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PHYSICAL AND MECHANICAL PROPERTIES OF *Eucalyptus urophylla*

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ABSTRACT

Eucalyptus urophylla is one of the most planted species in the world and in Brazil for presenting excellent productivity, good adaptability to the most varied types of soil and climate and wide application. The experiment was installed in randomized blocks with four replications, linear plots with six plants in a 3 x 2 m spacing. In this test, 21 progenies were selected in three replications, to evaluate the physical (basic density and shrinkage) and mechanical properties (shear, compression, modulus of elasticity and rupture) of the wood. There was no statistical difference between the progenies for the characteristics evaluated because it was juvenile wood. The basic density showed a positive correlation with the radial and volumetric shrinkage and a negative correlation with the shrinkage index. There is no correlation of DBH with the physical or mechanical properties of wood. The values obtained were low but with the potential to increase.

Keywords: Basic density, shrinkage, shear, compression parallel to the fibers, wood compression

INTRODUCTION

Eucalyptus urophylla is one of the most planted hardwood species in the world due to its broad genetic base, which gives it an enormous range of adaptations to climates and soils, as well as a wide application of wood. *E. urophylla* belongs to the subgenus *Symphyomyrtus*, section Latoangulatae, series Robustae. It is one of the few *Eucalyptus* species that does not occur in Australia, it occurs in Indonesia and Timor. The cpDNA distribution indicates that the species originated in Timor (the islands closest to Australia and with the greatest diversity of haplotypes) and later colonized the other islands. Nuclear genetic differentiation is lower (G_{ST} = 0.581) than that of chloroplasts (N_{ST} = 0.724), indicating the direction of colonization from East to West (Timor, Wetar, Alor, Pantar, Lomblen, Adonara and Flores) because the genetic diversity is largest in Timor. Differentiation by chloroplast and phenotypic DNA is 50% between islands, 25% between populations on the same island, and 25% within populations. Differentiation by nuclear DNA is low (F_{st} = 0.03), indicating little or no gene flow between islands and a lot of fixations by haplotypes, probably due to crosses with *E. alba* (FAO, 2015; HOUSE & BELL, 1994; NICOLLE, 2017; NICOLLE & JONES, 2018; PAYN et al., 2007; 2008; PRYOR et al., 1995; SCANAVACCA Jr. & GARCIA, 2021).

The origin is also very influential in relation to resistance to *Aulographina* spp. (Wetar 3% and Adonara 35% of attacked leaves) and *Mycisogaerekka* spp. (the percentage of attacks ranged from 8 to 19% within Flores Island) and seems to be controlled by a few genes (DVORAK et al., 2008).

The species is distributed from 7º 30' S to 10º S, and the longitude varies from 122 to 127º E, in a range of 500 km in disjunct populations across the islands. The altitude varies from 70 to 2960 m. The soil is basaltic. The temperature varies from 20 to 30º C, in the coldest months it can reach 15º C. Rainfall in Flores, Adonara and Lomblen varies from 1,085 to 1,100 mm, decreasing towards Wetar (East) to 850 to 925 mm. At higher altitudes in Timor, it can reach 1,300 mm (DVORAK et al., 2008; ELDRIDGE et al., 1994; GUNN & MCDONALD, 1991; HOUSE & BELL, 1994).

The bark is fibrous or rough at altitudes above 1000 m and smooth or partly smooth and partly fibrous in different proportions below 1000 m, due to hybridization with *E. alba*. It adapts well to temperatures ranging from 16 to 27º C and precipitation from 1000 to 2000 mm (FLORES et al., 2016; GUNN & MCDONALD, 1991; PRYOR et al., 1995).

The objective of this work is to study the physical and mechanical properties of *E. urophylla* in a progeny test with the most productive progenies in Brazil.

MATERIAL AND METHODS

The BEPP (Brazil *Eucalyptus* Potential Productivity) project, coordinated by the Institute of Forestry Research and Studies (IPEF), aimed to study the limiting factors of the productivity of commercial forests in Brazil. In this way, the best genetic materials of *E. urophylla* available in Brazil, from the first, second, third and fourth generations of improvement for cellulose and paper, in this way, 90 progenies from Timor and 77 from Flores were selected. The progenies were improved for volumetric productivity and resistance to pests and diseases. The assays were installed in six bioclimatic regions of Brazil (Af, Am, Aw, Cwa, Cfa and Cfb, according to the

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Köppen classification, Anhembi being one of them) to understand the influence of genetic and abiotic factors on the development of the species (FLORES et al., 2016; SILVA et al., 2018; STAPE et al., 2010).

