Engenharia Agrícola

ISSN: 1809-4430 (on-line)

www.engenhariaagricola.org.br

Doi: http://dx.doi.org/10.1590/1809-4430-Eng.Agric.v39n6p763-768/2019

TECHNICAL PAPER

EVALUATION OF THE *Peltophorum vogelianum* Benth. WOOD SPECIES FOR STRUCTURAL USE

André L. Christoforo[1*], Vinicius B. de M. Aquino[2], Anderson R. V. Wolenski[3], Victor A. De Araujo[4], Francisco A. R. Lahr[5]

[1*]Corresponding author. Universidade Federal de São Carlos (UFSCar)/ São Carlos - SP, Brasil.
E-mail: christoforoal@yahoo.com.br | ORCID ID: https://orcid.org/0000-0002-4066-080X

KEYWORDS

Peltophorum vogelianum, characterization, apparent density, regression models, analysis of variance (ANOVA).

ABSTRACT

Wood is a material used for various purposes since ancient times and is mainly used in civil and rural construction and industry. Due to the predatory exploitation of known trees, it is necessary to characterize new species for use in urban and rural structures as alternatives of species commonly used. This study aimed to determine the physical and mechanical properties of Guarucaia wood (*Peltophorum vogelianum* Benth.) based on the Brazilian standard ABNT NBR 7190 (1997) and estimate the strength and stiffness as a function of apparent density using the analysis of variance and also estimate stiffness as a function of its strength. The mechanical properties of *P. vogelianum* were considered compatible for structural use when compared with others used for the same purpose, being classified in the class C50 of dicotyledon species and evidencing the possibility of its use for structural purposes. According to the results of the poor quality in the fit of regression models in the statistical analysis, the strength and stiffness could not be estimated as a function of apparent density nor stiffness properties as a function of their respective strengths.

INTRODUCTION

Wood is a natural and renewable material that has been used by humans for various purposes since ancient times, such as shelters, tools, and supplies. Currently, this abundant material in Brazil has been used in the construction, furniture, pulp and paper, sports equipment, and musical instrument industry (Zangiácomo et al., 2014; Beech et al., 2017; Christoforo et al., 2017a).

The use of this a versatile material implies knowing all its properties (anatomical, physical, mechanical, and chemical) so that its use can be performed efficiently, meeting the environmental demands by products and services provided by society (Dias & Lahr, 2004; Machado et al., 2014; Christoforo et al., 2017b; Aquino et al., 2018).

The high demand for wood by the various sectors of the industry led to selective and predatory extraction of species known to the construction market, thus leading to an increase in prices of these wood species. Thus, it is necessary to characterize and evaluate new wood species for structural use (Lahr et al., 2016a; Cavalheiro et al., 2016; Silva et al., 2018). The use of wood species *Peltophorum vogelianum* Benth. can be considered a good alternative, occurring in the Brazilian states of Bahia, Rio de Janeiro, Minas Gerais, Goiás, Mato Grosso do Sul, and Paraná (Lorenzi, 1998).

Timber structures in Brazil are designed using the Brazilian standard ABNT NBR 7190 (1997), which establishes requirements for the design, classification, and characterization of wood, defining the tests for determining wood physical and mechanical properties. However, these tests require the use of expensive equipment, available only at research centers.

Apparent density, defined as the ratio between the mass and apparent volume, with samples at the standard moisture of 12%, is a physical property of easy experimental determination that can be correlated with strength and stiffness properties by mathematical methods, allowing their estimation (Almeida et al., 2014; Dadzie & Amoah, 2015; Almeida et al., 2016; Christoforo et al., 2016). The possibility of estimating the strength and

[2] Universidade Federal do Sul e Sudeste do Pará (UNIFESSPA)/ Santana do Araguaia - PA, Brasil.
[3] Instituto Federal de Santa Catarina (IFSC)/ São Carlos - SC, Brasil.
[4] Grupo de Pesquisa LIGNO/ Itapeva - SP, Brasil.
[5] Escola de Engenharia de São Carlos, Universidade de São Paulo (EESC/ USP)/ São Carlos - SP, Brasil.
Received in: 8-25-2018
Accepted in: 10-2-2019

stiffness properties as a function of apparent density is an alternative to reduce costs and time.

