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INFLUENCE OF HARVEST REGION ON PROPERTIES OF CAMBARÁ WOOD

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ABSTRACT

This research intends to evaluate the relation, aided by the Brazilian Standard and statistical analysis (Kruskal-Wallis ANOVA and bootstrap technique), between physical and mechanical properties of Cambará-Rosa wood harvested from three different regions: Vera, Mucajaí and South Rondonia. In addition, the possibility to estimate (regression models) physical and mechanical properties in function of apparent density was analyzed. Different climate and soil conditions which tree thrives may influence its growth and, consequently, its properties values. The results of ANOVA indicated an elevated equivalence index for all three regions. The bootstrap technique led to similar results for Vera and Mucajai regions, and for South Rondonia region, equivalence index equals to 89 %. The ANOVA results to estimate physical and mechanical properties in function of apparent density indicated that it is not possible to perform such estimates for Cambará-Rosa wood species.

Keywords: Density, *Erisma uncinatum*, mechanical properties, shrinkage, statistical analysis, timber structures.

INTRODUCTION

Brazil is the country with the largest wood flora biodiversity, presenting 8715 wood species. Brazil also displays the highest number of endemic wood species, with 4333 species. The country owns large vegetal cover, covering 58 % of its territory (493,5 million hectares). However, in this case, only a few number of

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native wood species is characterized, and this fact demonstrates the importance to know physical and mechanical wood properties for an efficient wood use (Dias and Lahr 2004, Cardoso *et al.* 2012, Beech *et al.* 2017, Christoforo *et al.* 2013, Christoforo *et al.* 2017a, SFB 2018).

Wood use in civil construction, mainly in structural purpose, presents great potential due its strength values are close to other civil construction materials such as steel and concrete. The wood is a natural and renewable material and displays a low energetic demand on its productive process (Muttil *et al.* 2014, Hurmekoski *et al.* 2015, Ferreira *et al.* 2017, Ramage *et al.* 2017, Wieruszewski and Mazela 2017, Nascimento *et al.* 2018).

Considering anatomical, physical, chemical and mechanical wood properties and the fact that for an appropriate use in civil construction it is crucial to know the wood properties, its characterization must be performed according the type of effort applied on wood (tension, compression or shear), direction in relation to the grain (parallel or perpendicular) and moisture classes. Also, the wood species can be classified in strength classes (Araújo 2007, Adamopoulos and Passialis 2010, Machado *et al.* 2014, Komariah *et al.* 2015, Ruiz-Aquino *et al.* 2018, Silva *et al.* 2018).

In Brazil, the timber structures, industrial or residential, are calculated by the ABNT NBR 7190 Brazilian Code (1997). This normative code presents the general conditions of execution, design and control of timber structures, also presents the requirements for wood characterization and the mean values of the physical and mechanical properties for some Brazilian wood species.

Cambará is a tree that reaches from 7 m to 18 m high. This type of tree can be found in the Amazon, in the Brazilian states of Acre, Amapá, Amazonas, Pará, São Paulo and Rondônia and in some countries neighboring Brazil such as Guyana, French Guiana, Suriname and Venezuela. This tree has fissured rough bark through narrow and long plaques. Its wood is soft with medium texture and fairly resistant. It is used in civil construction for general plating, plywood and boxes. It is indicated for mixed reforestations destined to the recovery and enrichment of degraded areas (Lorenzi 1998, IPT 2018).

The different climatic conditions, vegetation and soil in which the trees grow can influence the values of the physical and mechanical properties of the wood. Then, in this context, it is usual the presence of wood harvested from different regions in the same batch. On literature there are few researches evaluating the influence of harvest site on wood properties considering tropical hardwoods (Machado *et al.* 2014, Lahr *et al.* 2016a, Silva *et al.* 2018). Therefore, it is necessary to know their influence on the values of their properties and develop researches to verify the influence of site on physical and mechanical wood properties.

Dias and Lahr (2004) performed the complete characterization of the Cambará wood, placing it in the strength class C20 by its characteristic strength to the compression parallel to the fibers ($f_{c0,k}$) equal to 27,2 MPa and apparent density ($\rho_{ap,12}$) equal to 544 kg/m³.

