103a	85B	90A
Vd (nºmm^{-2})	18a	16b	12c	16a	13b	11c	15A	13B
RH (μm)	195a	195a	184b	206b	219a	221a	192B	215A
RW (μm)	19b	21a	19b	24b	25b	28a	19B	26A
RF (nºmm^{-1})	16b	17a	16b	16a	16a	14b	16A	15B
FL (μm)	866b	904b	960a	995a	989a	998a	910B	994A
FD (μm)	13.09b	14.14a	14.16a	14.62a	14.84a	14.98a	13.80B	14.80A
FL (μm)	7.26b	7.49ab	7.55a	7.51b	8.16a	8.44a	7.44B	8.06A
FWT (μm)	2.9b	3.3a	3.3a	3.6a	3.6a	3.8a	3.1B	3.7A
FC	0.55a	0.51b	0.53b	0.52b	0.45c	0.56a	0.54A	0.55A
WP (%)	44.39b	46.88a	47.11a	52.67a	48.88a	49.10a	45.90B	49.60A
RR	0.81b	0.88a	0.89a	1.07a	0.93ab	0.86b	0.87B	0.96A
SR	66.27a	64.64a	68.41a	70.51a	67.52a	67.54a	66.64A	68.46A
F(%)	41.58c	44.25b	46.08a	45.45ab	46.08a	44.25b	43.97B	45.26A
V (%)	18.91a	14.56b	12.97c	13.42b	14.5a	12.97b	15.48A	13.65B
AP (%)	14.64a	12.73b	11.72c	12.40ab	12.73a	11.72b	13.03A	12.28B
RP (%)	24.96b	28.44a	29.21a	28.7b	26.6c	31.04a	27.54B	28.79A

Pith = wood near the center of the trunk, Inter = wood between pith and bark (intermediate position), Bark = wood closest to the bark. ρ 12% = wood density at 12% humidity; VD = vessel diameter; Vd = vessel density; RH = ray height; RW = ray width; RF = ray frequency; FL = fiber length; FD = fiber diameter; FL = fiber lumen diameter; FWT = fiber wall thickness; FC = flexibility coefficient; WP = wall fraction; RR = Runkel ratio; SR = slenderness ratio. F = fiber percentage; V = vessel percentage; AP = axial parenchyma percentage; RP = radial parenchyma percentage. In the same line, for radial variation, the values of F and P are presented by Tukey test (differences in lowercase letters); for the comparison between species, values of *t* and P are presented by the *t* test (uppercase letters).

Medula = madeira próxima ao centro do tronco, Inter = madeira entre a medula e a casca (posição intermediária), Casca = madeira mais próxima da casca. ρ 12% = densidade da madeira a 12% de umidade; VD = diâmetro do vaso; Vd = densidade do vaso; RH = altura do raio; RW = largura do raio; RF = frequência do raio; FL = comprimento da fibra; FD = diâmetro da fibra; FL = diâmetro do lúmen da fibra; FWT = espessura da parede da fibra; FC = coeficiente de flexibilidade; WP = fração da parede; RR = razão Runkel; SR = proporção de esbeltez. F = porcentagem de fibra; V = porcentagem de vasos; AP = porcentagem do parênquima axial; RP = porcentagem do parênquima radial. Na mesma linha, para a variação radial, os valores de F e P são apresentados pelo teste de Tukey (diferenças em letras minúsculas); para a comparação entre as espécies, os valores de t e P são apresentados pelo teste t (letras maiúsculas).

4 DISCUSSION

According to Revista da Madeira (2007), a species is considered to have fast growth when it has productivity greater than 14 $m^3.ha^{-1}.year^{-1}$. Based on this metric, only *E. tereticornis* (16.13 $m^3.ha^{-1}.year^{-1}$) would be considered as fast-growing since *E. pellita* showed 9.37 $m^3.ha^{-1}.year^{-1}$. However, we emphasize that *E. pellita* was planted at 4 x 4m spacing, and certainly this type of planting influenced the result in comparison with *E. tereticornis*. According to Leles et al. (2001), the largest wood production per hectare was obtained in the 3 x2 spacing for *E. camaldulensis* and *E. pellita*, having observed a continuous decrease with increasing spacing. Neto et al. (2003) report spacing as one of factors that interferes with growth diameter and, consequently, wood properties. While wider spacing between trees produces a larger amount of wood, as a result of greater growth diameter, in a smaller spacing, the greater production of biomass may be related to higher number of plants per area. In our study, this is exactly what happened because despite the greater volume per hectare and greater mean annual increment having occurred in *E. tereticornis*, taller, wider trees and, therefore, greater individual volume occurred in *E. pellita*. Thus, we emphasize that differences must be analyzed based on the different spacing of each species: *E. pellita* was planted at 4 x 4 m spacing; thus, a tree = 0.621 m^3 occupies an area of 16 m^2. *E. tereticornis* was planted at 3 x 2 m spacing; thus, a tree = 0.242 m^3 occupies an area of 6 m^2. In summary, based on the results of our study, we believe that growth results are adequate to consider both species for paper and cellulose, since the indices resulting from our calculations show that both species can be used to produce paper with high mechanical resistance, such as writing, printing and packaging, as will be detailed below in the discussion of each index.

