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Wood quality for kraft pulping of *Eucalyptus globulus* origins planted in Uruguay

Qualidade da madeira para polpa celulósica kraft de *Eucalyptus globulus* plantados no Uruguai

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Resumo

A madeira *Eucalyptus globulus* é uma importante matéria-prima para produção de polpa celulósica kraft. O objetivo deste trabalho foi avaliar diferentes materiais genéticos de *E. globulus* em termos de propriedades da madeira e polpa celulósica. Os resultados mostram que os valores de densidade básica podem ser considerados normais para madeiras destinadas à produção de polpa celulósica; as procedências com as maiores densidades básicas são originadas do sul do estado de Victoria; as dimensões de fibras indicam que todos os materiais avaliados podem ser utilizados para produção de polpa celulósica kraft; o teor de holocelulose variou de 69 a 72%; os maiores rendimentos depurados foram obtidos para os materiais do sul do estado de Victoria.

Palavras-chave: *Eucalyptus globulus*, Qualidade da madeira, Densidade básica, Polpa celulósica, Polpa kraft, Dimensões de fibra, Composição química, Refino, Propriedades físicas

Abstract

Eucalyptus globulus is an important raw-material for kraft pulping and has a wide geographical distribution. The objective of this paper was to evaluate *E. globulus* origins in terms of their wood and pulp properties. The results showed that wood density values for the origins are within the values considered advisable for kraft pulp production; origins with the highest wood density were from the south of Victoria state; fiber dimensions indexes obtained in this study allow us to infer that all origins are suitable for paper production; holocellulose content varied from 69 to 72%; the highest screened yield values correspond to the origins from south Victoria.

Keywords: *Eucalyptus globulus*, Wood quality, Basic density, Pulp, Kraft pulp, Fiber dimensions, Chemical composition, Refining, Pulp strength

INTRODUCTION

Eucalyptus globulus Labill. ssp. *globulus* is original of Tasmania Island, Wilson's Promontory and the coast of the state of Victoria. It is found from 38°30' to 43°30'S latitude and 0 to 330 m altitude (FAO, 1981). This species, together with *E. robusta*, was among the first *Eucalyptus* to be introduced in Brazil, (GONZAGA *et al.*, 1984a). BARRICHELO and FOELKEL (1976) produced kraft pulp from its wood obtaining good results for tensile strength, bursting and stretch, results similar to those obtained from *E. saligna* and *E. grandis*. Several authors show that *E. globulus* wood is easily pulped and high values of tensile and bursting resistance are also easily achieved (FOELKEL, 1974; QUEIROZ, 1972; ZÁRATE and GIRONDA, 1980; BARRICHELO and BRITO, 1983; CÁCERES, 1983; GONZAGA *et al.*, 1984a; GONZAGA *et al.*, 1984b; KIBBLEWHITE *et al.*, 2000). *E. globulus* pulp is easily bleached and also used in the production of printing and writing paper. During the kraft pulping process, it provides slightly higher pulp yield and better mechanical characteristics than the soda process.

E. globulus stands out for its low lignin content and high content of total pentosans. The lignin content gives an idea of the difficulty in pulping while the pentosans are related to paper properties, which are dependable on the interbonding among fibers (QUEIROZ, 1972). Results from several studies show that *E. globulus*

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presents the highest pulp yield of all other *Eucalyptus* species. These values are a consequence of its low lignin content, which is usually inversely related to pulp yield. In general, pulp resistance increases with refining levels for most species. According to the literature, the mechanical properties of *E. globulus* pulp (except tear index values) are better than those of other *Eucalyptus* species. This *E. globulus* advantage could be explained, among other reasons, by its lower lignin content and mainly by its higher content of hemicellulose (QUEIROZ, 1972). According to Ratnieks, cited by Ferreira *et al.* (1997), pulps that develop resistance during refining are those with higher content of hemicellulose. A high content of hemicellulose favors the connection among fibers, while a lower content favors properties not dependent on fiber bonding such as tear resistance. The importance of hemicellulose in the development of resistance properties is correlated to fibrillation.

Even though *E. globulus* has a wide geographical distribution, it is restricted to limited environment types, including (i) areas of low precipitation and altitudes with low temperatures; and (ii) areas of well-drained soils with high precipitation and when in competition for resources with other species. All these factors suggest a high degree of genetic variation in the species (TURNER *et al.*, 1983; DUTKOWSKI *et al.*, 1997). Several studies with this species have shown a substantial variation between and within origins, not only in growth rates but also in pulping characteristics. It has been established that, within its area of natural distribution (Australia), the best origins regarding pulp, are originated from a small area in the west coast of Tasmania (ORME, 1983). According to this author, despite the differences between ages, handling and environmental aspects, pulp properties are usually more uniform within origins than between them. These results have important implications for commercial plantations since the best origins in terms of pulp quality are from the west coast of Tasmania (ORME, 1983).

