

Physical-Mechanical and Anatomical Characterization in 26-Year-Old *Eucalyptus resinifera* Wood

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ABSTRACT

In the present study, we aimed to characterize *Eucalyptus resinifera* wood through physical and mechanical assays and wood anatomy studies, as well as determine the relationships between the properties and anatomy of wood. We used samples collected from the area close to the bark of ten 26-year-old *E. resinifera* trees. We concluded that the specific gravity (G_b), compression (f_{c0}), and shear parallel to grain (f_{v0}) were ranked in strength classes C30, C40 and C60, respectively, and that volumetric shrinkage (VS) was ranked as high. A positive relationship between G_b and f_{v0} results from the higher specific gravity associated with higher tissue proportion, in turn, causing higher shear strength. Higher ray frequency increases shear strength, because rays act as reinforcing elements. A negative relationship between VS and vessel diameter occurs because vessel walls are highly resistant to collapse, and since larger lumens represent a higher proportion of empty spaces, less tissue is available for shrinkage.

Keywords: *Eucalyptus* wood quality, physical-mechanical properties, red mahogany, structure/properties relationships.

Caracterização Físico-Mecânica e Anatômica da Madeira de *Eucalyptus resinifera* com 26 Anos de Idade

RESUMO

Objetivamos caracterizar a madeira *Eucalyptus resinifera* por meio de ensaios físicos e mecânicos, e estudos de anatomia da madeira, bem como determinar as relações entre as propriedades da madeira e a anatomia. Usamos amostras próximas da casca de dez árvores de *E. resinifera* com 26 anos de idade. Concluímos que a densidade aparente (G_b), a compressão (f_{c0}) e o cisalhamento paralelo à grã (f_{v0}) foram classificados em três classes de resistência – C30, C40 e C60, respectivamente – e que a retração volumétrica (VS) foi classificada como alta. A relação positiva entre G_b e f_{v0} é decorrente do alto valor de densidade aparente associado à maior proporção de raios, proporcionando maior resistência ao cisalhamento. Raios mais frequentes aumentaram a resistência ao cisalhamento, pois os raios atuam como elementos de reforço. A relação negativa entre VS e diâmetro do vaso ocorre porque as paredes dos vasos são altamente resistentes ao colapso e maiores lumens representam uma maior proporção de espaços vazios, sendo que menos tecido está disponível para o encolhimento.

Palavras-chave: qualidade da madeira de *Eucalyptus*, propriedades físico-mecânicas, red mahogany, relação anatomia-propriedades.

1. INTRODUCTION

Eucalyptus resinifera Sm. (Myrtaceae) is a medium-sized tree attaining 40 to 45 m in height and 1.0 to 1.5 m in stem diameter. It occurs along the coastal regions of eastern Australia, from Jarvis Bay in New South Wales to Coen in Queensland (Kynaston et al., 2013). In Australia, *E. resinifera* is known as red mahogany, a name also used for *E. pellita*, as a standard trade name (Standards Australia, 2001), because these species have overlapping distributions and a high degree of genetic and morphological variation, leading to the recognition of subspecies or geographic races in each taxon (Le et al., 2009). *E. resinifera* wood is used for many applications in house construction, pulpwood, and fine furniture (Kynaston et al., 2013). The species does not tolerate heavy frost and severe water stress, but it does tolerate fire and has good regeneration by sprouting (Turnbull & Pryor, 1984).

In Brazil, *E. resinifera* was introduced in extensive reforestation programs in the southeast, where it is able to adapt to the subtropical humidity. The species has great potential for industrial applications, but the technological properties its wood require more study because its growth rate is lower than most *Eucalyptus* species cultivated for reforestation in Brazil (Lorenzi et al., 2003). Nonetheless, according to Hornburg et al. (2012), *E. resinifera* is used to a lesser extent in Brazil even though the quality of its lumber is the same as that of *Eucalyptus grandis*.