Wood density and pulp yield have been considered fundamental parameters in tree selection programs for pulping, in addition to tree growth (Silva et al., 2009; Borralho et al., 1993), and density is also a determining factor for the type of paper to be produced. Although, many studies have been showing that the density is vital for quality of pulp production (Scanavaca and Garcia, 2004; Trugilho et al., 2005; Santos et al., 2008b; Horáček et al., 2017), many others have been reported no correlation or weak correlation between these two properties (Miranda and Pereira, 2001; Seca and Domingues, 2006; Mokfienski et al., 2008; Silva et al., 2009). In this context, we highlight that the two species we studied have high wood density, *E. pellita* (0.939 $g.cm^{-3}$) and *E. tereticornis* (0.800 $g.cm^{-3}$), and a significant difference can be observed between them.

In agreement with Santos and Sansígolo (2007) we can differentiate the cellulose pulps considering its applications for printing and writing paper or absorbent paper. Thus, pulps from wood with lower basic densities are ideal for the first case. Pulps from denser hardwoods, like the present study, are ideal for absorbent paper, because they present fibers with greater thickness, therefore a greater potential of liquid absorption, and greater mass per length of fibers (Santos and Sansígolo, 2007; Mokfienski et al., 2008).

The density and diameter of vessels also influence paper quality. According to Foelkel (2009), higher density and diameter of vessels are undesirable in the production of quality writing paper. However, in general, in *Eucalyptus* species, these vessel features do not represent major problems for paper quality. It is interesting to note that wood used in paper production almost entirely comes from young trees. Similar to fibers, vessels also vary during secondary growth, and in general, an inverse relationship is noted between vessel density and diameter toward the bark, with narrower vessels in higher proportion in younger regions of the wood (Baas et al., 2004; Lachenbruch et al., 2011), a result highlighted in the present study (Tab. 3). Therefore, because the wood typically used for paper is young, it has narrower vessels, but the highest vessel proportion. When analyzing our results for vessels, *E. tereticornis* has vessels of a larger diameter, but with a lower density than *E. pellita*. The literature refers that a vessel frequency between 4 and 27 vessels per mm^{-2} with a tangential diameter between 170 μm and 221 μm is the best suit for pulp production (Dadswell, 1972; Carvalho, 1962; Hudson et al., 1996; Wilson et al., 1998). In general, the values found in this work were at the lower range of those reported above. In what concerns to *E. tereticornis* our results show that vessels diameter despite presenting a very identical value compared to Pirralho et al. (2014), its frequency, in average, is 50% lower (13 compared to 27). A variation in fiber dimensions is expected. Shorter cells with smaller diameter and thinner walls closer to the pith are features that tend to increase for adult wood close to the bark (Lachenbruch et al., 2011). Fiber dimensions did not change radially in *E. tereticornis*; only fiber lumen diameter was smaller next to the pith. In *E. pellita*, however, we saw more changes, with larger dimensions in all features in wood next to the bark.

With the exception of slenderness index in both species and wall fraction in *E. tereticornis*, the other quality ratios for paper varied statistically from pith to bark. It is worth mentioning that radial variations in the ratios do not always correspond to variations in the quality classes.

For some quality indexes, ideal values have been established for decades. Barrichelo and Brito (1976) proposed five groups for Runkel index: fibers classified in group I (up to 0.25) are considered excellent for paper, group II (0.25-0.50), very good, group III (0.5-1.0), good, group IV (1.0-2.0), regular, and in group V (above 2.0), they should not be used for paper production in view of low degree collapse. Thus, *E. pellita* and *E. tereticornis* present indexes considered suitable for use in cellulose production, as they fall into group III, with average values of 0.87 and 0.96 respectively. According to Foelkel et al. (1978), values greater than 1.5, are not recommended for industry since good quality cellulose would have an index below 1.

For wall fraction, both species are within the limit of up to 60% recommended by Foelkel et al. (1978), *E. pellita* at 45.90% and *E. tereticornis* at 46.90%. In practice, when wall fraction is greater than 40%, industries admit that fibers will be more rigid and difficult to collapse, resulting in the production of looser mesh paper without much connection between fibers. Consequently, the corresponding paper is more porous, bulky, rough and absorbent (Foelkel, 2007).

No differences in flexibility coefficient were noted between species. Flexibility coefficient refers to the ease of union between the fibers, and according to Bektas et al. (1999), values between 0.50 and 0.75, as found in this study, classify the fibers as flexible, which when intertwined, tend to form highly resistant paper. Saikia et al. (1997) mention that species with good flexibility values, which we observed in *E. pellita* and *E. tereticornis*, are suitable for production of paper with high mechanical resistance, such as writing, printing and packaging.

Slenderness ratio determines the tearing property of paper. High value of slenderness ratio of fibres provides well bonded and better formed paper (Ashori and Nourbakhsh, 2009). We did not observe differences in slenderness index, neither in radial variation, nor between species. Considering that values more than 33 is good for pulp and paper production (Xu et al., 2006) the studied species could be classified as good for this purpose (66.64 for *E. pellita* and 68.46 for *E. tereticornis*).

5 CONCLUSIONS

Both species have potential for use in the production of paper and cellulous. Based on wood density, both species seem more indicated for the production of absorbent paper. The dimensions and frequencies vessels do not seem to impair quality in the two types of paper and cellulose. Based on the quality indexes calculated from fiber dimensions, we did not observe any variation in the flexibility coefficient between species; however, this index was more heterogeneous with the lowest value in the median position of *E. tereticornis.* The Runkel index showed that both species can be considered suitable for the production of pulp, being classified in the class of good. However, it should be noted that these are at the upper limit of the class with values close to the regular one. The slenderness index did not differ between species, and owing to this value, it was not possible to point out which species had the best performance. The results obtained with *E. pellita* and *E. tereticornis* show that both species can be used to produce paper with high mechanical resistance, such as writing, printing and packaging.

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