Segundinho *et al.* (2013) evaluated Cambará glulam beams to determine the dynamic elasticity modulus (E_{Mvt}) and the static modulus of elasticity (E_M). These values were determined by means of the transversal vibration tests and by static bending tests, respectively. The rupture modulus (f_M), compressive strength (σ_{cp}) and the parallel modulus of elasticity (E_{cp}) were also determined. In the compression tests, Cambará wood was classified in the strength class C30 of the hardwoods.

Lahr *et al.* (2016b) also characterized *Erisma uncinatum* and placed this wood species on strength class C20 of hardwoods ABNT NBR 7190 (1997). It must be pointed out that each research used Cambará samples harvested from different sites.

The apparent density of the wood, referring to the moisture content of 12 %, is a physical property of easy determination and this can be easily related to the properties of strength and rigidity from the use of mathematical methods. This is an alternative to reduce time and costs on properties determination (Christoforo *et al.* 2014, Machado *et al.* 2014, Dadzie and Amoah 2015, Almeida *et al.* 2016, Christoforo *et al.* 2017a).

Therefore, the aim of this research was the evaluation of the influence of different harvest regions of Cambará wood specie in their physical and mechanical properties. Thus, with the properties of each region, it was verified if the mean property obtained from all batches of the different harvesting sites were equal to the average of the same property for each harvest site batch. Also, the possibility of estimating the physical properties, the strength and stiffness by the apparent density was also evaluated using the ANOVA of the regression models.

MATERIAL AND METHODS

Experimental procedure

Three homogenous Cambará (*Erisma uncinatum* Warm.) batches, compounded by different trunks with 12 m³ of wood each, were harvested from three different sites in Brazil: Vera, Brazilian state of Mato Grosso (Ver) (12°21'24,80"S; 55°19'36,89"O), Mucajaí, Brazilian state of Roraima (Muc) (2°20'4,66"N; 60°58'43,49"O) and southern region of the Brazilian state of Rondônia (SRo) (12° 5'25,48"S; 60°14'18,16"O). The characteristics of growth sites and of Cambará trees are given in Table 1. All wood samples were stored with moisture content of 12 %, according to the ABNT NBR 7190 Brazilian standard (1997).

Table 1: Characteristics of Cambará tree growth sites.

Site	Vera (Ver)	Mucajaí (Muc)	Southern Region of Rondonia (SRo)
Tree age (years)	32-37	35-41	31-36
Altitude (m)	378	72	270
Rainfall ($mm \cdot yr^{-1}$)	1940	1639	1715
Mean temperature (°C)	25,1	27,1	27,7
DBH (cm)	59	53	62
Soil origin	Clay	Sand	Clay
Height to the top (m)	9	11	12

From each Cambará batch from each different harvest site (Ver, Muc and SRo) were extracted 12 proof tests for each property considered in the wood characterization, according to the ABNT NBR 7190 Brazilian Standard (1997). Table 2 shows the tests that were performed in this case.

All mechanical and physical tests were performed at the Wood and Timber Structures Laboratory (LaMEM), Department of Structural Engineering (SET), São Carlos Engineering School (EESC), University of São Paulo (USP). Statistical analysis was carried out in the Federal University of São Carlos (UFSCar) using the software BioStat 5.3. ® (Instituto de Desenvolvimento Sustentável Mamirauá- Brazil, 2008).

Table 2: Physical and mechanical properties of Cambará wood evaluated in this research according the ABNT NBR 7190 Brazilian Standard (1997).

		NA per Region		
Properties	Symbol	Ver	Muc	SRo
Apparent density	ρ_{12}	12	12	12
Total radial Shrinkage	$\varepsilon_{r,2}$	12	12	12
Total tangential Shrinkage	$\varepsilon_{r,3}$	12	12	12
Compressive strength parallel to the grain	f_{c0}	12	12	12
Tensile strength parallel to the grain	f_{t0}	12	12	12
Tensile strength normal to the grain	f_{t90}	12	12	12
Shear strength parallel to the grain	f_{v0}	12	12	12
Splitting strength	f_{s0}	12	12	12
Conventional strength on static bending test	f_M	12	12	12
Modulus of elasticity in parallel directions to the grain	E_{c0}	12	12	12
Modulus of elasticity in tension parallel to the grain	E_{t0}	12	12	12
Conventional modulus of elasticity on static bending test	E_m	12	12	12
Hardness parallel to the grain	f_{H0}	12	12	12
Hardness normal to the grain	f_{H90}	12	12	12
Toughness	W	12	12	12
Compressive Strength Normal to the Grain	f_{c90}	12	12	12
Modulus of Elasticity on compression normal to the grain	E_{c90}	12	12	12

NA: Number of Samples.
Vera (Ver), Mucajaí (Muc), Southern Region of Rondonia (SRo).