To evaluate the woods of different *Eucalyptus* species for use as lumber and fuel, the Instituto Florestal conducted the planting of 23 species, including *E. resinifera* (Gurgel-Garrido et al., 1997). Sato et al. (2007) evaluated the silvicultural potential of *E. resinifera* in the same population of our study and concluded that *i*) variation among progenies for volume is enough to be explored from selection, *ii*) the species has growth potential for DBH to be used in commercial reforestation and *iii*) the expected genetic gain in selection among plants within progenies indicates a favorable improvement of the species.

Based on the positive indication for species improvement, as proposed by Sato et al. (2007), our objectives were to *i*) characterize *Eucalyptus*

resinifera wood through physical and mechanical assays and wood anatomy studies and *ii*) determine relationships between wood properties, such as specific gravity, volumetric shrinkage, compression test parallel to grain, shear test parallel to grain, and anatomy.

2. MATERIAL AND METHODS

2.1. Study site and sampling

The study was carried out in 1985 at the Luiz Antônio Experimental Station (Figure 1) in the municipality of Luiz Antônio, São Paulo state, Brazil, with 16 progenies from the municipality of Mareeba, Australia, in a randomized block design with 10 repetitions, five plants per plot, and spacing of 3 × 2 m (Gurgel-Garrido et al., 1997). The planting was located at latitude 21° 40' S, longitude 47° 49' W, 550 m above sea level. The average annual rainfall is 1365 mm over Oxisol or sandy textured soils. Climate is Cwa according to Köppen classification (Ventura et al., 1965-1966).

At 26 years of age, 10 trees were collected from an exploratory forest inventory (Table 1). An 8 cm-thick disc was removed from the DBH region of each tree. In each disc, samples were collected from the area close to the bark for physical and mechanical assays and wood anatomy studies (Figure 1).

2.2. Physical-mechanical properties

Specific gravity (G_b) was determined according to Glass & Zelinka (2010). Samples (2 × 2 × 3 cm) were saturated by treatment with vacuum system for 72 h to obtain the green volume of wood. Subsequently, the samples were dried in a laboratory kiln to determine the oven-dried mass at 102 ± 3 °C.

Volumetric shrinkage (VS) was determined according to ABNT (1997) and was obtained from the same samples used to measure basic density. The samples were saturated in water (green moisture content), measured with a caliper, and oven-dried at 102 ± 3 °C. The dry volume of each sample was then determined. Volumetric shrinkage is the difference in percentage between the green moisture contents.

