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WOOD QUALITY OF SIX EUCALYPTUS CLONES PLANTED IN NORTHERN MATO GROSSO STATE, BRAZIL

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ABSTRACT

The present work had the goal of assessing the wood quality through physical-mechanical properties of six 5-year old eucalyptus clones currently planted in northern Mato Grosso State, Brazil. The following clones were assessed, five of them *Eucalyptus grandis* x *Eucalyptus urophylla* hybrids and one a clone of *Eucalyptus camaldulensis*. The physical-mechanical properties were basic density as a function of tree height; pith-to-bark direction; linear, tangential and radial shrinkage; and anisotropic coefficient, longitudinal and parallel compression and static bending strengths; and hardness. *Eucalyptus grandis* x *Eucalyptus urophylla* hybrids showed the best wood quality. Concerning to mechanical results, the clones reached intermediate values of strength and rigidity, qualifying them for use in structural applications with less stringent requirements. Considering that all the clones had juvenile wood, the mechanical properties were satisfactory, making the clones suitable for industrial uses.

KEYWORDS: Eucalyptus, clones, juvenile wood, physical-mechanical properties, dimensional stability, hardness, compression strength, static bending strength.

INTRODUCTION

Currently in the world, there is strong pressure to minimize the use of wood from tropical forests, notably for lumber to make furniture and flooring among other uses. One of the more efficient initiatives to preserve natural forests is to obtain wood from short-cycle planted forests (Evans 1999). With a reforested area of 7.84 million hectares (less than 1% of the country's territory), planted forests now supply 90% of a industrial wood consumed in Brazil (Brazilian tree industry. Report 2018). Among the species employed in reforestation, the *Eucalyptus* genus is by far the most common throughout the country, with a total of 5.7 million hectares (Brazilian tree industry. Report 2017), composed of different species, provenances, varieties, hybrids and clones. Because of Brazil's large land mass and varied climate conditions, the consolidation of eucalyptus as the main genus used for reforestation is the result of effective and well-coordinated breeding programs that have resulted in a large pool of clones able to adapt to different soils and climates and to provide wood types suitable for many uses. However, the wood quality from these forest stands is influenced by a series of factors, such as age, genetic material, site quality, growing space, fertilization and environmental interactions (Downes et al. 1997, Koman and Feher 2015, Chen and Zhu 2019). Besides differences in genetic quality, climate and site quality have strong effects on forest productivity and wood quality, decisively affecting its end use (Larson et al. 2001). Another factor to consider is that with higher productivities, the harvesting ages are declining, to the point where there is insufficient time to obtain mature wood from clonal stands, so that the wood harvested is all juvenile (Santos et al. 2016, Rocha et al. 2018). Add to this the fact, wood characterization results usually cannot be extrapolated from one place or climate to other because a single clone as a function of its genetic plasticity can express its anatomical traits in different ways from one place to another. In the early days of cloning, the genetic materials were mostly developed for pulp and paper production (Ramirez et al. 2009, Morais et al. 2017). With the success of clones for that purpose, the market rapidly changed, with rising demand for wood to make particleboard and charcoal, as well as for fuel, with each use having its particular technical requirements. Now the quality assessment work, besides having a wide range of technical aspects for classification of wood, also has to evaluate wood from trees harvesting at young ages (Chen et al. 2009, Gonçalves et al. 2009, Serenini et al. 2019). For the efficient utilization of this wood, above all if the end use is structural, the analysis has to provide enough knowledge of physical-mechanical properties. To obtain products of recognized quality, the assessment of wood quality is of fundamental importance because it will define the correct end use and the limits for structural sizing (Nogueira et al. 2018).

Mato Grosso has stood out in the last 20 years as main state on the agriculture and forestry frontier in Brazil, and during this period, many clones have been planted, sometimes experimentally and without any specific end use in sight other than wood production itself (Ferreira et al. 2019, Serenini Jr et al. 2019). In that context, the present work had the objective of characterizing the physical-mechanical properties of juvenile wood from six high-yield clones currently planted in northern Mato Grosso and indicating possible industrial uses as a function of their wood quality.