Aiming to classify Cambará wood batches into strength classes according to the ABNT NBR 7190 Brazilian Code (1997) the characteristic values of the strength properties (Equation 1) were calculated, as well as the average values of the physical and mechanical properties. The experimental results of strength to the specific request (f) were placed in ascending order ($f_1 \leq f_2 \leq f_3 \ldots \leq f_n$), neglecting the highest value when the number of test bodies was odd. The characteristic value may not be less than 70 % of the mean value of the strength in this method.

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

Statistical analysis

The analysis of variance (ANOVA) of Kruskal-Wallis (non-parametric test) was used to consider the influence of the Cambará wood extraction factor on physical and mechanical properties. For this, the level of significance (α) of ANOVA considered was 5 %. The null hypothesis (H_0) consisted in considering that the property of the wood of a certain region was equivalent to the same property considering the totality of the joint results of the three extraction sites, and in the difference of means of the two groups (considering region and set of regions) as the alternative hypothesis (H_1). Thus, the p-value (probability of P) of the test higher than the value of 5 % of significance denoted the equivalence of means of the two groups (acceptance of H_0), and non-equivalence with p-value less than 0,05.

In order to evaluate the comprehensiveness of the results of the analysis of variance (ANOVA) in the study of the influence of the extraction regions for each property investigated, the simulation technique or bootstrap resampling was used, being a simulation, from a small sample, of numerous samples with withdrawal and replacement of some of their elements. For this, with the accepted level of significance of 5 %, the assumed null hypothesis (H_0) was in the consideration of the equivalence of the means of each property coming from an isolated region with the same property considering the joint result of the three regions and the alternative hypothesis (H_1), the non-equivalence of the two groups. The number of simulations adopted in this evaluation was 10000.

The estimated physical and mechanical properties of Cambará wood as a function of apparent density were made by the use of the regression models (Equation 2, Equation 3, Equation 4 and Equation 5) and were analysed by ANOVA. In Equation 2, Equation 3, Equation 4 and Equation 5, Y represents the dependent variable, which may be a physical or mechanical property, X represents the independent variable, defined as the apparent density and a and b are the parameters of the least squares fitted models.

$$Y = a + bX(Lin - linear) \quad (2)$$

$$Y = ae^{bX}\,(Exp - exponential) \quad (3)$$

$$Y = a + b\ Ln(X)(Log\text{ - }logarithmic) \quad (4)$$

$$Y = aX^{b}\,(Geo - geometric) \quad (5)$$

For the analysis of variance of the regression models, considering the 5 % level of significance (α), the null hypothesis consisted of the non-representativeness of the models tested (H0: β = 0), and in the representativeness as an alternative hypothesis (H1: $\beta \neq 0$). p-value higher than the level of significance implied the acceptance of the null hypothesis and the model tested was not representative. Therefore, in this case, variations of the apparent density ($\rho_{ap,12\%}$) were unable to explain the variations of the estimated property and should be refuted. Otherwise, the model tested was representative.

Besides the use of analysis of variance, which allowed or not to accept the representativeness of tested models, the values of the coefficient of determination (R^2) were obtained in order to evaluate the capacity of variation of the apparent density, thus allowing the determination of models with the best fit. It is worth mentioning that the apparent density was used to estimate 16 properties, being 2 physical properties and 14 mechanical properties, using 4 different mathematical models, (linear, exponential, logarithmic and geometric) totalizing 64 adjustments.

RESULTS AND DISCUSSION

Table 3, Table 4 and Table 5 present the mean values ($\bar{x}$), coefficients of variation (Cv), maximum (Max) and minimum values (Min), the mean confidence interval (CI – 95 % confidence) of the physical and mechanical properties, as well as the characteristic values (f_{wk}) of the strength properties of Cambará wood. In this case, the results are presented for the woods originated from Vera (Ver) in Brazilian state of Mato Grosso, Mucajaí (Muc) in Brazilian state of Roraima and Southern region of Brazilian state of Rondônia (SRo), respectively.