Results obtained by Turner *et al.* (1983) show that the pulping quality of *E. globulus* wood varies substantially depending on the origin. According to these authors, only a small part of the variation in wood properties has been explained in terms of age, climatic or geographical factors and there are signs that at least part of the variability be genetically driven. This explanation can be used for selecting and breeding pulpwood trees. Similar results showing variation in pulping characteristics caused by origin have been reported by several authors (FERRARI and MUGHINI, 1995).

The objective of this paper was to evaluate several *E. globulus* origins (Australia) in terms of (i) their wood properties and (ii) the properties of their pulp obtained using the kraft process.

MATERIAL AND METHODS

Material

This study evaluated seven *Eucalyptus globulus* ssp *globulus* origins from a six-year-old provenance trial planted in the north of Uruguay. The site coordinates are latitude 31° 40´ S, longitude 56° 00´, and altitude 100 m. The trial was planted on deep, well-drained sandy soils presenting very low fertility. The origins came from the following areas of Australia (Table 1).

Each origin was formed by a variable number of progenies (Table 1). From each progeny, 5 trees were selected. The selected trees were cut, and disks approximately 2.5 cm thick at the base, 25, 50, 75 and 100% of the commercial height (i.e. height at 6 cm over-bark diameter) were collected. The diameter of the disks without bark were measured and then cut into four wedges at angles of 90°. The first wedge was used to determine basic density; the second to evaluate the chemical composition of wood; the third used for kraft pulping and the fourth wedge was kept in case additional replications were required.

Table 1. List of origins evaluated. (Lista das procedências avaliadas)

Code	Locality		Latitude	Longitude	Altitude	Number of progenies
1	Jeeralangs-Yarram.	S. VIC	38.24	146.31	225	3
12	Pepper Hill Road.	NE.TAS	41.38	147.51	540	5
10	N Cape Barren Island.	E.Bass	40.22	148.13	20	4
14	Lake Leake RD Swansea.	E. TAS	42.01	147.58	300	5
21	Geeveston Area.	S. TAS	43.13	146.54	360	5
16	Moogara.	S.TAS	42.47	146.55	500	5
8	Flinders Island.	E.Bass	40.06	148	15	5

VIC: Estate of Victoria, Australia; TAS: Tasmania Island, Australia.

Chemical composition and fiber dimensions were determined for each origin using a composite sample obtained by grouping the respective wedges from each tree at different height from all progenies.

Methods

Basic density was determined using the hydrostatic scale method (ABNT NBR 11941). The basic average density of each tree was determined through the basic density of each wedge and their respective diameter without bark, using the following expression:

$$da = \frac{1}{2}\,\frac{(D^2_B+D^2_{25\%})(d_b+d_{25\%})+...+(D^2_{75\%}+D^2_{100\%})(d_{75\%}+d_{100\%})}{D^2_B+D^2_{100\%}+2(D^2_{25\%}+...+D^2_{75\%})}$$

where:
da = average basic density of the tree, g/cm³
D = inside-bark disk diameters at different percentage heights, cm
d = basic density of the wedges at different percentage heights, g/cm³

The following analyses were carried on for each origin to determine their chemical composition: Lignin Klason: TAPPI T 13 wd-74 ; Total extractive: TAPPI T 12 wd-82.

For each origin, fifty fibers were measured for their fiber length, wall thickness and lumen diameter. The Runkel index, felting and flexibility ratios and wall fraction were therefore obtained from fiber dimensions.

The progenies kraft pulping was accomplished in a rotative digester, with 8 capsules of 500 mL capacity each. A wood sample of each progeny was obtained from the same composite sample. The pulping conditions were: Wood sample, oven dry: 80 g; Active alkali charge (%) = 15 as Na_2O on oven dry wood; Sulfidity = 25 %; Maximum temperature = 170 °C; Time to reach maximum temperature = 90 min; Time at maximum temperature= 45 min; Liquor to oven dry wood ratio = 4/1 L/kg.

After pulping, screened yield, rejects content and Kappa number were determined (TAPPI T 236 om-85). Pulp from each origin was then refined in a centrifugal mill (Jokro Mühle) at 150 rpm, using 16g of oven-dried pulp per pot and 265 ml of water, at 9,000, 15,000 and 18,000 revolutions. The refining level was determined using the Schopper-Riegler scale (SCAN-M3:65). Samples for the physical-mechanical test, with approximate weight (grammage) of 60g/m2, were obtained in a Köthen-rapid trial-sheet maker apparatus and conditioned in acclimatized atmosphere, with a relative humidity of 50 ± 2% at 23 ± 2°C (TAPPI T 402 om-93). The physical-mechanical properties evaluated were: Apparent specific gravity: (TAPPI T 220 sp-96); Apparent specific volume: (TAPPI T 220 sp-96); Tensile index: (TAPPI T 494 om-96); Tensile energy absorption index: (TAPPI T 494 om-96); Tensile rigidity index: (TAPPI T 494 om-96).