MATERIAL AND METHODS

Wood collection was carried out in 5-year old clonal eucalyptus stands planted and managed by the company Flora Sinop Ltd., located at the geographical coordinates 11°52'1.06"S and 55°28'10.68"W, in the municipality of, Mato Grosso, Brazil. The trees were planted in an entirely randomized block design with four replicates with 3 x 2 m planting space. The types of eucalyptus planted and assessed were five *Eucalyptus grandis* x *Eucalyptus urophylla* hybrids (VV H13, EUCA 105, F1F1 H13, F1 F11 and F1 F8) and one clone of *Eucalyptus camaldulensis* (F1F3 C219). The region where the experiment is deployed has a moist tropical climate, Aw in the Köppen classification, with two well-defined seasons (dry and wet) (Alvares et al. 2014). Average annual precipitation is 1,818 mm, maximum and minimum temperatures are 36°C and 16°C, respectively. The rainy season lasts from October to April and the dry season from May to September. The soil in the experimental area has clay loam texture, composed of sand, silt and clay in the proportions of 47.6, 10.1 and 42.3%, respectively. Fertilization of all experimental plots was carried out according to the results of the soil analysis, with 150 g·plant^{-1} of NPK (6–30–10) at the time of sowing, followed by two more fertilizations after 6, 12 and 24 months of age with 100 g·plant^{-1} of NPK (20–0–20) and 20 g·plant^{-1} of boric acid. No thinning was carried out.

Five trees of each clone were harvested with a chainsaw, for a total of 30 trees. After tree cutting off the crown from each trunk, five 3 cm thick disks were collected, respectively at 0, 25, 50, 75 and 100% of the resulting commercial log length, following the procedures described by Benin et al. (2017). To evaluate density in the radial direction, test specimens were collected for each tree height in three positions in pith-to-bark direction, respectively, inner (adjacent to pith), outer (adjacent to bark), and an intermediate position. Also, a log with length of 2.00 m was obtained from each trunk at the base. Wood disks were used for basic density determination following the procedures described by the standard NBR 11941/03 (Brazilian Association of Technical Standards. The logs were sawn to obtain 8 cm wood planks, as recommended by the standard COPANT 458/72 (Pan American Standards Commission). Wood planks were air-dried for 90 days in a covered patio and then taken to a woodworking facility to collect the test specimens for the further mechanical assays. Thus, 20 test specimens per clone were collected for each mechanical test. The test specimens were conditioned at 65 ±1% relative humidity and 25 ± 1°C until reaching equilibrium moisture content of 12%.

For dimensional stability assessment, 20 test specimens were obtained with dimensions of 2 cm wide, 2 cm thick and 10 cm long. The dimensions were measured with accuracy of 0.01 mm, initially at the equilibrium moisture content and after soaking for 26 days until complete water saturation. After saturation, the test specimens were oven dried at 103 ±1°C until reaching constant weight. Longitudinal, tangential and radial linear wood shrinkage tests were performed according to COPANT 462/72. The anisotropy factor was calculated as the ratio between tangential and radial shrinkage.

Mechanical assessment of the wood followed the procedures of ASTM D 143/14 by using a universal testing machine (Emic Instron, São José dos Pinhais, PR, Brazil) equipped with a 30 kN compression/tension load cell. The following properties were determined, respectively, strength and rigidity under compression parallel (f_{c0} and E_{c0}) and perpendicular (fc90 and Ec90) to wood grain, strength and rigidity under static bending (f_M and E_M) and Janka hardness on the longitudinal, radial and tangential axis (f_H Long, f_H Rad and f_H Tang).

Radial and tangential variation of basic wood density was analyzed in a randomized block design with factorial array. Effects of experimental treatments (clones) and sampling position were statistically assessed by applying analysis of variance (ANOVA) and the F-test at 5% significance, and when significant, the Scott-Knott test at 5% significance was employed to compare the means. The other physical-mechanical properties were evaluated by ANOVA and the Scott-Knott test at 5% significance for variables detected as having statistical differences by the F-test.

RESULTS AND DISCUSSION

The clone performances are summarized in Tab. 1 and 2. As can be seen, those clones were all very productive: at age of 5 years they, they produced outstanding yields of solid wood per hectare.

Tab. 1: Means and standard deviations for DBH and height of 5-year-old Eucalyptus clones.