Table 3: Results obtained from the physical and mechanical properties of Cambará wood from the municipality of Vera - MT.

Property	$\bar{x}$	Cv (%)	Mín	Máx	CI	f_{wk} (MPa)
$\rho_{ap,12\%}$ (g/cm^3)	0,59	10,00	0,53	0,61	0,56; 0,61	---
$\varepsilon_{r,2}$ (%)	4,84	33,98	2,21	6,94	3,91; 5,77	---
$\varepsilon_{r,3}$ (%)	7,52	29,91	3,73	10,95	6,24; 8,79	---
f_{c0} (MPa)	45,58	11,27	36,00	53,00	42,32; 48,83	40,00
f_{t0} (MPa)	63,85	41,77	27,00	111,00	46,90; 80,79	25,16
f_{t90} (MPa)	2,70	27,41	1,80	4,10	2,22; 3,17	2,02
f_{v0} (MPa)	8,90	18,02	7,00	12,00	7,88; 9,92	7,55
f_{s0} (MPa)	0,46	14,78	0,30	0,60	0,41; 0,50	0,37
f_M (MPa)	94,73	25,23	41,00	117,00	79,54; 109,91	49,62
f_{H0} (MPa)	48,21	14,11	40,00	59,00	43,89; 52,53	41,23
f_{H90} (MPa)	34,40	9,84	28,00	41,00	32,25; 36,55	30,42
f_{c90} (MPa)	7,28	16,09	6,00	9,00	6,54; 8,02	6,46
W (N·m)	5,65	26,73	3,10	8,70	4,69; 6,61	---
E_{c0} (MPa)	11919	27,56	7326	18024	9832; 14006	---
E_{t0} (MPa)	11426	37,74	4519	19421	8687; 14167	---
E_M (MPa)	11262	26,98	7725	16473	9332; 13192	---
E_{c90} (MPa)	529	13,23	425	634	484; 573	---

Table 4: Results obtained from the physical and mechanical properties of Cambará wood from the municipality of Mucajaí - RR.

Property	$\bar{x}$	Cv (%)	Mín	Máx	CI	f_{wk} (MPa)
$\rho_{ap,12\%}$ (g/cm^3)	0,54	9,96	0,47	0,67	0,51; 0,57	---
$\varepsilon_{r,2}$ (%)	3,61	26,71	2,26	5,31	3,00; 4,22	---
$\varepsilon_{r,3}$ (%)	7,16	13,68	6,11	9,61	6,53; 7,78	---
f_{c0} (MPa)	37,38	25,42	27,00	58,00	31,34; 43,42	25,63
f_{t0} (MPa)	57,36	22,58	32,00	75,00	49,13; 65,59	38,22
f_{t90} (MPa)	2,58	30,65	1,40	3,80	2,07; 3,08	1,28
f_{v0} (MPa)	9,55	20,99	6,00	12,00	8,27; 10,82	6,63
f_{s0} (MPa)	0,38	29,08	0,20	0,60	0,31; 0,45	0,17
f_M (MPa)	81,14	15,59	64,00	107,00	73,10; 89,18	71,07
f_{H0} (MPa)	62,35	23,91	43,00	95,00	52,88; 71,82	46,31
f_{H90} (MPa)	38,58	49,78	22,00	94,00	26,38; 50,78	22,23
f_{c90} (MPa)	6,31	18,28	5,00	9,00	5,58; 7,04	4,97
W (N·m)	4,90	36,82	2,90	8,90	3,74; 6,02	---
E_{c0} (MPa)	9190	25,17	7018	14856	7720; 10658	---
E_{t0} (MPa)	9776	15,74	8150	12342	8799; 10753	---
E_M (MPa)	9424	17,90	7473	12569	8352; 10496	---
E_{c90} (MPa)	481	11,79	386	572	444; 517	---

Table 5: Results obtained from the physical and mechanical properties of Cambará wood from the municipality of Southern region of Rondonia.