RESULTS AND DISCUSSION

Figure 1 shows the average basic densities of the origins evaluated. All values are within those values reported in the literature for this species (BARRICHELO and FOELKEL, 1976; CÁCERES, 1983; KIBBLEWHITE *et al.*, 2000). These values are also within the recommended range for pulp production, i.e., from 0,450 to 0,650 g/cm³ (BARRICHELO and BRITO, 1976; FOELKEL *et al.*, 1975; FOELKEL, 1978; WEHR, 1991; FONSECA *et al.*, 1996; KRAMER, 1998). According to several authors, the use of wood with these basic density values promotes a relatively easy pulping process. This is due to (i) the good penetration of the liquor, (ii) the low proportion of vessel elements or parenchyma content in the wood, and (iii) the low contents of rejects and good resistance of the pulp. Figure 1 also indicates there were basic density differences between origins. Origins 1, 8 and 14 presented higher values (0,535, 0,521 and 0,527 g/cm³, respectively) when compared to origins 10, 12, 16 and 21 (0,514, 0,513, 0,513 and 0,511 g/cm³, respectively). The origins with the highest values of basic density are from the south of Victoria state (Origin 1), from the northeast of Tasmania (Origin 14) and from the Bass straight (Origin 8).

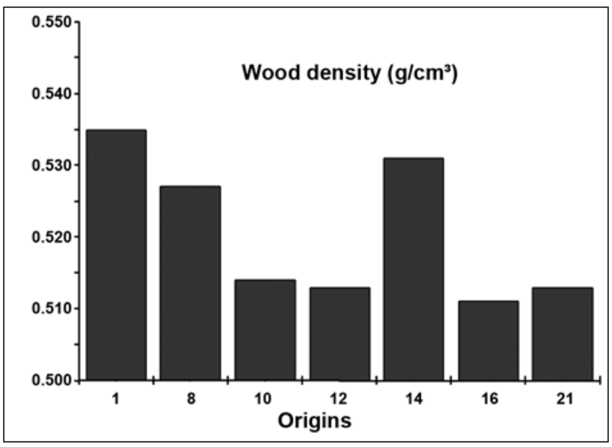

Figure 1. Average basic density of *Eucalyptus globulus* origins. (Densidade básica media das procedências de *Eucalyptus globulus*).

Fiber length was similar between origins, with values ranging from 0,880 to 0,940 mm, values similar to those reported in the literature (QUEIROZ, 1972; TOMAZELLO FILHO, 1985; FERRARI and MUGHINI, 1995) (Figure 2). Fiber width was also relatively constant between origins, with values ranging from 13.60 to 14.90 µm. These values are inferior to the typical values cited in the literature, which could be attributed to the young age of trees used in this study. Lumen diameters varied between 7,96 and 9,62 µm.

Figure 3 presents the relationships between fiber dimensions of different origins.

Figure 4 displays the wood chemical composition for each origin. The total lignin content varied from 23,8 to 26,0%; these values are higher than the most common values reported by other authors. In general, *E. globulus* wood is considered to have lower lignin content when compared to other *Eucalyptus* species (QUEIROZ, 1972; FOELKEL *et al.*, 1975; BARRICHELO and BRITO, 1976; BARRICHELO and BRITO, 1983; BARRICHELO and FOELKEL, 1976; CÁCERES, 1983; GAMOEDA, 1988; PALMER *et al.*, 1990; TEXEIRA and SOARES, 1992; and FERREIRA *et al.*, 1997). The holocellulose content varied from 69,0 to 72,0%; these values are a little lower than those cited in the literature. The total extractive content varied from 3,8 to 4,8%.

Figure 5 shows Kraft pulping results. The kappa number obtained from all pulps in the study ranged from 16,5 to 21,5. Since values above 20 can be considered high for bleachable grades and considering a kappa number about 18 as typical for *Eucalyptus* bleachable pulps, pulps from origins 14 and 16 would require higher alkali charges, which would lead to a lower yield.

Given the relationship between Kappa number and screened yield, the ratio of these parameters was calculated to enable comparisons of origins with different Kappa numbers. This relationship can be considered a measurement of the pulping process selectivity once the screened yield can be considered as a representation of the carbohydrate content and the kappa number a measurement of lignin content. This relationship demonstrates that origins 8, 10, 12 and 21 presented the best pulping performance (high carbohydrate retention and lignin removal). These origins also had the smallest values of basic density, which may be related to an easier cooking liquor penetration and subsequent lignin removal. These differences in impregnation easiness and liquor diffusion can be influenced by the differences in wood porosity between origins associated to the different fiber diameter and wall thickness values.