Clone code	DBH (cm)	Height (m)
FI F8	15.46 ± 0.551	16.98 ± 3.41
FI F3 C219	15.93 ± 0.575	13.89 ± 1.95
FI F1 H13	17.34 ± 0.359	16.45 ± 5.40
FI F11	13.68 ± 0.557	16.60 ± 1.67
VV H13	17.14 ± 0.461	19.63 ± 1.51
EUCA 105	17.41 ± 0.993	19.49 ± 1.60

*DBH – diameter at breast height.

Tab. 2: Means and standard deviations for annual increment, volume per tree and volume per hectare of 5-year-old Eucalyptus clones.

Clone code	*MAI (m^3 ha^{-1} ano^{-1})	Volume (m^3)	Volume per hectare (m^3 ha^{-1})
FI F8	66.60 ± 2.80	0.1998 ± 0.0084	333.02 ± 13.99
FI F3 C219	69.91 ± 16.59	0.2097 ± 0.0498	349.53 ± 82.93
FI F1 H13	64.90 ± 20,56	0.1947 ± 0.0617	324.51 ± 102.78
FI F11	68.12 ± 14.91	0.2044 ± 0.0447	340.61 ± 74.55
VV H13	74.16 ± 2.90	0.2225 ± 0.0087	370.81 ± 14.49
EUCA 105	64.45 ± 23.31	0.1933 ± 0.0699	322.24 ± 116.57

* MAI - mean annual increments.

Statistical differences of basic density of clones were detected at 5% significance (Tab. 3). However, the only significant interaction was detected for sampling position, while all the other interactions assessed were not statistically significant at 5%. Clones F1 F3 C219 and F1 F8 showed higher values for basic density, while EUCA 105, F1 F1 H13 and F1 F11 had intermediate values. In turn, VV H13 presented the lowest basic density value. The coefficients of variation found for the basic densities were lower than 10%, which demonstrates that the sampling method and number of samples collected were adequate to correctly interpret the variation of the evaluated property, as commented by Gujarati and Porter (2009).

Usually, wood of higher density has higher mechanical strength, which is best for industrial processing. Furthermore, the clones assessed in the present work that showed the highest values of basic density, despite being juvenile, were suitable for industrial use.

Tab. 3: Means, standard deviations and statistical comparison of wood basic density of six eucalyptus clones at 5 years of age.

Clone code	Species/Hybrid	Basic density(g·cm^{-3})
VV H13	*E. grandis x E. urophylla*	0.475 ± 0.035 c
EUCA 105	*E. grandis x E. urophylla*	0.482 ± 0.043 b
FI F1 H13	*E. grandis x E. urophylla*	0.487 ± 0.042 b
FI F11	*E. grandis x E. urophylla*	0.487 ± 0.040 b
FI F8	*E. grandis x E. urophylla*	0.494 ± 0.048 a
FI F3 C219	*E. camaldulensis*	0.501 ± 0.055 a

*Means followed by same letters in the column are statistically equal by the Scott-Knott test at 5% significance.

Statistical comparison for the basic densities as function of tree height in the columns and radial position of sampling in the rows is presented (Tab. 4). There was no significant statistical interaction between the clones and basic density, so the results are grouped in only one table, meaning the variations are the same for all clones. Considering the wood density along the tree height, no clear pattern behavior could be observed. Several research works, there is no defined pattern for the behavior of basic density with tree height for *Eucalyptus* species and clones planted in Brazil, but several researchers have reported a decrease of wood density until 50% height and an increase from that point to the top. On the other hand, Alzate et al. (2005) reported the basic density of 8-year-old *Eucalyptus grandis* x *Eucalyptus urophylla* hybrid trees clearly increasing from the base to the top. In contrast, Chies (2005) reported a decrease in wood density with trunk height, explaining that such behavior is expected since as the height increases, the percentage of mature wood in the tree decreases.

Tab. 4: Statistical comparison of basic density as function of tree height and radial direction for all assessed clones.

Tree height (%)	Radial position		
	Outer	Intermediate	Inner
0	0.529 Aa	0.496 Ab	0.439 Cc
25	0.525 Aa	0,484 Ab	0.473 Ab
50	0.525 Aa	0.491 Ab	0.426 Cc
75	0.504 Ba	0.486 Ab	0.460 Bc
100	0.539 Aa	0.459 Bc	0.481 Ab

*Means followed by the same uppercase letters in the columns and lowercase letters in the rows are statistically equal by the Scott-Knott test at 5% significance; **Tree height after cutting crown.