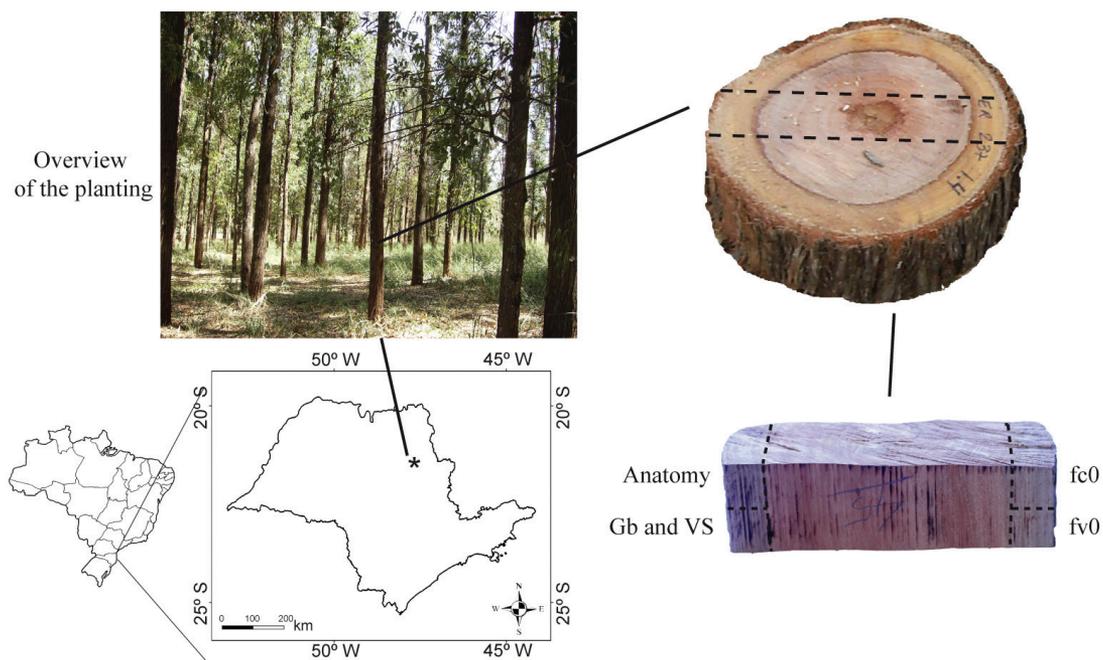


Figure 1. Study area location, overview of the planting and wood samples of 26-year-old *Eucalyptus resinifera* for wood anatomy. G_b = specific gravity, VS = volumetric shrinkage, f_{c0} = compression test parallel to grain, and f_{v0} = shear test parallel to grain.

Table 1. Dendrometric data of 26-year-old *Eucalyptus resinifera* trees. DBH = diameter at breast height.

Tree	Height (m)	DBH (cm)
1	19	19
2	23	24
3	17	16
4	22.5	19
5	21.5	22
6	22	23
7	21.5	17
8	25	22
9	20.5	22.5
10	18	20
Mean	21	20.45

A compression test parallel to grain (f_{c0}) was performed with samples (2 × 2 × 3 cm) in a universal assay machine (ABNT, 1997). The samples had previously been measured using a caliper with accuracy of 0.01-0.05 mm to determine their areas, with a moisture content of 12%. We applied the same rate of strain, i.e., loading rate of the NBR 7190 norm (ABNT, 1997), which is a load application velocity of 10 MPa/min.

A shear test parallel to grain (f_{v0}) was performed with the samples (2 × 2 × 3 cm), assaying a shear area of 5 cm² (ABNT, 1997). One side of the area was sheared 2cm, imposed by the size of the sample section. The second part was the largest amount possible between the first side and the critical value at which compression occurs in the area of the shear plate instead of the shearing of the sample, the amount used was 2.5 cm. The load application velocity was 2.5 MPa/min, therefore, the difference from standard was the rate of load application, but the application rate of the tension was specified in the standard.

2.3. Wood anatomy

We cut small pieces from the side of samples and prepared macerations according to the modified Franklin method (Berlyn & Miksche, 1976). Then samples were boiled for about 60 min in water, glycerin and alcohol (4:1:1). For the anatomical studies, 16-20 μm transverse and tangential longitudinal sections were cut with a sledge microtome; the sections were stained with safranin

solution 1%, washed with distilled water, and mounted on slides in a solution of water and glycerin (1:1). The terminology and characterization of wood followed the IAWA list (IAWA Committee, 1989). All anatomical measures were obtained in a microscope (Olympus CX 31) equipped with a camera (Olympus Evolt E330) and a computer with image analyzer software (Image-Pro 6.3).

2.4. Statistical analyses

Descriptive statistical analysis was conducted to obtain the means, standard deviations, minimum and maximum values. Linear regression analyses were performed between physical-mechanical properties and anatomical features, and results with $p < 0.05$ were considered significant. Statistical analyses were performed following the PROC REG procedure of SAS (SAS, 1999).

3. RESULTS AND DISCUSSION

The mean, minimum, and maximum values and standard deviation of 26-year-old *Eucalyptus resinifera* wood properties are presented in Table 2. Specific gravity, compression, and shear parallel to grain are ranked according to the strength classes of hardwoods from C20 to C60, the latter being more resistant (ABNT, 1997). These classes were created and standardized to guide professionals in the choice of suitable timber depending on the application.

The mean value for specific gravity of *E. resinifera* was 0.74 g.cm^{-3} , ranked at the limit of class C30. For compression parallel to grain and shear parallel to grain, *E. resinifera* wood was ranked in classes C40 and C60, respectively.