Figure 6 displays the Schopper-Riegler degree values, apparent specific gravity, apparent specific volume and tensile index by revolution number. As expected from previous studies (FOELKEL, 1974; ZÁRATE and GIRONDA, 1980; REINOSO, 1983; BARRICHELO and BRITO, 1983; GONZAGA *et al.*, 1984a; GONZAGA *et al.*, 1984b; LUDEÑA LARA and BUENO ZÁRATE, 1989; SANSIGOLO and CURVELO, 1995; FERREIRA and FIGUEREDO, 2001), the Schopper-Riegler degrees increased as the revolution number (refine time or energy refine consumption) increased. The comparative analysis of the Schopper Riegler degrees shows different refining behaviors because some origins refined faster than others (e.g. origins 1, 10 and 12).

The apparent specific gravity increased with increasing refining time, which is consistent with results from several *Eucalyptus* species studies. Refining increases the degree of fiber bonding, therefore making sheets more compact per unit of volume and, consequently, increasing their density (FOELKEL, 1974; BARRICHELO and FOELKEL, 1976; BUGAJER, 1979; BARRICHELO and BRITO, 1983; REINOSO, 1983; GONZAGA, 1984; TEXEIRA and SOARES, 1992; SANSIGOLO and CURVELO, 1995; FERREIRA and FIGUEREDO, 2001; KIBBLEWHITE *et al.*, 2001).

Pulp tensile index of various origins was similar to those cited by several authors in similar experimental conditions (QUEIROZ, 1972; FOELKEL, 1974; BARRICHELO and FOELKEL, 1976; BARRICHELO and BRITO, 1976; BARRICHELO and BRITO, 1983; GONZAGA, 1984; VAN WYK and GERISCHER, 1994). Origins tended to show a higher tensile index as the time of refining increased (despite a few discrepant values). At 9,000 revolutions, the highest tensile indexes were obtained by origins 10, 12 and 14 (74, 76 and 75 N.m/g, respectively) while the smallest indexes were obtained by origins 16 and 21 (49 and 57 N.m/g, respectively). At 18,000 revolutions all tensile indexes were similar and ranged between 70 and 80 N.m/g. In general, origins 1, 10, 12, and 14 showed the highest tensile indexes, which could be explained by their high felting indexes (F.I.). These results agree with those obtained by Tamolang and

Wangaard, 1961; Wangaard *et al.*, 1966; Foelkel and Barrichelo, 1975; Repetti, 1990; Paula and Alves, 1980. Origins 16 and 21, like it was observed for specific gravity, showed the highest differences in tensile index when passing from 9,000 to 18,000 revolutions.