The experiment was installed in December 2009, in Randomized Complete Blocks with 167 progenies from six provenances, in four replications with six plants per plot, spaced 3 x 2 m. Anhembi is located at 22º 40' S and 48 º 10' W and at 455 m altitude, on flat terrain. The experiment was installed on a Dystrophic Yellow Latosol (EMBRAPA, 2018), containing 5% silt, 13% clay and 82% sand. The climate, according to the Köppen classification, is Cwa, with hot and rainy summers and moderately cold and dry winters. The occurrence of frosts is rare. The average annual temperature is 23º C and the average temperature of the coldest and hottest months are respectively 17.1 º C and 23.7 º C. The minimum and maximum temperatures are, respectively, 5 º C and 34 º C. The average annual precipitation is 1,100 mm and the annual water deficit is 20 mm (ESALQ, 2022).

Twenty-one progenies were selected in three replications (Blocks 1, 2 and 3). The selection was made foreseeing the thinning or cutting at the end of the work to evaluate the physical and mechanical properties of the wood; in this way, the selection went under; the best tree in the plot was not selected, since in the future the test will be transformed into a seed production area. Before cutting, DBH (diameter at breast height) was measured at approximately 1.30 m from the ground, using a metallic suture with a precision of 1 cm.

The physical properties [basic density (Bd) and shrinkage] and mechanical properties (resistance to shear tangential to the growth rings, resistance to compression parallel to the fibers, resistance to static bending and modulus of elasticity in static bending) were evaluated, according to the NBR standard 7190/22. The mechanical tests were performed on a digital computerized electromechanical universal machine Contenco UMC 300.

Statistical analyzes were performed using the SAS 9.3 statistical package using the Proc Glimmix procedure and Pearson's correlation using Proc Corr and proc ttest for the paired t test. Data normality was evaluated using Proc Univariate. The significance level was set at 5% probability.

RESULTS AND DISCUSSION

Data normality was evaluated using the univariate proc (asymmetry, kurtosis, median and Shapiro-Wilk test). All data evaluated showed normal distribution.

Table 1. Average per progeny of the physical properties of dry woods.

Prog	ST	SR	SL	SV	SI	Bd (Kg m^{-3})	DBH
32	12,20	10,52	0,31	23,03	1,16	528,67	18,10
33	11,09	7,80	0,35	19,24	1,42	477,18	20,80
51	10,45	6,22	0,82	17,49	2,23	485,14	24,07
52	9,16	5,24	0,46	14,86	1,88	472,73	21,70
53	8,04	5,32	0,17	13,47	1,53	498,40	23,10
54	10,70	4,04	0,30	15,04	2,79	421,57	20,57
59	9,47	6,77	0,74	18,01	1,40	470,06	25,97
75	9,68	4,36	0,53	14,58	3,43	420,42	19,90
82	12,08	7,60	0,28	19,95	1,87	479,12	23,47
85	10,14	5,94	0,69	17,23	1,83	491,13	21,70
88	10,56	6,66	0,29	17,51	1,62	505,46	20,23
91	12,91	8,90	0,31	22,11	1,52	512,32	22,97
92	9,49	4,35	0,42	14,26	2,20	439,26	23,17
94	8,65	5,96	0,42	15,03	1,47	500,87	21,03
101	10,93	5,87	0,62	17,42	2,00	468,16	19,00
108	8,94	5,59	0,59	15,13	1,97	444,44	19,37
125	11,48	7,98	0,89	20,39	1,49	498,13	21,60
133	8,67	5,33	0,56	14,56	1,75	504,23	22,43
137	9,44	6,48	0,41	16,33	1,46	482,44	22,50
138	11,40	8,63	0,35	20,38	1,81	505,75	17,60
142	11,54	6,60	0,24	18,38	1,76	479,81	22,00
Average	10,34	6,50	0,47	17,39	1,84	479,96	21,35
SD	2,30	2,57	0,30	4,46	0,82	53,55	3,45
CV	22,75	38,68	58,77	25,50	42,48	11,25	16,48

Where: ST = Shrinkage tangential; SR = shrinkage radial; SL = shrinkage longitudinal; SV = shrinkage volumetric; SI = shrinkage index; Bd = basic density; DBH = diameter at breast height; SD = standard deviation; CV = coefficient of variation.