The appendix B of the Brazilian standard ABNT NBR 7190 (1997) presents standard tests for determining stiffness properties (compressive and tensile strength parallel to fibers, compressive and tensile strength perpendicular to fibers, and static bending) of the wood, requiring testing machines, strain gauges, or dial indicators to measure deformations, unlike the strength properties, which are obtained from the relationship between the maximum stresses and geometric properties of the cross-sections of samples.

Considering the importance of stiffness properties in the sizing of wood structures, such as bridges, sheds, and timber residences (Ruelle et al., 2011; Machado et al., 2014; Dadzie & Amoah, 2015; Komariah et al., 2015), it is important to evaluate the possibility of estimating the stiffness properties as a function of the respective strength properties.

No studies can be found in the literature on the physical, mechanical, or anatomical characterization of the species *P. vogelianum* Benth., which reinforces the unprecedentedness of the present research. In order to contribute to the use of new wood species for structural purposes, this research aimed to characterize the wood species *P. vogelianum* Benth., as well as evaluate the possibility of estimating strength and stiffness properties as a function of apparent density and stiffness properties as a function of their strength properties.

MATERIAL AND METHODS

Wood samples from *P. vogelianum* extracted from western Pará State were properly stocked, resulting in samples with moisture content close to 12%, which is the equilibrium humidity defined by the Brazilian standard ABNT NBR 7190. The specimens were approximately 15 years old until harvesting.

Tests were performed at the Laboratory of Wood and Wood Structures (LaMEM), Department of Structural Engineering (SET), São Carlos Engineering School (EESC), University of São Paulo (USP).

Physical and mechanical properties were obtained according to prescriptions of the Brazilian standard ABNT NBR 7190 (1997), as set out in Appendix B. The evaluated properties and the number of experimental determinations per property are shown in Table 1. Three physical and 12 mechanical properties were evaluated, resulting in obtaining 180 experimental values. *P. vogelianum* wood was classified in the appropriate strength class (ABNT, 1997), according to the characteristic value of the compressive strength parallel to fibers ($f_{c0,k}$).

TABLE 1. Physical and mechanical properties evaluated for the species *Peltophorum vogelianum*.

Property	Abbreviation	ND
Apparent density	ρ_{12}	12
Total radial shrinkage	TRS	12
Total tangential shrinkage	TTS	12
Compressive strength parallel to fibers	f_{c0}	12
Compressive strength perpendicular to fibers	f_{c90}	12
Tensile strength parallel to fibers	f_{t0}	12
Tensile strength perpendicular to fibers	f_{t90}	12
Shear strength parallel to fibers	f_{v0}	12
Strength to cracking	f_{s0}	12
Conventional strength in static bending test	f_m	12
Hardness parallel to fibers	f_{H0}	12
Hardness perpendicular to fibers	f_{H90}	12
Longitudinal modulus of elasticity in the compressive parallel to fibers	E_{c0}	12
Modulus of elasticity in the compressive perpendicular to fibers	E_{c90}	12
Longitudinal modulus of elasticity in the tensile parallel to fibers	E_{t0}	12
Conventional modulus of elasticity in the static bending test	E_m	12
Toughness	W	12

ND – number of determinations.

The classification of *P. vogelianum* wood in the strength classes for the dicotyledon group was performed using [eq. (1)], where f_k is the characteristic strength value and n is the number of specimens. The strength results from Equation 1 should be placed in ascending order ($f_1 \leq f_2 \leq \ldots \leq f_n$), not considering the highest value if the number of specimens is odd, and not taking f_k values lower than f_1 and nor at 0.70 of the mean value.

$$f_{c0,k} = \left(2 \cdot \frac{f_1 + f_2 + f_3 + \ldots + f_{(n/2)-1}}{(n/2)-1} - f_{n/2} \right) \cdot 1{,}10 \quad (1)$$

Regression models (Equations 2 to 5) based on analysis of variance (ANOVA) were used to estimate strength and stiffness properties as a function of wood apparent density and also stiffness as a function of strength, with *Y* being the estimated property (dependent variable), *X* the independent variable, and a and b the parameters adjusted by the least-squares method.