Property	$\bar{x}$	Cv (%)	Mín	Máx	CI	f_{wk} (MPa)
$\rho_{ap,12\%}$ (g/cm^3)	0,56	4,17	0,53	0,61	0,55; 0,57	---
$\varepsilon_{r,2}$ (%)	3,70	14,06	2,89	4,68	3,36; 4,03	---
$\varepsilon_{r,3}$ (%)	7,10	11,54	5,34	7,95	6,57; 7,62	---
f_{c0} (MPa)	43,44	12,84	35,00	52,00	39,98; 46,98	39,18
f_{t0} (MPa)	63,65	23,91	41,00	87,00	53,98; 73,32	41,68
f_{t90} (MPa)	3,12	35,05	1,80	4,90	2,43; 3,81	1,63
f_{v0} (MPa)	7,86	24,60	5,00	11,00	6,63; 9,09	4,93
f_{s0} (MPa)	0,70	24,33	0,50	1,10	0,59; 0,81	0,48
f_M (MPa)	93,57	18,09	72,00	122,00	82,81; 104,32	75,43
f_{H0} (MPa)	52,75	17,05	38,00	65,00	47,03; 58,46	38,06
f_{H90} (MPa)	40,43	16,12	30,00	49,00	36,29; 44,57	29,97
f_{c90} (MPa)	6,14	24,01	4,00	8,00	5,21; 7,07	4,32
W (N·m)	5,80	32,13	3,20	8,80	4,66; 6,94	---
E_{c0} (MPa)	10380	16,72	8732	13262	9277; 11483	---
E_{t0} (MPa)	10612	22,61	7626	14498	9087; 12136	---
E_M (MPa)	9904	17,53	7728	12560	8801; 11007	---
E_{c90} (MPa)	520	17,78	370	645	461; 578	---

The observation of the characteristic values obtained for the compressive strength parallel to the grain ($f_{c0,k}$) of the wood removed from the three analyzed regions shows that there were differences between them, with which one being classified on different strength classes. The woods from Vera, Mucajaí and Southern region of Rondônia were classified, in this case, in strength classes C40, C20 and C30, respectively.

These values are higher than the values presented by the ABNT NBR 7190 Brazilian standard (1997), which classifies Cambará wood only in strength class C20, regardless of the extraction site.

The mean values of the tensile strength parallel to the grain (f_{t0}) for the regions of Vera and Southern Rondônia were approximately 63 MPa. These values are above the value presented in the ABNT NBR 7190 Brazilian Standard (1997), equal to 58,1 MPa. For the Mucajaí region, the mean value of the tensile strength parallel to the grain (57,4 MPa) was below the disposed in the same Normative Code.

Analyzing the mean values of the shear strength (f_{v0}) parallel to the fibers, the values of all regions were higher than the value established in ABNT NBR 7190 Brazilian Standard (1997), equal to 5,8 MPa. The values ranged from 7,86 MPa for the Southern region of Rondônia to 9,55 MPa for the Mucajaí region.

It was also observed that the characteristic strength on static bending ($f_{M,k}$) presented a difference between the values of the Vera region and the Mucajaí and Southern region of Rondônia regions. The characteristic values ($f_{M,k}$) presented in this case were 49,62 MPa for the Vera region, 71,07 MPa and 75,43 MPa for the regions of Mucajaí and Southern Rondônia, respectively.

The results of the mechanical properties (f_{c0}, f_{t0}, f_{t90}, f_{v0}, f_{s0}, f_M, E_{c0}, E_{t0}, E_{M0}, f_{H0}, f_{H90}, W) obtained in this study were close to the results obtained in the studies by Dias and Lahr (2004), Lahr *et al.* (2016b) and also close to the data provided by the Institute of Technological Research (IPT 2018).

Table 6 shows the results (p-values) of the Kruskal-Wallis ANOVA, for each physical and mechanical property, confronting a region with the set of results of the three regions (Ver, Muc, SRo) with P-values considered to be significant underlined (P-value < 0,05).

Table 6: Results of p-values of the Kruskal-Wallis ANOVA.

Prop,	Ver×(Ver, Muc, SRo)	Muc×(Ver, Muc, SRo)	SRo×(Ver, Muc, SRo)
ρ_{12}	0,0994	0,1092	0,9619
$\varepsilon_{r,2}$	0,1398	0,3407	0,6003
$\varepsilon_{r,3}$	0,7841	0,7478	0,9620
f_{c0}	0,1390	0,0699	0,7385
f_{t0}	0,9430	0,6167	0,6679
f_{t90}	0,7110	0,5827	0,3580
f_{v0}	0,9711	0,2181	0,2333
f_{s0}	0,5511	0,0122	0,0021
f_M	0,2522	0,1073	0,6419
f_{H0}	0,1043	0,0775	0,8861
f_{H90}	0,4031	0,4383	0,1072
f_{c90}	0,0877	0,5986	0,2368
W	0,5836	0,2679	0,5756

Vera (Ver), Mucajaí (Muc), Southern Region of Rondonia (SRo).