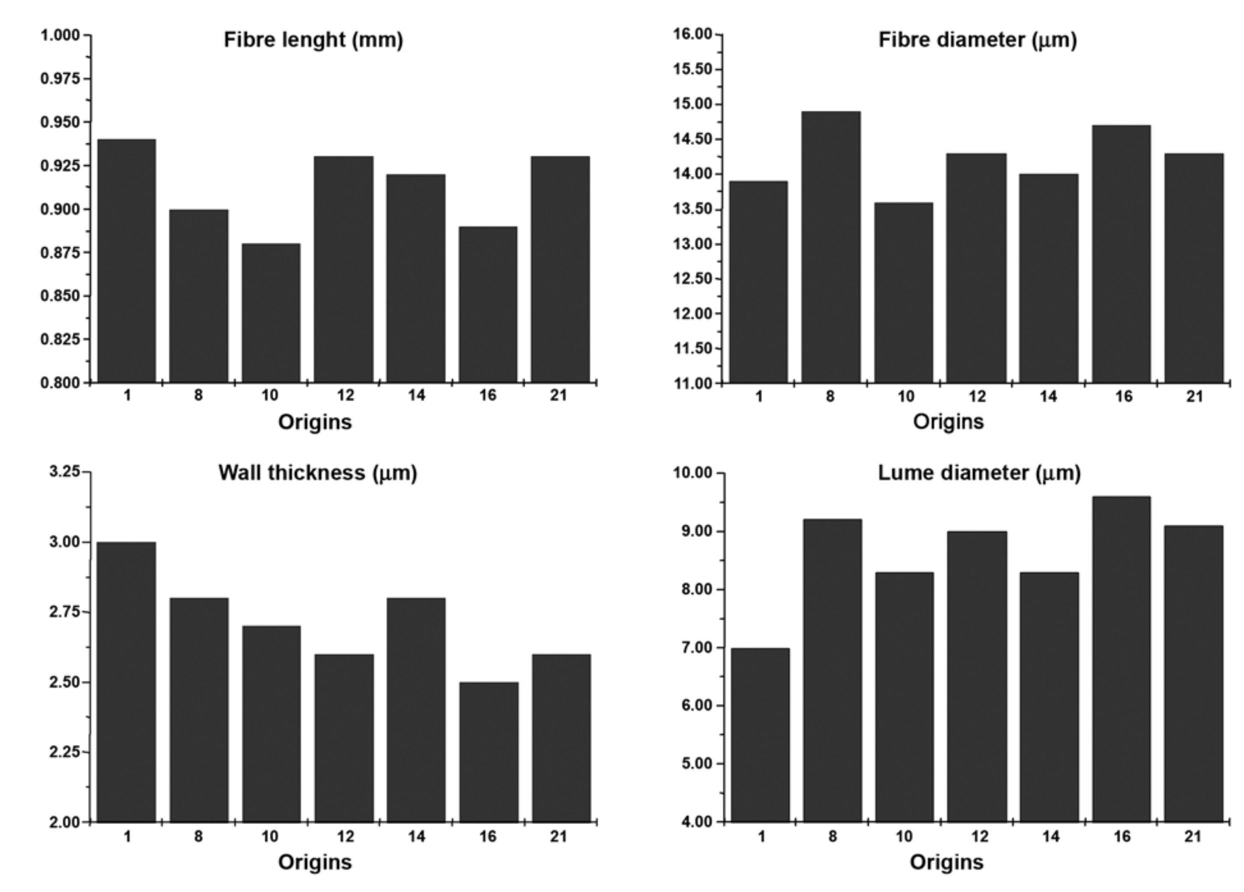

Figure 2. Fiber dimensions of *Eucalyptus globulus* origins. (Dimensão das fibras de *Eucalyptus globulus*).