$$Y = a + b \cdot X \quad \text{[Lin – linear]} \quad (2)$$

$$Y = a \cdot e^{b \cdot X} \quad \text{[Exp – exponential]} \tag{3}$$

$$Y = a + b \cdot Ln(X) \quad \text{[Log – logarithmic]} \tag{4}$$

$$Y = a \cdot X^{b} \quad \text{[Geo – geometric]} \tag{5}$$

The ANOVA of regression models at 5% significance level (α) showed that the null hypothesis formulated consisted of non-representativeness of tested models (H_0: $\beta = 0$) and representativeness as an alternative hypothesis. P-value higher than the significance level implies the acceptance of H_0 (the model is not representative, i.e., variations in the independent variable cannot explain variations in the estimated properties), refuting it otherwise (the tested model is representative). The coefficient of determination (R^2) was used to evaluate the quality of the obtained adjustments, allowing selecting the best accuracy for each evaluated relationship. Fifty-five density regression models were used as an estimator of 16 other variables (including the physical properties TRS and TTS), and 16 other models for strength properties as stiffness estimators, which resulted in 72 equations in all.

RESULTS AND DISCUSSION

Table 2 shows the mean values (X_m), coefficients of variation (CV), maximum values (Max), minimum values (Min), and the mean confidence interval (CI, 95% confidence) of physical and mechanical properties of Guarucaia wood, already shown in Table 1.

TABLE 2. Results obtained from the physical and mechanical properties of Guarucaia wood.

Property	X_m	CV (%)	Min	Max	CI
ρ_{ap} (g/cm^3)	0.92	8.00	0.73	0.98	0.87; 0.97
$\varepsilon_{r,2}$ (%)	4.13	18.00	3.45	6.12	3.67; 4.58
$\varepsilon_{r,3}$ (%)	8.09	11.00	7.23	9.89	7.54; 8.63
f_{c0} (MPa)	64.00	10.00	53.00	71.00	58.18; 65.81
f_{t0} (MPa)	75.00	18.00	54.00	103.00	66.10; 83.89
f_{t90} (MPa)	5.60	19.00	4.00	7.80	4.90; 6.29
f_{v0} (MPa)	20.00	18.00	16.00	26.00	17.45; 22.54
f_{s0} (MPa)	1.00	14.00	0.80	1.20	0.93; 1.06
f_M (MPa)	95.00	16.00	76.00	124.00	85.47; 104.53
f_{H0} (MPa)	96.00	16.00	60.00	117.00	86.47; 105.53
f_{H90} (MPa)	77.00	24.00	33.00	94.00	65.56; 88.43
W (N·m)	12.70	39.00	6.00	19.30	9.59; 15.81
E_{c0} (MPa)	16214	14.00	13196	19605	14789; 17639
E_{t0} (MPa)	14370	16.00	10765	18075	12931; 15809
E_M (MPa)	15002	22.00	12328	24559	12868; 17136

Based on the characteristic value [56 MPa] of the compressive strength parallel to fibers ($f_{c0,k}$) of *P. vogelianum* wood (Equation 1), it was grouped into the strength class C50 of dicotyledons.

The f_{c0} value [64 MPa] of Guarucaia wood was close to the value obtained in the study carried out by Dias & Lahr (2004) [62 MPa]. This species is in the same resistance class as Cupiúba [57 MPa] (Silva et al., 2018) and *Eucalyptus urophylla* [46 MPa] (Lahr et al., 2017), which are commonly used in structures (ABNT NBR 7190, 1997).

The value of compressive strength parallel to fibers (f_{c0}) of *P. vogelianum* wood [64 MPa] was higher when compared to other species, such Branquilho [48 MPa] (ABNT NBR 7190, 1997), Louro Preto [56 MPa] (ABNT NBR 7190, 1997), Cambará [34 MPa] (Lahr et al., 2016b), and Angelim Araroba [50 MPa] (ABNT NBR 7190, 1997). Branquilho, Louro Preto, and Angelim Araroba woods are indicated for structural use (ABNT NBR 7190, 1997), reinforcing the potential use of Guarucaia wood species for this purpose.