Volumetric shrinkage average was 16.67%, ranked as high according to Santos et al. (2008), i.e., low resistance to swelling and shrinkage.

Mori et al. (2003) found basic density of 0.89 g.cm^{-3} and volumetric shrinkage of 20.63% in *E. resinifera* tested in barrels for storage of sugar cane spirits, but Mori's study did not mention the age of the trees. Ferreira & Kageyama (1978) reported density of 0.50 g.cm^{-3} in 6 to 8-year-old *E. resinifera*, a value similar to that reported by Trugilho (2009) with 4-year-old trees. This variation probably results from the increase in density that occurs toward the bark, and it has already been reported in *E. resinifera* by Fonseca (1971). Density increases with age in relation to the increase in the incorporation of dry mass (Santana et al., 2012).

When comparing the wood density of *E. resinifera* with other *Eucalyptus* species, the results vary: Lima et al. (2011) found the same value as ours (0.74 g.cm^{-3}) in 25-year-old *E. umbra*, while lower densities were reported in 15-year-old *E. saligna* (0.55 g.cm^{-3}) by Oliveira & Silva (2003), and *E. grandis* (0.49 g.cm^{-3}) by Lima & Garcia (2005).

Van Vuuren et al. (1978) reported 21.7% of volumetric shrinkage for *E. resinifera* in South Africa. Wood shrinkage is affected by many variables, but greater shrinkage is generally associated with greater density (Glass & Zelinka 2010). However, our value (16.67%) is lower than that reported by Poubel et al. (2011) for 15-year-old *E. pellita* (17.34%), by Oliveira and Silva (2003) for 16-year-old *E. saligna* (28.69%), and by Lima & Garcia (2005) for 18-year-old *E. grandis* (21%). *E. resinifera* and *E. pellita* showed very similar values, a likely result of the similarity between these two types of wood, which are both known by the standard trade name of red mahogany (Standards Australia, 2001; Le et al., 2009).

Numerous wood cracks or, anatomically speaking, checks were observed, i.e., cell separation along the grain. This could be related to the high value of volumetric shrinkage. According to Hillis & Brown (1978), fast-growing *Eucalyptus* species

Table 2. Mean values for specific gravity (G_b), volumetric shrinkage (VS), compression parallel to grain (f_{c0}), and shear parallel to grain (f_{v0}) of 26-year-old *Eucalyptus resinifera* wood.

Property	Mean	Standard deviation	Minimum value	Maximum value
G_b (g.cm^{-3})	0.74	0.04	0.67	0.83
VS (%)	16.67	2.73	13.32	21.33
f_{c0} (MPa)	55.87	6.15	48.10	67.20
f_{v0} (MPa)	16.16	2.91	10.05	19.57

present excessive wood shrinkage, and this causes drying defects, such as warping and cracks.

We did not find other studies describing the values of compression parallel to grain (f_{c0}) or shear parallel to grain in *E. resinifera*, but our f_{c0} result (55.87 MPa) was different when compared with other wood species in the genus: higher than that mentioned by Lima & Garcia (2005) for 18-year-old *E. grandis* (49.95 MPa) and lower than that mentioned by Lima & Garcia (2011) for 21-year-old *E. grandis* (59 MPa). We reported a shear parallel to grain result of 16.16 MPa, which was higher than that mentioned by Lima & Garcia (2011), who reported 13.8 MPa.

The mean, minimum, and maximum values and standard deviation of 26-year-old *Eucalyptus resinifera* anatomical features are presented in Table 3.