A final conclusion is the broad variation of anatomical characteristics among genotypes and provenances *Eucalyptus* clones, such as fiber length, fiber wall thickness, number of vessels, and percentages of axial and radial parenchyma cells Carrillo et al. 2015). Other authors assessing samples from the same height positions as the present work, concluded that only the samples collected at 25% height are representative of the average basic density of the whole tree, so a single point in the trunk should be sampled in the cases of *Eucalyptus saligna* and *Eucalyptus grandis* (Souza et al. 1986). We found that the basic density varied significantly for all clones in both longitudinal and radial direction, following the pattern cited by Koch (1972).

With regard to the variation of basic density in radial direction, the predominant behavior was for this to increase from pith to bark in practically all the positions along the tree height. However, at the 100% position, there was a significant decrease at the intermediate point, followed by increase when close to the pith. This type of variation at that tree height point can be attributed by the variation in wood quality due to branch insertions. As discussed by Gonçalez et al. (2006), the gradual increase of the wood density from bark to pith observed in the present work is common in many species of *Eucalyptus*. Our results for the behavior of basic density in the radial direction are similar to the results found by Lopes et al. (2011), who investigated 18-year-old *Eucalyptus grandis*, *Eucalyptus urophylla* and *Eucalyptus dunnii* trees to analyze their suitability for furniture production. The basic densities observed in this work indicate that the juvenile wood from 5-year-old trees of all six clones is suitable for furniture production as well. However, other properties should be evaluated to corroborate that statement, as will be discussed next.

The highest dimensional alterations of wood usually occur in the tangential direction in relation to growth rings, followed by the radial direction, and are negligible in the longitudinal direction. The values presented here fit this pattern. The values determined for tangential, radial and volumetric shrinkage and anisotropy coefficient for the five eucalyptus clones are shown next (Tab. 5). Through the analysis of the standard deviations in that table, the variation of means obtained from the experimental results can be classified as having moderate dispersion, since in general they had coefficients of variation in the range of 10 to 20%.

Tab. 5: Means, standard deviations and statistical comparison of radial, tangential and volumetric shrinkage and anisotropy coefficient.

Clone code	Shrinkage (%)			Anisotropy factor
	Radial	Tangential	Volumetric	
VV H13	4.91 ± 0.74 b	6.73 ± 0.94 c	11.36 ± 1.37 c	1.39 ± 0.23 a
FI F8	4.68 ± 1,05 b	7.57 ± 1.28 b	11.91 ± 1.81 c	1.69 ± 0.43 a
FI F1 H13	5.11 ± 0.86 b	7.42 ± 0.82 b	12.19 ± 1.32 c	1.49 ± 0.27 a
EUCA 105	5.14 ± 0.97 b	7.66 ± 1.37 b	12.49 ± 1.89 c	1.52 ± 0.24 a
FI F11	5.30 ± 0.94 b	8.41 ± 1.06 a	13.39 ± 1.58 b	1.63 ± 0.32 a
FI F3 C219	6.04 ± 1.40 a	8.89 ± 1.47 a	14.49 ± 2.18 a	1.52 ± 0.34 a

*Means followed by the same letters in the columns are statistically equal by the Scott-Knot test at 5% signif.

F1 F3 C219 showed the highest values of radial, tangential and volumetric shrinkage, respectively, 6.04, 8.89 and 14.49%, statistically differing from all other wood types, except for F1 F11 in tangential shrinkage. VV 13 had the lowest values of tangential and volumetric shrinkage, respectively 6.37 and 11.36%. In the case of radial shrinkage, F1 F3 C219 is close to the value of 6.05% found by Carvalho et al. (2015) for 16-year-old *Eucalyptus cloeziana*. Also, Motta et al. (2014), assessing a *Eucalyptus grandis* x *Eucalyptus urophylla* hybrid, determined radial shrinkage of 5.02%, close to the values detected in the present work for the clones EUCA 105, VV H13 and F1 F1 H13.