Considering the mean value obtained for apparent density [0.92 g/cm^3], *P. vogelianum* wood can be classified as a heavy wood (Melo et al., 1990), in the same class as Pariri [0.92 g/cm^3] (Almeida et al., 2015), Jatobá [1.08 g/cm^3] (Lahr et al., 2016c), *Minquartia guianensis*, *Lecythis poiteaui*, *Mezilaurus itauba*, *Manilkara huberi*, *Brosimum rubescens* (Silveira et al., 2013), and Cupiúba [0.84 g/cm^3] (Silva et al., 2018). *P. vogelianum* wood presented a higher density when compared to *Cedrela odorata* [0.41 g/cm^3] (Fernandes et al., 2018), *Liquidambar* sp. [0.55 g/cm^3] (Freitas et al., 2015), and *Hovenia dulcis* [0.51 g/cm^3] (Leite et al., 2014).

The Brazilian standard ABNT NBR 7190 (1997) establishes the maximum value of the coefficient of variation as a criterion to consider an adequate characterization, being 18% for perpendicular and 28% for tangential strengths. All properties met the normative requirement, except toughness (W), which exceeded the limit (39%).

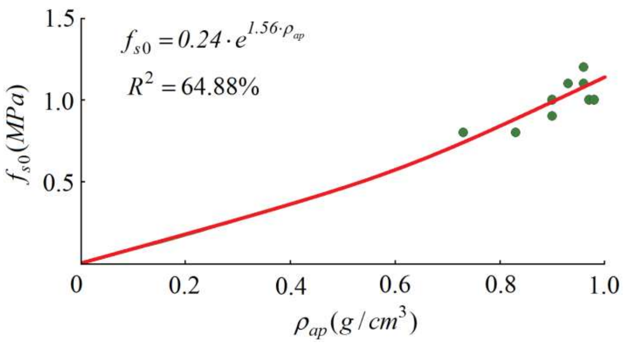
Table 3 shows the best adjustments obtained using regression models for apparent density in the estimation of the other properties, in which the models considered significant by ANOVA (5% significance) are underlined.

TABLE 3. Regression models based on apparent density as an estimator of other properties.

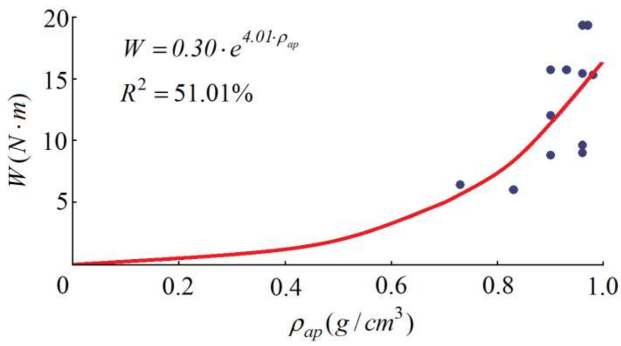
EP	Model	P-value	a	b	R^2 (%)
TRS	Exponential	0.8048	4.74	−0.16	0.64
TTS	Geometric	0.2377	8.37	0.43	13.62
f_{c0}	Linear	0.3054	39.03	25.56	10.45
f_{t0}	Geometric	0.7099	75.41	0.24	1.44
f_{t90}	Linear	0.5751	3.25	2.56	3.25
f_{v0}	Exponential	0.1917	8.45	0.94	16.39
f_{s0}	Exponential	<u>0.0016</u>	0.24	1.56	64.88
f_M	Logarithmic	0.8314	96.57	11.64	0.48
f_{H0}	Logarithmic	0.2758	101.45	59.25	11.73
f_{H90}	Logarithmic	0.1996	84.82	81.95	15.86
W	Exponential	<u>0.0090</u>	0.30	4.01	51.01
E_{c0}	Geometric	0.3962	16721.39	0.42	7.29
E_{t0}	Geometric	0.1533	15306.90	0.81	19.27
E_M	Linear	0.9588	14982.02	−0.02	0.03

EP – estimated property.

Apparent density was considered significant only in the estimation of strength to cracking (f_{s0}) [R^2 = 64.88%] and toughness (W) [R^2 = 51.01%], being the exponential model the best fit for both properties. Figure 1 shows the two regression models considered significant.



(a)



(b)

FIGURE 1. Density models as cracking (a) and toughness (b) estimators.