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There were no statistical differences between the progenies for the DBH according to origin (Flores or Flores & Timor) or breeding generation (second or third). The paired t test between the largest (21.55 cm) and the smallest (19.45 cm) DBH within the progeny showed a statistical difference (t value 12.18 and probability < 0.0001). The heterogeneity of the stand can lead to losses of up to 13%, in addition, fertilization can cause losses of up to 30% in productivity, in our experiment the difference was 10%, fully justified by the heterogeneity of genetic material and delay in replanting (BINKLEY, 2004; SILVA et al., 2021; STAPE et al., 2010). DAP did not correlate with the physical or mechanical properties of the wood. Related results were found by other researchers (CRUZ et al., 2003; EVANGELISTA et al., 2010; LAHR et al. 2017; SERENINI et al. 2020).

There were no statistical differences between the progenies for any measure of shrinkage, nor for the basic density, because we are working with transition material, with a low amount of extractives and the anatomical dimensions are quite variable to mask possible differences between the progenies. The coefficient of variation reflects this, therefore, for longitudinal shrinkage (SL) the most influential element is the fiber length, which is also the anatomical element with the greatest variability, resulting in the highest SV. In radial shrinkage (SR), the most important feature is fiber wall thickness, resulting in the second highest CV, because fiber thicknesses consistently increase from pith to bark. For tangential shrinkage (ST), the fiber thickness and the diameter of the vessels and radii are important, which do not vary much in thickness and length, decreasing the CV in relation to SR. For volumetric shrinkage (SR), the main components are ST (± 60%) and SR (± 39%); as ST is more influential, CV has reduced considerably. For the SI, the ratio between ST and SR, the value was also high because, while the fiber wall thicknesses consistently increase from the medulla to the bark, increasing the SR, the diameters and heights of the vessels practically remain constant, the ST remains constant. constant, which lowers the AI and raises the CV.

In *Eucalyptus*, depending on the dimensions and arrangements of the fibers, the SL decreases with the age of the tree, ranging from 12.24 to 0.64% of the total shrinkage variation. SR increases from 25.31 to 46.33% and ST increases from 48.12 to 74.89% of the total wood shrinkage. In the present work, the SL ranged from 3.64% to 1.34%, showing that this is juvenile wood because in mature wood, the longitudinal shrinkage is less than 1%. The high longitudinal shrinkage makes wood for carpentry unfeasible because it makes fitting and gluing parts difficult. Other evidence that this is juvenile wood is the low deposition of extractives and the high incidence of collapse due to the low thickness of the fiber wall (Figure 1). With the aging of the plant, the SR increases a lot and the ST little, resulting in a decrease in the SI, which in *Eucalyptus* varies from 1 to 3, the lower the better, because they are related to warping of the wood, mainly the twist, of this way, with SI below 1.50, the wood is considered suitable for carpentry. Related results were found by other researchers (EVANGELISTA et al., 2010; GALLIO et al., 2016; LOPES et al., 2011; MULLER et al., 2014; OLIVEIRA et al., 2010; POLOZZI et al., 2012; SCANAVACA Jr. & GARCIA, 2004).

Basic density correlated with SR (0.6411, $p < 0.0001$), SV (0.4447, $p = 0.0003$) and SI (-0.6796, $p < 0.0001$). Bd does not correlate with ST because ST varies truly little with tree age and Bd grows consistently, so they do not correlate. As fiber wall thickness increases with age and so does Bd, the correlation is higher than with SV because it is more influenced by ST. The correlation with SI is negative because SI decreases with age and Bd increases. Equivalent results were found by other researchers (SCANAVACA Jr. & GARCIA, 2004; WU et al., 2006).

Figure 1. Specimens with node, collapse, and low extractive deposition.

Table 2. Mean per progeny of mechanical properties of woods dried in air and humidity corrected to 12%.