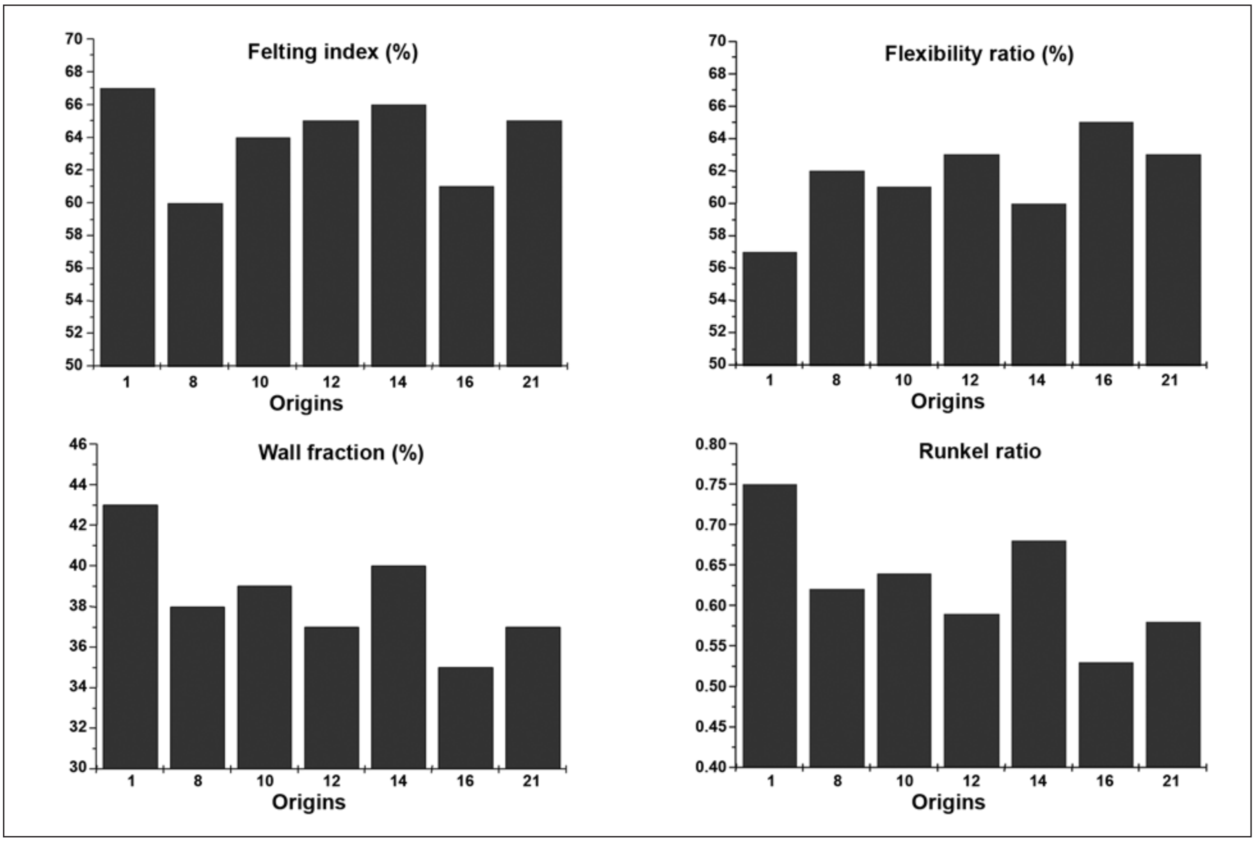

Figure 3. Relationship among fiber dimensions of *Eucalyptus globulus* origins. (Relação entre as dimensões das fibras de *Eucalyptus globulus*).

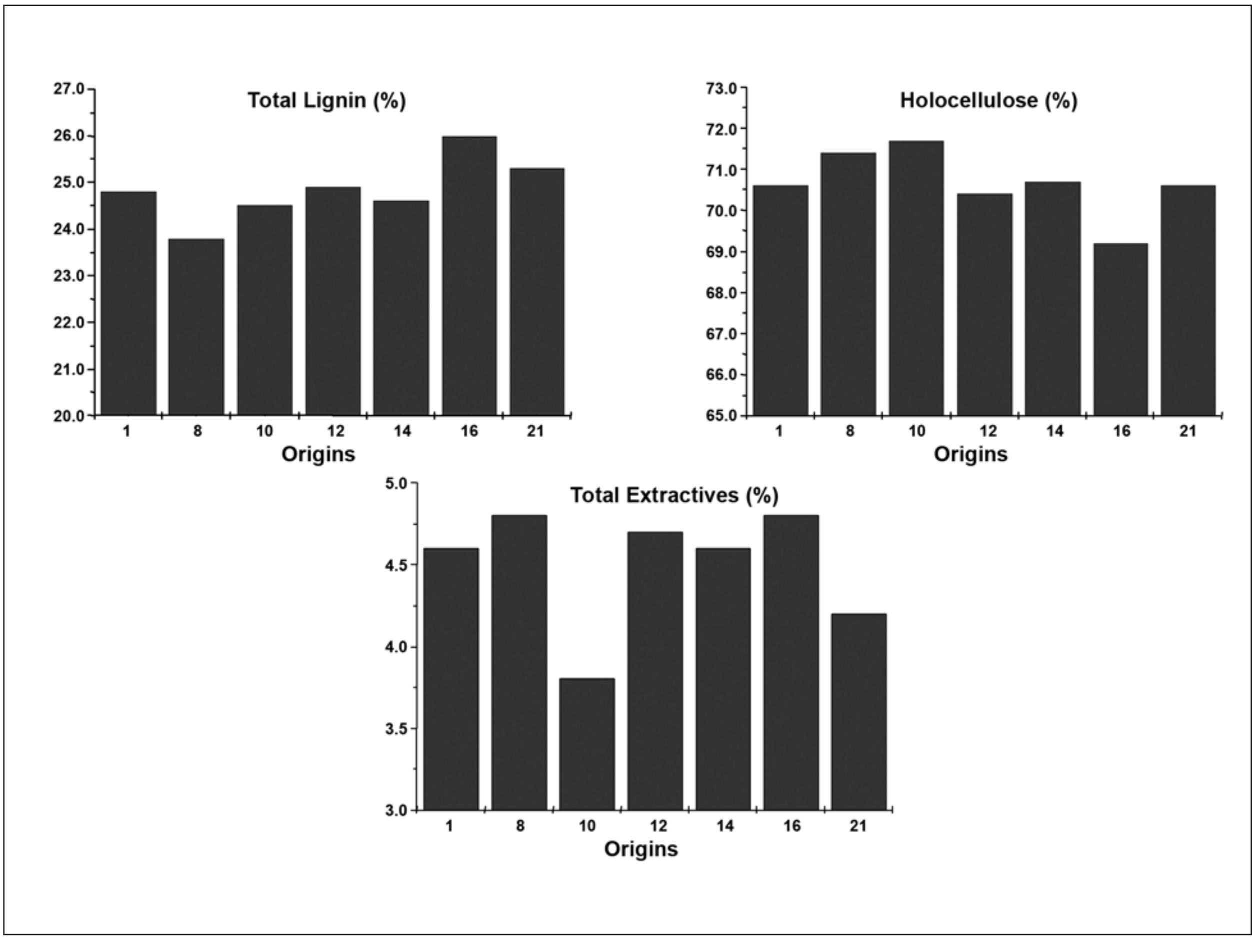

Figure 4. Wood chemical composition of *Eucalyptus globulus* origins. (Composição química da madeira de *Eucalyptus globulus*)