The significant adjustments in Table 3 show that the coefficients of determination are below 70% and hence with low precision (Christoforo et al., 2017a). The poor quality of the adjustment of regression models in the statistical analysis of properties indicates the impossibility of using the apparent density as their estimator in the present study. This impossibility (low precision) to estimate most properties may be due to the anatomical characteristics of the wood itself, which requires further studies to evaluate if there is an effective relationship. Related studies have shown the existence of a good correlation between apparent density and other properties due to the use of more than one wood species and mean values instead of sample values. The use of the mean value reduces the intrinsic variability of wood, but this approach could not be used here, as it is only one species. It is important to point out that Almeida et al. (2014) evaluated the use of apparent density with toughness estimator and found good quality regression models in the adjustment [$R^2 > 70\%$]. It can be explained by the use of species with different densities and strength classes. Silva et al. (2018) also found a significant relationship between apparent density and toughness, with good fit quality [R^2 = 75.82%].

In addition, some authors have found significant relationships between apparent density and compressive strength, such as for woods of *Calycophyllum multiflorum* [R^2 = 52.59%] (Christoforo et al., 2017a), *Vatairea* sp. [R^2 = 63.57%] (Lahr et al., 2016a), and Castelo [R^2 = 52.84%] (Almeida et al., 2016), different from that found for Guarucaia in the present study.

Table 4 shows the best adjustments obtained in the estimation of stiffness properties as a function of their strength property.

TABLE 4. Regression models to estimate stiffness properties as a function of strength properties.

EP	Model	P-value	a	b	Equation	R^2 (%)
E_{c0}	Linear	0.8051	18076	−30	$E_{c0} = a + b \cdot f_{c0}$	0.64
E_{t0}	Geometric	0.1946	2862	0.37	$E_{t0} = a \cdot f_{t0}{}^{b}$	16.19
E_M	Geometric	0.8040	9498	0.10	$E_M = a \cdot f_m{}^{b}$	0.65

EP – estimated property.

Table 4 shows that the models were not significant, revealing the impossibility of estimating stiffness properties as a function of the respective strength property.

CONCLUSIONS

The characterization of *P. vogelianum* wood was adequate for structural use according to the Brazilian standard ABNT NBR 7190 (1997).

Considering the criteria established in the Brazilian standard and due to the characteristic compressive strength value, *P. vogelianum* wood is classified into the C50 strength class, being compatible with other species of structural use. It evidences the possibility of using Guarucaia wood for structural use.

According to the values of coefficients of determination obtained in the adjustments, regression models did not show good precision in the estimation of the properties, revealing the impossibility of using the apparent density as an estimator of other properties and strength properties as an estimator of stiffness properties. More comprehensive results require the use of a variety of species.

ACKNOWLEDGMENTS

To the Coordination for the Improvement of Higher Education Personnel (CAPES) and the National Council for Scientific and Technological Development (CNPq) for all the support provided during the development of this research.

REFERENCES

Almeida DH, Scaliante RM, Christoforo AL, Varanda LD, Lahr FAR, Dias AA, Calil Junior C (2014) Tenacidade da madeira como função da densidade aparente. Revista Árvore 38(1)203-207.

Almeida DH, Chahud E, Almeida TH, Christoforo AL, Branco LAMN, Lahr FAR (2015) Determination of Density, Shear and Compression Parallel to the Grain Strengths of Pariri (*Pouteria sp.*), Brazilian Native Wood Specie. International Journal of Materials Engineering 5(5):109-112.

Almeida TH, Almeida DH, Christoforo AL, Chahud E, Branco LAMN, Lahr FAR (2016) Density as Estimator of Strength in Compression Parallel to the Grain in Wood. International Journal of Materials Engineering 6(3):67-71.

Aquino VBM, Almeida JPB, Almeida DH, Almeida TH, Panzera TH, Christoforo AL, Lahr FAR (2018) Physical and Mechanical Characterization of *Copaifera sp.* Wood Specie. International Journal of Materials Engineering 8(3):55-58.

ABNT - Associação Brasileira De Normas Técnicas (1997) NBR 7190: projeto de estruturas de madeira. ABNT, 107 p.

Beech E, Rivers M, Oldfield S, Smith PP (2017) GlobalTreeSearch: The first complete global database of tree species and country distributions. Journal of Sustainable Forestry 36(5)454-489.

Cavalheiro RS, Almeida DH, Almeida TH, Christoforo AL, Lahr FAR (2016) Density as Estimator of Shrinkage for Some Brazilian Wood Species. International Journal of Materials Engineering 6(3):107-112.