Progenies	Shear (MPa)	Compression (MPa)	MOR (MPa)	MOE (MPa)
32	66,04	57,52	38,23	7839,82
33	47,00	43,25	29,90	8136,85
51	54,18	39,15	39,37	8776,99
52	51,62	41,78	38,21	9142,61
53	51,80	47,80	34,57	7250,97
54	39,54	32,38	45,10	8234,75
59	40,03	40,68	31,17	9309,83
75	50,60	44,48	36,97	8541,12
82	58,56	39,42	37,00	8497,88
85	44,36	41,26	35,10	8086,76
88	19,43	41,27	52,10	13010,23
91	43,83	44,21	30,30	13569,73
92	38,78	48,93	36,30	13004,57
94	38,38	46,18	39,23	10497,04
101	33,68	43,05	36,63	8959,46
108	45,52	49,77	34,27	11586,14
125	52,15	44,79	35,07	8401,37
133	39,37	42,42	34,17	8032,78
137	54,03	40,77	39,90	9703,43
138	45,42	56,83	47,26	11038,22
142	39,70	44,53	35,90	5576,67
Mean	45,69	44,40	37,21	9335,06
DP	14,77	8,65	8,59	3804,64
CV	32,25	18,40	22,96	42,36

Where: MOE = Modulus of elasticity in static bending; MOR = Modulus of rupture in static flexion

There were no statistical differences between the progenies for any of the mechanical properties of the dry woods due to the high variability of the juvenile wood. The averages of these properties by progeny are shown in Table 2.

At the anatomical level, the increase in the thickness of the fiber walls and the decrease in the microfibril angle are the main factors responsible for the increase in density. The amounts of holocellulose, lignin and extractives vary with genetics and environment. Normally, the amount of cellulose, lignin, and extractives, which are positively correlated with mechanical properties, increase with age, while hemicelluloses decrease. Juvenile woods present low percentage of lignin and basic density, consequently inferior mechanical properties. As the plant ages, these percentages increase, which are positively correlated with mechanical properties, cellulose with tensile strength, lignin with resistance to compression, shear, static bending, etc. Extractives are related to the resistance of pests and diseases as well as the embellishment of wood by color.

Some researchers evaluated *E. urophylla* at seven years old and obtained comparable results (ADORNO & GARCIA, 2003; ANDRADE et al., 2010; EVANGELISTA et al., 2010; VEIGA et al., 2018). SCANAVACA Jr. & GARCIA (2004) evaluated 19-year-old and found much higher values for all properties.

Basic density correlated with fiber parallel compression (0.3178, p = 0.0126), MOR (0.3371, p = 0.0079) and MOE (0.2533, p = 0.0499). There was no correlation with shear as a function of fiber wall thickness, which varied greatly. Compression correlates with MOE (0.3216, p = 0.0115) and MOR with MOE (0.3803, p = 0.0025).

Shear was not correlated because while the other properties are influenced by all fiber dimensions and other elements, shear is only influenced by fiber wall thickness, and its high variability did not allow this property to correlate with the others. Compression showed a reasonable correlation with flexion. Considering the age of the trees, good correlations can be considered. The MOR and MOE, as they were calculated in the same piece, a better correlation was expected. The different fiber lengths favored the MOE, the literature shows that the MOR increases consistently with tree age, as a function of fiber thickness, but the MOE does not.

The mechanical properties are lower in juvenile wood in relation to mature wood in 90% for compression, 70% for MOE and 70% to 80% for shear (GEIMEr et al., 1997). Wood pieces containing 40 to 60% juvenile wood, decrease the MOR by 15%, and pieces with 90 to 100% juvenile wood, decrease the MOR by 29% (BARRETT & KELLOGG, 1989).

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The low correlation index is a function of fiber dimensions. Some researchers found weak correlations for these same properties due to working with juvenile wood (ADORNO & GARCIA, 2003; VEIGA et al., 2018); and other better correlations for working with mature wood (SCANAVACA Jr. & GARCIA, 2004).

CONCLUSIONS

The results allow us to conclude that:

• There is no correlation between DBH and the physical and mechanical properties of the wood.

• Basic density has a positive correlation with SR, SV and a negative correlation with SI.

• The basic density has a weak correlation with the mechanical properties because the wood is young.

With the aging of the plant, in addition to the beautification of the wood by the color, the mechanical properties improve because the fibers become thicker, improving all the mechanical properties, especially the shear parallel to the fibers, in which the thickness of the fiber is the most important characteristic, therefore, all properties should improve as the plant ages and these properties should be evaluated when the progenies are 20 years old.

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