With the exception of Mori et al. (2003) and Ammon (2011), we did not find other studies describing the anatomical characteristics of *Eucalyptus resinifera* wood. Mori et al. (2003) found higher vessel frequency (14.7 mm^{-2}) than that found in the present study (9 mm^{-2} , Table 3). Ammon (2011) reported lower values for fiber length (941 μm), vessel diameter (95 μm), height and frequency of rays (192 μm and 4 mm^{-1} , respectively), but a higher value for vessel length (527 μm), while the values for fiber wall thickness (5 μm) and vessel frequency (9 mm^{-2}) were equal to those of this study (Table 3). In the studies of Mori et al. (2003) and Ammon (2011), age and radial position of samples were not mentioned; thus, we speculate that the differences observed between these two studies and our data, in addition to the expected variations between trees, could have been

influenced by age and sampling because, according to Gartner (1995), many species show typical radial pattern in many wood characteristics, e.g., increase in fiber length and an inverse relationship between frequency and diameter of vessel toward the bark. It is worth mentioning that our values derive from samples near the bark of 26-year-old trees.

Linear regression analyses showed a positive relationship between shear parallel to grain, specific gravity and ray frequency (Figure 2a, b), but a negative relationship between volumetric shrinkage and vessel diameter (Figure 2c).

A positive relationship was observed between specific gravity and shear parallel to grain. Since specific gravity depends on cell wall thickness and the diameter of lumen cells, higher shear strength is indirectly related to the greater proportion of cell walls and smaller proportion of cell lumens. Dias & Lahr (2004), who studied 40 hardwood species, found a weak relationship between wood density and shear parallel to grain, whereas Kretschmann (2008) observed a positive relationship ($r^2 = 0.62$) between these two properties in 340 specimens from 28-year-old *Pinus taeda*, showing that this relationship also occurs in softwoods. Usually, mechanical properties tend to be related to wood density, but these relationships are more difficult to explain in hardwoods because their anatomical nature is more complex than that of softwoods (Zhang, 1994).

The positive relationship between shear parallel to grain and ray frequency can be explained by the rays themselves, which help to prevent the slippage of growth layers by shear stress, locking them like a bolt (Mattheck & Kubler, 1995). The role of ray cells

Table 3. Mean values for fiber length (FL), fiber wall thickness (FWT), vessel element length (VEL), vessel diameter (VD), vessel frequency (VF), ray height (RH), ray width (RW), and ray frequency (RF) of 26-year-old *Eucalyptus resinifera* wood.

Feature	Mean	Standard deviation	Minimum value	Maximum value
FL (μm)	1016	116	846	1181
FWT (μm)	5	0.81	3	6
VEL (μm)	483	87	308	590
VD (μm)	147	15	127	173
VF ($\text{n}^\circ\text{mm}^{-2}$)	9	1.18	8	12
RH (μm)	225	25.9	183	278
RW (μm)	23	3	16	26
RF ($\text{n}^\circ\text{mm}^{-1}$)	6	0.8	5	7