Christoforo AL, Almeida TH, Almeida DH, Santos JC, Panzera TH, Lahr FAR (2016) Shrinkage for Some Wood Species Estimated by Density. International Journal of Materials Engineering 6(2):23-27.

Christoforo AL, Arroyo FN, Silva DAL, Panzera TH, Lahr FAR (2017a) Full characterization of *Calycophyllum multiflorum* wood specie. Engenharia Agricola 37(4):637-643.

Christoforo AL, Aftimus BHC, Panzera TH, Machado GO, Lahr FAR (2017b) Physico-mechanical characterization of the *Anadenanthera colubrina* wood specie. Engenharia Agricola 37(2):376-384.

Dadzie PK, Amoah M (2015) Density, some anatomical properties and natural durability of stem and branch wood of two tropical hardwood species for ground applications. European Journal of Wood and Wood Products 73(6):759-773.

Dias FM, Lahr FAR (2004) Estimativa de propriedades de resistência e rigidez da madeira através da densidade aparente. Scientia Forestalis/Forest Sciences (65):102-113.

Fernandes NCL, Valle MLA Calderon CMA (2018) Características físicas e anatômicas de *Cedrela odorata* L. e *Cedrelinga cateniformis* Ducke. Floresta e Ambiente 25(1):1-10.

Freitas TP, Feuchard LD, Oliveira JTS, Paes JB, Arantes MDC (2015) Caracterizações anatômica e físico-mecânica da madeira de *Liquidambar sp*. Floresta 45(4):723-734.

Komariah RN, Hadi YS, Massijaya MY, Suryana J (2015) Physical-mechanical properties of glued laminated timber made from tropical small-diameter logs grown in Indonesia. Journal of the Korean Wood Science and Technology 43(2):156-167.

Lahr FAR, Aftimus BHC, Arroyo FN, Almeida DH, Christoforo AL, Chahud E, Branco LAMN (2016a) Full Characterization of *Vatairea sp.* Wood Specie. International Journal of Materials Engineering 6(3):92-96.

Lahr FAR, Arroyo FN, Almeida TH, Almeida Filho FM, Mendes IS, Christoforo AL (2016b) Full Characterization of *Erisma uncinatum* Warm. Wood Specie. International Journal of Materials Engineering 6(5):147-150.

Lahr FAR, Christoforo AL, Silva CEGD, Andrade Junior JR, Pinheiro RV (2016c) Avaliação de propriedades físicas e mecânicas de madeiras de jatobá (Hymenaea stil. Revista Arvore 40(1):147-154.

Lahr FAR, Nogueira MCJA, Araujo VA, Vasconcelos JS, Christoforo AL (2017) Physico-mechanical characterization of the *Eucalyptus urophylla* wood specie. Engenharia Agricola 37(5):900-906.

Lorenzi H (1998) Árvores brasileiras: manual de identificação e cultivo de plantas arbóreas nativas do Brasil. Nova Odessa, Editora Plantarum, 2 ed. v 2.

Machado JS, Louzada JL, Santos AJA, Nunes L, Anjos O, Rodrigues J, Simões RMS, Pereira H (2014) Variation of wood density and mechanical properties of blackwood (Acacia melanoxylon R. Br.). Materials and Design 56:975-980.

Melo JE, Coradin VTR, Mendes JC (1990) Classes de densidade de madeira para a Amazônia brasileira. In: Congresso Florestal brasileiro. São Paulo, Anais...

Ruelle J, Beauchêne J, Yamamoto H, Thibaut B (2011) Variations in physical and mechanical properties between tension and opposite wood from three tropical rainforest species. Wood Science and Technology 45(2):339-357.

Silva CEG, Almeida DH, Almeida TH, Chahud E, Branco LAMN, Campos CI, Lahr FAR, Christoforo AL (2018) Influence of the Procurement Site on Physical and Mechanical Properties of Cupiúba Wood Species. BioResources 13(2):4118-4131.

Silveira LHC, Rezende AV, Vale AT (2013) Teor de umidade e densidade básica da madeira de nove espécies comerciais amazônicas. Acta Amazonica 43(2):179-184.

Zangiácomo AL, Christoforo AL, Lahr FAR (2014) Módulo de elasticidade aparente em vigas roliças estruturais de madeira Pinus elliottii. Ambiente Construído 14(1):7-13.