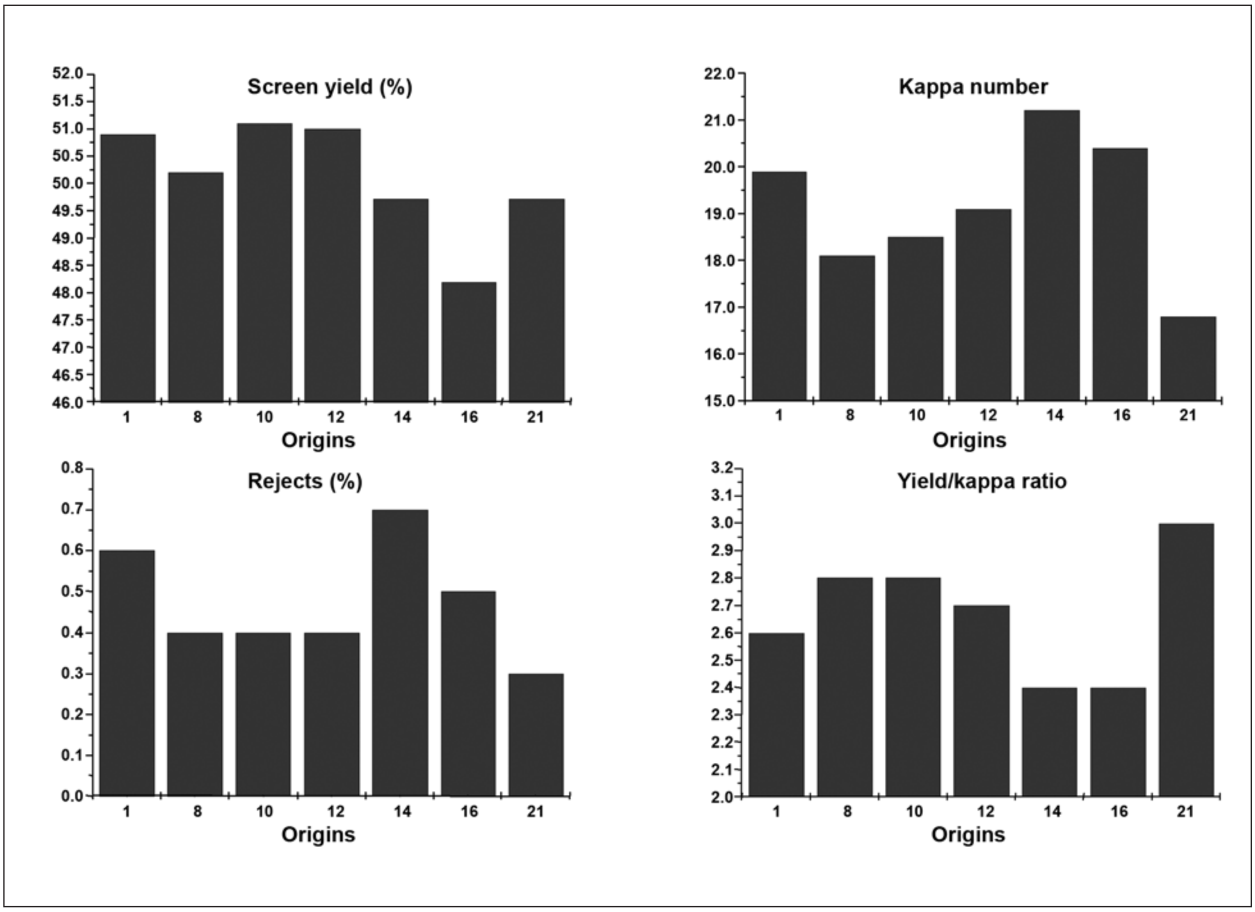

Figure 5. Results of the kraft pulping of *Eucalyptus globulus* origins. (Resultados da polpa celulósica kraft de *Eucalyptus globulus*)