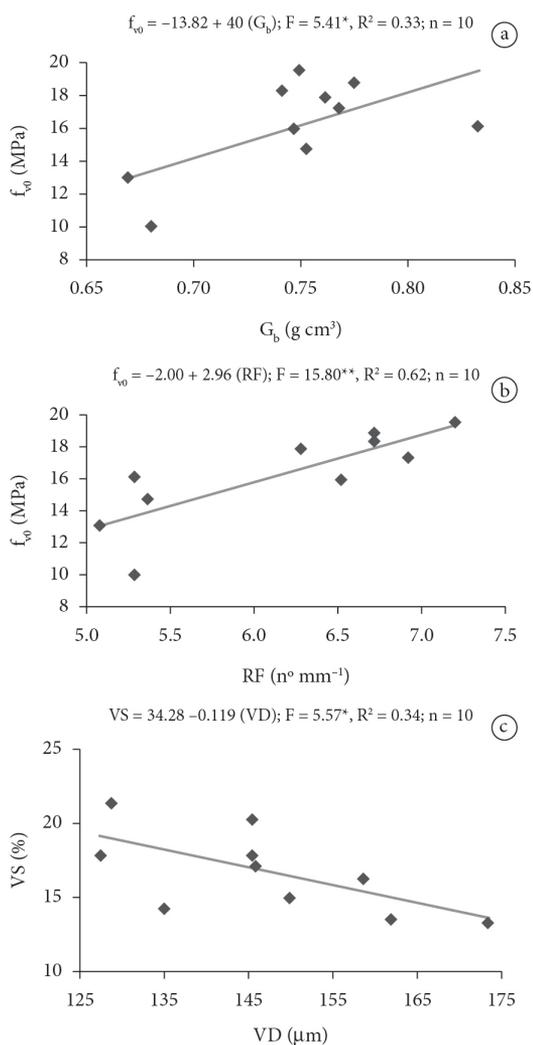


Figure 2. Relationships between the properties and anatomy of 26-year-old *Eucalyptus resinifera* wood. a) Shear parallel to grain (f_{v0}) as a function of specific gravity (G_b); b) Shear parallel to grain as a function of ray frequency (RF); c) Volumetric shrinkage (VS) as a function of vessel diameter (VD).

as reinforcing elements of wood tissue has also been discussed by Burgert et al. (1999).

A significant negative relationship was observed between volumetric shrinkage and vessel diameter. Almeida (2006), who studied two temperate hardwoods, *Betula alleghaniensis* and *Fagus grandifolia*, and five tropical hardwoods, including *Cedrelinga cateniformis*, *Brosimum alicastrum*, *Cariniana domesticata*, *Aspidosperma macrocarpon* and *Robinia coccinea*, found a negative relationship ($r^2 = 0.74$) between shrinkage factor and vessel

diameter. Lobão et al. (2011), studying nine Brazilian native species, including *Balfourodendron riedelianum*, *Hymenolobium petraeum*, *Ocotea porosa*, *Aspidosperma polyneuron*, *Cedrela odorata*, *Schizolobium parahyba*, *Apeiba tibourbou*, *Ochroma pyramidale* and *Tabebuia serratifolia*, and two *Eucalyptus* species, *E. grandis* and *E. saligna*, also found a negative relationship between volumetric shrinkage and vessel diameter. We understand that a negative relationship between volumetric shrinkage and vessel diameter occurs because larger vessel lumens represent a higher proportion of empty spaces, leaving little or no tissue to shrink. In addition, the vessel wall is highly resistant to implosion during drying because, according to Baas et al. (2004), vessels withstand high pressures caused by transpiration. This statement helps to explain the lower shrinkage for vessels of larger diameters.

4. CONCLUSIONS

Specific gravity, compression and shear parallel to grain were ranked in strength classes C30, C40 and C60, respectively (ABNT, 1997), and volumetric shrinkage was ranked as high (Santos et al., 2008). Anatomical features were partially different from other studies, possibly owing to the expected variations between trees, age and sampling. A positive relationship between specific gravity and shear parallel to grain can be explained by higher specific gravity, which is caused by a higher proportion of tissue. This, in turn, results in higher shear strength. Higher frequency of rays increases shear strength because rays act as reinforcing elements. A negative relationship between volumetric shrinkage and vessel diameter occurs because vessel walls are highly resistant to collapse, and larger lumens represent a higher proportion of empty spaces, with correspondingly less tissue available for shrinkage.

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REFERENCES

Almeida G. *Influence de la structure du bois sur ses propriétés physico-mécaniques à des teneurs en humidité élevées* [tese]. Québec: Université Laval; 2006.

Ammon RA. *Anatomia do lenho de dez espécies de Eucalyptus L'Hér* [monografia]. Seropédica: Instituto de Florestas, Universidade Federal Rural do Rio de Janeiro; 2011.

Associação Brasileira de Normas Técnicas - ABNT. *Projeto de estruturas de madeira*: projeto NBR 7190/1997. Rio de Janeiro, 1997. 107 p.

Baas P, Ewers FW, Davis SD, Wheeler EA. Evolution of xylem physiology. In: Poole I, Hemsley A, editors. *Evolution of Plant Physiology*. London: Elsevier Academic Press (Linnaean Society Symposium Series); 2004. p. 273-295.