Concerning the tangential shrinkage, VV H13 had the lowest value, 6.73%, followed by F1 F1 H13, F1 F8 and EUCA 105 with respective values of 7.42, 7.57 and 7.66%. All these values are lower than those found by Muller et al. (2014), who evaluated wood from 6-year old *Eucalyptus benthamii* and determined 13.87% for that parameter. When wood from different sources and tree ages were assessed, respectively, 10-years for *Eucalyptus grandis* x *Eucalyptus urophylla* hybrid (Motta et al. 2014), 16-years for *Eucalyptus cloeziana* and *Eucalyptus grandis* (Carvalho et al. 2015) and 10-years for *Eucalyptus cloeziana*, all had higher values than those presented in this work for tangential shrinkage. Regarding volumetric shrinkage, VV H13 showed the lowest value (11.36%) while the F1 F3 C219 had the highest one (14.49%). Nevertheless, in general the values presented here are similar to the values reported by Motta et al. (2014) and Carvalho et al. (2015), authors already cited above, who reported, respectively, 13.75 and 13.03% for this wood's physical parameter. However, the values of this study are lower than those reported by Alves et al. (2014) and Muller et al. (2014), of 18.52 and 19.68%, respectively, for 6-year-old *Eucalyptus benthamii* and 10-year-old *Eucalyptus cloeziana* wood.

According its volumetric shrinkage, wood was classified by Gonçalez et al. (1997) into three groups: low volumetric shrinkage when this parameter is in the range of 4 to 9%; moderate from 9.1 to 14%; and high for values from 14.1 to 19%. According to this classification, only F1 F3 C219 is in the group of high volumetric shrinkage, with a mean value of 14.49%. The other clones are included in the group of moderate shrinkage. With respect to the anisotropic factor (AF), this parameter as the most important index for evaluating the dimensional stability of wood, establishing that wood is considered excellent for AF values from 1.2 and 1.5, normal for values from 1.5 to 2.0 and low quality for values greater than 2.0. We observed that VV H13 had the lowest AF value (1.39) followed by F1 F1 H13 (1.49). However, since there was no statistical difference among the determined AFs, all the clones can be classified as excellent quality or at least normal if the statistical equality is disregarded, which demonstrates they have real potential for furniture production, for example. All the experimental values are significantly lower than that reported by Muller et al. (2014), who found 2.36 for 6-year-old *Eucalyptus benthamii* wood. Despite being lower, the values are closer to the result found by Motta et al. (2014) of 1.81 for a eucalyptus clone. They are likewise close to the values reported of 1.59 and 1.71 reported by Carvalho et al. (2015) respectively for 16-year-old *Eucalyptus grandis* and *Eucalyptus cloeziana*. An interesting outcome can be highlighted regarding to the wood quality of the clones assessed here: they have virtually the same quality as the mature wood reported by the authors mentioned above for different eucalyptus species. Based on the results of volumetric shrinkage and anisotropic factor, it is possible to assert that for all clones if their wood is properly sawn and air or oven dried, it will not present any restriction for industrial uses.

The mean values for the moduli of rupture (f_{c0}) and elasticity (E_{c0}) obtained, respectively, in the parallel compression test, and for the moduli of rupture (f_{c90}) and elasticity (E_{c90}) in the perpendicular compression test for the six eucalyptus clones (Tab. 6). Also, the comparative means and standard deviations are shown below (Tab. 6). In results of the parallel compression tests showed on statistical difference among the clones EUCA 105, VV H13, F1 F1 H13, F1 F3 C219 and F1 F11, with values slightly higher than 40 MPa for all them. The lowest value obtained was for the F1 F8 with 39.19 MPa, which is statistically lest resistant compared to the rest. Modulus of elasticity (E_{c0}) expresses the ability of a material to return to its original condition after being submitted to deformation without alterations in its properties and structural integrity. The highest values for this parameter were obtained for EUCA 105, VV H13, F1 F3 C219 and F1 F11, but they did not differ statistically from each other. However, two clones, respectively, F1 F1 H13 and F1 F8, had the lowest values, 10,370 and 9,884 MPa, and were statistically less elastic than the others.

Tab. 6: Means, standard deviations and statistical comparison for the parallel compression moduli of rupture (f_{c0}) and elasticity (E_{c0}) and perpendicular compression moduli of rupture (f_{c90}) and elasticity (E_{c90}).