The data in Table 6 indicates that the Mucuri and Southern Rondônia regions, when evaluated separately, presented results of the properties with 94 % of equivalence in relation to the set of properties of the Cambará species considering all three regions results. On the other hand, the Vera region presented full equivalence (100 %) with the joint properties.

Table 7 shows the P-values of ANOVA, the results extrapolated by the simulation technique or bootstrap resampling of each property by confronting a region with the set of results of all three regions (Ver, Muc, SRo).

Table 7: Results of p-values of the ANOVA using bootstrap technique.

Prop,	Ver×(Ver, Muc, SRo)	Muc×(Ver, Muc, SRo)	SRo×(Ver, Muc, SRo)
ρ_{12}	0,1320	0,1861	0,1786
$\varepsilon_{r,2}$	0,0841	0,2516	0,3492
$\varepsilon_{r,3}$	0,3591	0,1903	0,2902
f_{c0}	0,1350	0,0884	0,3584
f_{t0}	0,2507	0,4556	0,2484
f_{t90}	0,2961	0,4902	0,3239
f_{v0}	0,0762	0,2570	0,2174
f_{s0}	0,4318	0,0189	0,0056
f_M	0,4642	0,1388	0,4645
f_{H0}	0,0950	0,0698	0,3427
f_{H90}	0,2868	0,1397	0,4387
f_{c90}	0,0909	0,3597	0,2303
W	0,3112	0,3279	0,4280
E_{c0}	0,1331	0,1329	0,1145
E_{t0}	0,4521	0,3516	0,0045
E_M	0,1993	0,2874	0,3236
E_{c90}	0,4219	0,2224	0,2755

Vera (Ver), Mucajaí (Muc), Southern Region of Rondonia (SRo).

The results of the analysis of variance presented in Table 7 showed that the regions of Mucajaí and South of Rondônia continued to present a high equivalence index, maintaining 94 % for the Mucajaí region and 89 % for the South of Rondônia region. The Vera region continued to maintain full equivalence with the joint results of the Cambará properties from the set of regions. It can be observed that the resampling technique got worsen the equivalence rate of the South of Rondônia region, reducing from 94 % in Kruskal-Wallis ANOVA to 89 % in ANOVA with extrapolation of results with the resampling technique.

Considering the arranged results, it was verified that the harvest regions, object of this research, did not influence in the physical and mechanical properties of Cambará wood. This confirms the Brazilian Code ABNT NBR 7190 (1997) lack of consideration of possible influences on properties due to extraction regions.

Machado *et al.* (2014) and Lahr *et al.* (2016a) also obtained similar results in the evaluation of regions of influence for blackwood and Jatobá wood, respectively, extracted from different harvest sites. However, Silva *et al.* (2018) found different results for the evaluation of the influence of extraction regions on Cupiúba wood, with influence on the physical and mechanical properties due to the extraction region.

Observing the information presented on Table 1, the differences on soil type, rainfall, tree age and altitude did not influence significantly on Cambará wood properties, as demonstrated by the statistical analysis. Considering some issues along harvest and testind process, it was not possible to evaluate the differences along the tree, using juvenile and mature wood, once wood was sawed on harvest site and randomly distributed on truck, being impossible to distinguish mature and juvenile wood, pointing out that Cambará wood is tropical wood specie.

Table 8 presents the best adjustments obtained by property taking into account the four types of adjustments used in this research for the three regions (considering the set of regions as a single group). In this case a and b are the coefficients adjusted by the Least Squares Method, R^2 the coefficient of determination (measures the quality of fit) and the p-value being the probability p that allows judging the representativeness (p-value $<$ 0,05) or the non-representativeness (p-value $>$ 0,05) of the models tested. It is worth noting that the adjusted models were estimated by the apparent density, whose values ranged from 0,47 g / cm^3 to 0,67 g / cm^3.

Table 8: Results of p-values of the ANOVA of regression models.