Berlyn GP, Miksche JP. *Botanical microtechnique and cytochemistry*. Iowa: The Iowa University Press; 1976. 326 p.

Burgert IA, Bernasconi E, Eckstein D. Evidence for the strength function of rays in living trees. *Holz Roh Werkstoff* 1999; 57: 397-399. <http://dx.doi.org/10.1007/s001070050367>

Dias FM, Lahr FAR. Estimativa de propriedades de resistência e rigidez da madeira através da densidade aparente. *Scientia Forestalis* 2004; 65: 102-113.

Ferreira M, Kageyama PY. *Melhoramento genético da densidade básica da madeira do eucalipto*. In: *Anais do Congresso Florestal Brasileiro*; 1978; Manaus. São Paulo: SBS; 1978. v. 2, p. 148-52.

Fonseca FMA. *Qualificação tecnológica de madeiras de eucalipto*. Contribuição para o estado macro, microscópico, físico e mecânico da madeira de algumas espécies de eucaliptos cultivados em Angola. Angola: Instituto de Investigação Agronômica de Angola; 1971. 72 p.

Gartner BL. Patterns of xylem variation within a tree and their hydraulic and mechanical consequences. In: Gartner BL, editor. *Plant stems: physiology and functional morphology*. New York: Academic Press; 1995. p. 125-149. <http://dx.doi.org/10.1016/B978-012276460-8/50008-4>

Glass S, Zelinka SL. Moisture Relations and Physical Properties of Wood. In: Ross R, editor. *Wood Handbook*. Centennial Edition. FPL-GTR-190. U.S. Department of Agriculture, Forest Service, Forest Products Laboratory; 2010.

Gurgel-Garrido LMA, Siqueira ACMF, Cruz SF, Romanelli RC, Ettori LG, Crestana CSM, et al. Programa de melhoramento genético florestal do Instituto Florestal. *IF Série Registros* 1997; 18: 1-53.

Hillis WE, Brown AG. *Eucalyptus for wood production*. Melbourne: CSIRO; 1978. 434 p.

Hornburg UKF, Eleotério JR, Bagattoli TR, Nicoletti AL. Qualidade das toras e da madeira serrada de seis espécies de eucalipto cultivadas no litoral de Santa Catarina. *Scientia Forestalis* 2012; 40(96): 463-471.

International Aviation Womens Association - IAWA Commitee. List microscope features of hardwood identification. *IAWA Bulletin* 1989; 10(3): 221-259.

Kretschmann DE. *Influence of juvenile wood content on shear parallel, compression, and tension transverse to grain strength and mode I fracture toughness for loblolly pine*. Madison: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory; 2008. 25 p. Research Paper FPL-RP-647.

Kynaston WT, Eccles DB, Hopewell GP. *Timber Species Series*. Queensland Government - Department of Agriculture, Fisheries and Forestry. 2013. [cited 2013 jul. 18]. Available from: <http://www.daff.qld.gov.au/forestry/using-wood-and-its-benefits/wood-properties-of-timber-trees/red-mahogany>.

Le S, Nock C, Henson M, Shepherd M. Genetic differentiation among and within three red mahoganies (series Annulares), *Eucalyptus pellita*, *E. resinifera* and *E. scias* (Myrtaceae). *Australian Systematic Botany*, 2009; 22(5): 332-343. <http://dx.doi.org/10.1071/SB09004>

Lima IL, Garcia JN. Efeito da fertilização em propriedades mecânicas da madeira de *Eucalyptus grandis*. *Ciência Florestal* 2011; 21: 601-608.

Lima IL, Garcia JN. Influência do desbaste em propriedades físicas e mecânicas da madeira *Eucalyptus grandis* Hill ex-Maiden. *Revista do Instituto Florestal*. 2005; 17: 151-160.