Clone Code	f_{c0}	E_{c0}	f_{c90}	E_{c90}
	(MPa)			
FI F8	39.19 ± 3.91 b	9,884 ± 1,037 b	5.52 ± 1,26 a	379.54 ± 90.16 a
FI F3 C219	41.42 ± 4.83 a	10,736 ± 1,137 a	5.17 ± 0.96 a	382.86 ± 174.42 a
FI F1 H13	42.34 ± 2.65 a	10,370 ± 706 b	6.08 ± 1.39 a	414.92 ± 141.94 a
FI F11	43.03 ± 4.22 a	10,832 ± 1,089 a	5.37 ± 1.25 a	350.89 ± 101.89 a
VV H13	43.28 ± 3.63 a	10,728 ± 1,042 a	5.87 ± 1.71 a	399.37 ± 131.51 a
EUCA 105	43.35 ± 3.19 a	10,978 ± 787 a	6.04 ± 0.99 a	387.30 ± 157.89 a

*Means followed by the same letters in the columns are statistically equal by the Scott-Knot test at 5% signif.

When studying wood from 28-year-old Eucalyptus umbra trees, Nogueira et al. (2018) measured a mean 4.27 MPa value for parallel-to-wood grain compression strength, lower than the mean values determined for the more resistant clones assessed in this work and equal to the other clones. Nevertheless, the result of 14,577 MPa found by the authors for the elasticity modulus surpass those obtained for all the clones evaluated here. Furthermore, Nogueira et al. (2018) worked with mature wood. In the same line of comparing the results of wood from trees of different ages, Muller et al. (2014) assessed the wood quality of stands of 6-year-old *Eucalyptus benthamii* submitted to 20% thinning and found mean values for parallel compression and elasticity modulus of 37.34 and 2,565 MPa, respectively, values moderately lower compared to our results. In another comparison example, Benin et al. (2017) reported mean value of 31.23 MPa for parallel compression and 4.621 MPa for rigidity of juvenile wood from 6-year-old *Eucalyptus benthamii* trees, again significantly lower. That fact indicates that despite being harvested at lower age and presenting only juvenile wood, the clones evaluated here are promising from the standpoint of strength in terms of industrial utilization.

With respect to the compression perpendicular to wood grain, there was no statistical difference at 5% significance among the clones for the modulus of rupture and the modulus of elasticity, with values varying in the ranges of 5.17 to 6.08 and 350.89 to 414.92 MPa, respectively. These results are higher than those reported by Nogueira et al. (2018), cited above, who evaluated 28-year-old Eucalyptus umbra wood.

The standard deviations of the results for the parallel compression mostly can be classified as having low dispersion, demonstrating the homogeneity of the wood from the six clones. However, for compression strength perpendicular to wood grain, the standard deviations were very dispersed. Thus, despite the young harvest age, the experimental results showed real potential for diversified uses such as small structures, as long as correct dimensions are established. Only F1 F8 was statistically less resistant than the others at 5% significance. It is important to highlight that these results indicate a limitation regarding more demanding structural uses, where wood with higher densities and thus greater strengths is recommended, characteristics not possible to obtain with young trees of eucalyptus clones.

The mean values determined for the moduli of rupture (fM) and elasticity (EM) for the static bending assay are shown hereafter (Tab. 7). The table also reports the mean values of Janka hardness measured in three dimensional directions, longitudinal, radial and tangential (fH Long, fH Rad and fH Tang). All the standard deviations associated with the experimental results reveal moderate to high dispersion around the means. Despite this dispersion, there was no statistical difference among the values of both moduli of rupture and elasticity, with values varying, respectively, from 69.72 to 77.95 MPa and from 6,089 to 7,119 MPa.

Tab. 7: Means, standard deviations and statistical comparison for the strength (f_m) and modulus of elasticity (E_m) from the static bending assay, and Janka hardness parallel (f_H Long), radial (f_H Rad) and tangential (f_H Tang) to wood grain.