Prop,	Model	P-value	a	b	Expression	R^2 (%)
$\varepsilon_{r,2}$	Exponential	0,0000	0,39	4,05	$\varepsilon_{r,2} = a \cdot e^{b \cdot \rho_{12}}$	46,96
$\varepsilon_{r,3}$	Linear	0,0007	-1,53	15,51	$\varepsilon_{r,3} = a + b \cdot \rho_{12}$	28,72
f_{c0}	Linear	0,0012	-2,62	78,75	$f_{c0} = a + b \cdot \rho_{12}$	26,70
f_{t0}	Linear	0,1868	13,61	84,71	$f_{t0} = a + b \cdot \rho_{12}$	5,07
f_{t90}	Logarithmic	0,1567	4,18	2,40	$f_{t90} = a + b \cdot Ln(\rho_{12})$	5,82
f_{v0}	Linear	0,3389	12,44	-6,36	$f_{v0} = a + b \cdot \rho_{12}$	2,69
f_{s0}	Logarithmic	0,4407	0,67	0,26	$f_{v0} = a + b \cdot Ln(\rho_{12})$	1,76
f_M	Geometric	0,1279	128,64	0,67	$f_M = a \cdot \rho_{12}{}^b$	6,68
f_{H0}	Logarithmic	0,5931	47,30	-12,48	$f_{H0} = a + b \cdot Ln(\rho_{12})$	0,85
f_{H90}	Geometric	0,0794	58,92	0,837	$f_{H90} = a \cdot \rho_{12}{}^b$	8,77
f_{c90}	Linear	0,0018	-1,09	13,50	$f_{c90} = a + b \cdot \rho_{12}$	25,10
W	Exponencial	0,1255	0,20	1,63	$W = a \cdot e^{b \cdot \rho_{12}}$	6,76
E_{c0}	Linear	0,0007	-5775	28713	$E_{c0} = a + b \cdot \rho_{12}$	28,83
E_{t0}	Linear	0,2028	3347	12807	$E_{t0} = a + b \cdot \rho_{12}$	4,73
E_M	Linear	0,0963	2887	12898	$E_M = a + b \cdot \rho_{12}$	7,92
E_{c90}	Geometric	0,3124	596	0,29	$E_{c90} = a + b \cdot Ln(\rho_{12})$	3,00

Only five regression models were considered significant by ANOVA (p-value < 0,05), all of them presenting a coefficient of determination (R^2) of less than 50 %, indicating poor quality in the adjustment made (Montgomery 2012). Thus, as in the study by Lahr *et al.* (2016b), there was no possibility of estimating physical and mechanical properties of Cambará by empirical modelling.

Christoforo *et al.* (2017a) evaluated the relationship between the apparent density and the physical and mechanical properties of the wood species *Calycophyllum multiflorum* and found relationships with good quality in the adjustment ($R^2 > 70$ %), as well as Lahr *et al.* (2016c) for wood species *Vatairea sp*. However, Aquino *et al.* (2018) did not find relations between apparent density and physical and mechanical properties of *Copaifera sp.*, as well as Christoforo *et al.* (2017b) for the wood specie *Anadenanthera colubrina*.

Also, the low p-value and R^2 coefficient may be demonstrated by anatomical composition of Cambará wood species, where force application on fragile wood structures, such wood polyosis, contributes for a brittle rupture (Morando *et al.* 2019, Christoforo *et al.* 2020). Further researches on wood anatomy must deal this behavior of wood under force application on different positions along and normal the grain.

CONCLUSIONS

The physical and mechanical properties of Cambará wood samples were determined in this study according to ABNT NBR 7190 (1997) Brazilian standard. In this case, some properties presented few divergences, with site having no influence on physical and mechanical properties. Cambará woods from each extraction region were classified in strength classes C20, C30 and C40. These classifications were higher than the reference value presented in ABNT NBR 7190 (1997) Brazilian standard.

The analysis of variance (ANOVA) showed full equivalence for the Cambará wood extracted from the Vera region when compared to the results set. The regions of Mucajaí and South of Rondônia presented an equivalence index equal to 94 %. Using the resampling technique, the equivalence index of the southern region of Rondônia was reduced to 89 %. For the regions of Vera and Mucajaí, the equivalence indexes obtained in ANOVA were maintained.

Most of the regression models used to estimate the physical and mechanical properties of the Cambará wood as a function of apparent density were not significant by ANOVA. The models that were significant showed a coefficient of determination (R^2) of less than 50 %. This implies in the impossibility of estimating physical and mechanical properties in function of the apparent density.

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