Lima IL, Longui EL, Garcia R, De Luca EF, Da Silva FGJ, Florsheim SMB. Propriedades da Madeira de *Eucalyptus umbra* R. T. Baker em Função do Diâmetro e da Posição Radial na Tora. *Floresta e Ambiente* 2011; 18(3): 289-298. <http://dx.doi.org/10.4322/floram.2011.049>

- Lobão MS, Castro VR, Rangel A, Sarto C, Tomazello M F, Silva FGS Jr, et al. Agrupamento de espécies florestais por análises univariadas e multivariadas das características anatômica, física e química das suas madeiras. *Scientia Forestalis* 2011; 39(92):469-477.
- Lorenzi H, De Souza HM, Torres MAV, Bacher LB. *Árvores exóticas no Brasil: madeiras, ornamentais e aromáticas*. Nova Odessa: Instituto Plantarum; 2003. 368 p.
- Mattheck C, Kubler H. *Wood – The internal optimization of trees*. Berlin: Springer-Verlag; 1995. 129 p.
- Mori AF, Mendes LM, Trugilho PF, Cardoso MG. Utilização de Eucaliptos e de madeiras nativas no armazenamento da aguardente de cana-de-açúcar. *Ciência e Tecnologia de Alimentos* 2003; 23(3): 396-400. <http://dx.doi.org/10.1590/S0101-20612003000300018>
- Oliveira JTS, Silva JC. Variação radial da retratibilidade e densidade básica da madeira de *Eucalyptus saligna* Sm. *Revista Árvore* 2003; 27(3): 381-385. <http://dx.doi.org/10.1590/S0100-67622003000300015>
- Poubel DS, Garcia RA, Latorraca JVF, Carvalho AM. Estrutura Anatômica e Propriedades Físicas da Madeira de *Eucalyptus pellita* F. Muell. *Floresta e Ambiente* 2011; 18(2): 117-126. <http://dx.doi.org/10.4322/floram.2011.029>
- Santana WMS, Calegario N, Arantes MDC, Trugilho PF. Effect of age and diameter class on the properties of wood from clonal *Eucalyptus*. *Cerne*, 2012; 18 (1): 1-8. <http://dx.doi.org/10.1590/S0104-77602012000100001>
- Santos JA, Santos J, Borralho N, Araújo J. Caracterização das Potencialidades de Utilização da Madeira de Híbridos de Eucalipto. *Silva Lus* 2008, 16(1): 63-81.
- Statistical Analysis System Institute - SAS. *SAS Procedures Guide*. version 8 (TSMO). Cary: SAS Institute Inc.; 1999.
- Sato A, Sebbenn A, Moraes E, Zanatto A, Freitas M. Seleção dentro de Progênes de *Eucalyptus resinifera* aos 21 anos de idade em Luiz Antônio – SP. *Revista do Instituto Florestal* 2007; 19(1): 93-100.
- Standards Australia. *AS/NZS 1148:2001: Timber – Nomenclature – Australian, New Zealand and imported species*. Australian Standard, New Zealand Standa, SAI Global Limited; 2001. Available from: www.saiglobal.com.
- Trugilho PF. Densidade básica e estimativa de massa seca e de lignina na madeira em espécies de *Eucalyptus*. *Ciência e Agrotecnologia* 2009; 33(5): 1228-1239. <http://dx.doi.org/10.1590/S1413-70542009000500005>
- Turnbull JW, Pryor LD. *Choice of species and seed sources*. In: Hillis WE, Brown AG, editors. *Eucalyptus for wood production*. Sidney: CSIRO, Academic Press; 1984. cap. 2, p. 6-65.
- Van Vuuren NJJ, Banks CH, Stöhr HP. Shrinkage and density of timbers used in the Republic of South Africa. 1978. Bulletin (South Africa. Department of Forestry (1945-1980), 57.
- Ventura A, Berengut G, Victor MAM. Características edafoclimáticas das dependências do Serviço Florestal do Estado de São Paulo. *Silvicultura em São Paulo* 1965-1966; 4: 57-140.
- Zhang SY. Mechanical-properties in relation to specific-gravity in 342 chinese woods. *Wood and Fiber Science*, 1994; 26(4): 512-526.