Clone Code	f_M	E_M	f_H Long	f_H Rad	f_H Tang
	(MPa)		(N)		
FI F8	69.72 ± 7.87 a	6,254 ± 967 a	4,553 ± 809 a	3,665 ± 793 a	3,729 ± 892 b
FI F1 H13	70.83 ± 12.64 a	6,089 ± 849 a	4,070 ± 682 a	3,834 ± 756 a	3,910 ± 588 a
EUCA 105	71.42 ± 19.46 a	6,940 ± 1795 a	4,250 ± 901 a	3,988 ± 645 a	4,114 ± 729 a
VV H13	74.89 ± 16.78 a	6,246 ± 1421 a	4,480 ± 1,128 a	4,085 ± 643 a	4,108 ± 788 a
FI F11	76.06 ± 13.45 a	6,718 ± 1505 a	4,408 ± 541 a	3,171 ± 753 b	3,394 ± 724 b
FI F3 C219	77.95 ± 10.47 a	7,119 ± 1853 a	4,694 ± 905 a	3,631 ± 441 a	3,859 ± 756 a

*Means followed by the same letters in the columns are statistically equal by the Scott-Knot test at 5% signif.

The values obtained in the present work are in range between 69.72 and 77.95. When evaluating clones of a *Eucalyptus urophylla* x *Eucalyptus grandis* hybrid, Gonçalves et al. (2009) determined that static bending strength varied from 82.95 to 83.21 MPa and modulus of elasticity from 9,652 to 9,798 MPa. In turn, Nogueira et al. (2018) obtained 84.1 MPa for mean static bending strength of wood from Eucalyptus umbra and mean modulus of elasticity equal to 14,310 MPa. All the values reported in both studies are higher than the experimental values of this work. Wood from 6-year-old *Eucalyptus benthamii* assessed by Muller et al. (2014) showed mean values for fM and EM from the static bending assay equal to 83.53 and 9,755 MPa, respectively, results higher than those obtained for the clones evaluated here. Benin et al. (2017), assessing the same eucalyptus species at the same age with plant spacing of 3 x 2 m, observed mean values of 74 and 8,330 MPa for the same parameters, respectively, fM and EM, which are closer to the values observed for the six clones in this work. Low static bending strength can limit the uses of wood in construction in applications requiring higher resistance, like bridges and roofs. Thus, structural sizing should be carefully analyzed of wood for use in these types of projects.

Concerning Janka hardness, there were no statistical differences among the clones in the longitudinal direction, with the highest values varying from 4,070 to 4,694 N. In radial direction, there was no difference among the clones, except F1 F11, which had lower hardness, differing from the others. In the tangential direction, there also was no statistical difference among EUCA 105, VV H13, FI F1 H13 and FI F3 C219, with respective hardness values of 4,114, 4,108, 3,910 and 3,859 N. The clones having the lowest mean values of hardness were F1 F8 and F1 F11, with 3,729 and 3,394 N, differing statistically from the others. Our results are lower than those reported by Muller et al. (2014), who studied 6-year-old *Eucalyptus benthamii* wood and observed 5,633, 5,138 and 4,317 N for hardness in the longitudinal, radial and tangential to grain directions, respectively. The results for the six clones are also lower than those determined by Gonçalez et al. (2006) for *Eucalyptus grandis* wood with, 5,207 and 6,512 N in the radial and tangential directions, and for *Eucalyptus cloeziana* wood, with 11,111 and 11,444 N in the radial and tangential directions. Additionally, Nogueira et al. (2018), working with mature wood from 28-year-old Eucalyptus umbra trees, found mean Janka hardness equal to 1,175 N in the parallel and 2.092 N in the longitudinal direction, values lower than those found in this work. However, considering the results obtained in the hardness assays, all six clones can be classified as medium grade and all them reached the requirements recommended by the Brazilian National Wood Flooring Association.

CONCLUSIONS

The wood from the six eucalyptus clones can be classified as light or medium density. The density values varied between 0.475 and 0.501 $g \cdot cm^{-3}$. Regarding volumetric shrinkage, the wood samples were classified as average grade, and concerning the anisotropic factor they were mostly classified as normal (1.39 to 1.69). The mechanical properties indicated intermediate values of strength and rigidity, which enables the trees to be harvested at four years to provide wood for civil construction with adequate structural sizing. The compressive strength values varied between 39.19 and 43.35 MPa, and static bending between 69.72 and 76.06 MPa. Although the clones' wood is essentially juvenile, the use of this material for industrial purposes such as flooring and furniture most likely can be achieved without restriction, if the sawing and drying processes are properly conducted according to the recommended procedures.

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