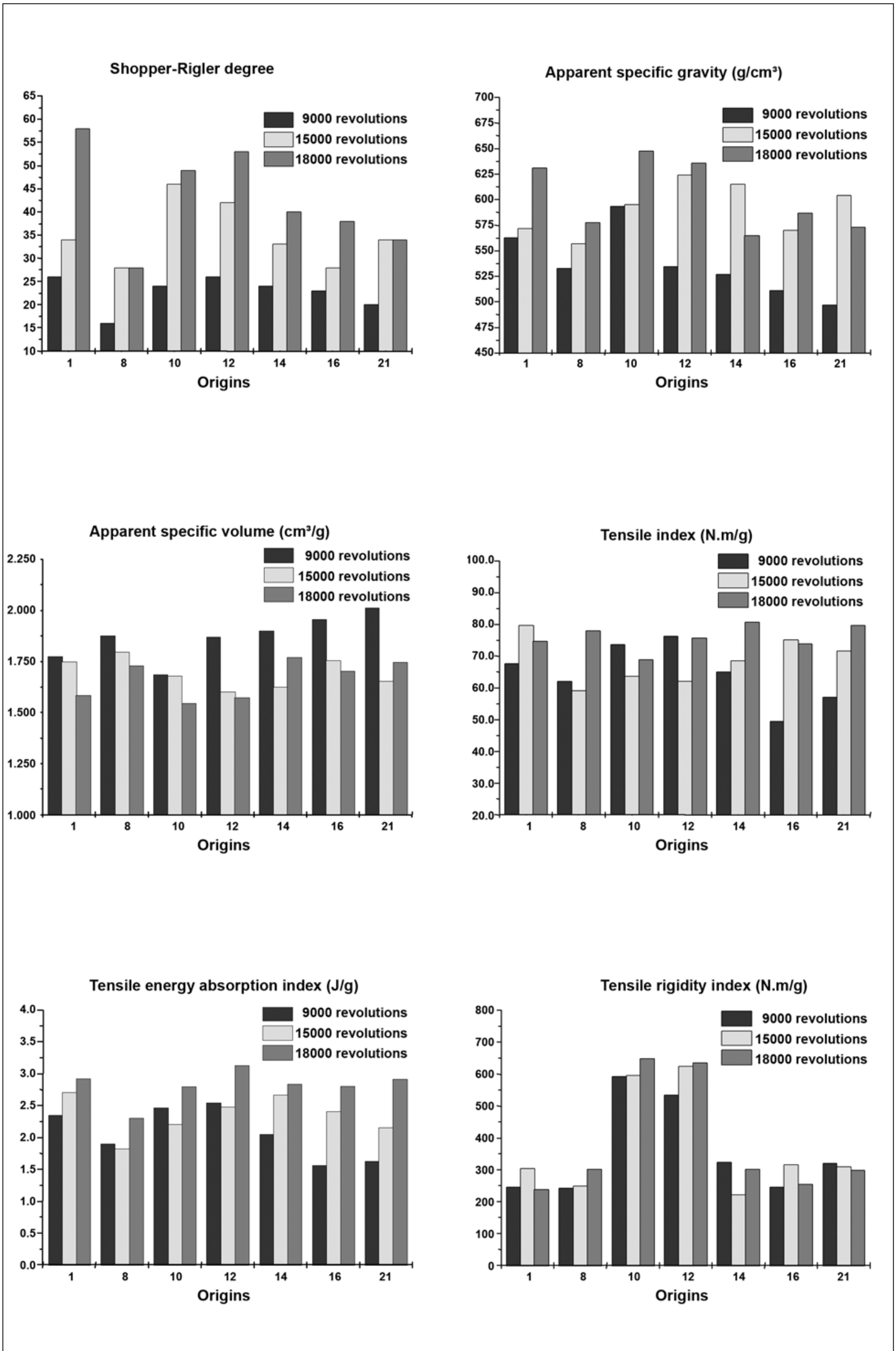

Figure 6. Results of physical-mechanical pulp properties for *Eucalyptus globulus* origins. (Resultados das propriedades físico-mecânicas da polpa celulósica de *Eucalyptus globulus*).

CONCLUSIONS

Wood density values for the origins studied are within the values considered advisable for kraft pulp production. Origins with the highest wood density were from the south of Victoria State (Origin 1), from northeast Tasmania (14) and from Bass Strait (Origin. 8), with values of 0,535, 0,531 and 0,527 g/cm³, respectively.

Considering fiber dimensions, the indexes obtained in this study allow us to infer that all origins are of good quality for paper production.

The relatively low values of lignin content for all origins (between 23.8 to 26%) were expected. Holocellulose content was similar between origins and a little lower when compared to values mentioned in the literature, with values that varied from 69 to 72%. The total extractive content varied from 3.8 to 4.8%.

The highest screened yield values correspond to the origins from south Victoria (1), north Tasmania (10) and Bass Strait (12). These origins presented 51% of screened yield on average.

Origins 1, 10 and 12 were the easiest to refine and presented the highest apparent specific gravity values of the pulp.

The highest values of tensile strength were obtained by origins 1, 10, 12 and 14 for a targeted value of 25o SR (67,6, 73,8, 76,4 and 65,1 N.m/g., respectively).

Based on these results, the authors conclude that the best origins in terms of screened yield and kappa number are 1 (South Victoria), 10 (Cape Barren Island of the Bass Strait) and 12 (Northeast of Tasmania). Origins 10 and 12 showed the best performance in terms of refining and pulp resistance.

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