# Influence of the Procurement Site on Physical and Mechanical Properties of Cupiúba Wood Species

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Studies that estimate technological properties of tropical wood species (especially those from the Amazon Rainforest) for their use in building construction, mainly structures, are very desirable. This paper aimed to investigate, aided by ABNT NBR 7190 (1997) recommendations, by Kruskal-Wallis analysis of variance (ANOVA), and regrouping bootstrap simulation technique, the influence of procurement sites (Caracaraí and Bonfim do Sul, State of Roraima, Brazil) and Cláudia (State of Mato Grosso, Brazil) on physical and mechanical properties of a Cupiúba wood species (*Goupia glabra* Aubl.). It was intended to assess the possibility of estimating (by linear, exponential, geometric, and logarithmic mathematical models) the physical and mechanical properties investigated as a function of density at 12% of moisture content. The results of ANOVA indicated equivalence in 94% of the properties of the Caracaraí and Claudia sites, and no equivalence in 50% of the properties in the Bonfim site; even after extrapolation by the bootstrap simulation technique, the non-equivalence was still 44%. Results obtained from the regression models implied a possibility of an estimate of the physical and mechanical properties of Cupiúba wood species using density as the estimator.

*Keywords: Amazon forest; Mechanical properties; Physical properties; Regression Models; Tropical wood*

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## INTRODUCTION

Brazil is one of the main countries in the world in relation to forest potential, mainly because of the Amazon Forest region in its territory (Laurance *et al*. 2001; Hubbell *et al*. 2008; Walker *et al*. 2009). Recent research estimates that there are 16,000 tree species in the Amazon Forest, the majority in Brazilian territory (Steege *et al*. 2016); however, a small fraction of these species have their physical and mechanical properties already determined (Cassiano *et al*. 2013; Christoforo *et al*. 2017). These data show how studying technological properties of Brazilian native woods is important for their rational use (IMAFLORA 2017; FSC 2017).

For applications of wood in civil engineering, mainly for structural purposes (bridges, roofs, and formworks, for example) the knowledge of its properties is essential, as has been pointed out (Kollmann and Côté 1968; Bodig and Jayne 1993; Calil Jr. *et al.* 2003; Herzog *et al.* 2004; Calil Jr. and Molina 2010). Due to its anatomical characteristics, wood must be characterized according to effort (compression, tension, or shear), directions related to the grain (parallel or perpendicular), and moisture classes (Almeida *et al.* 2013; Toong *et al.* 2014; Icimoto *et al.* 2015; Cavalheiro *et al.* 2016).

In Brazil, the design of timber structures must be developed according to ABNT NBR 7190 (1997). This Code presents all the necessary performance requirements, including strength classes for dicotyledons and conifers. It also presents mean values of some physical and mechanical properties for several Brazilian native species (Lahr *et al.* 2016; Almeida *et al*. 2017a).

Cupiúba (*Goupia glabra* Aubl.) is a wood species whose properties are presented by the ABNT NBR 7190 (1997) Code. It is native from the Amazon Forest (Hirai *et al.* 2007) and, in Brazil, found in the states of Acre, Amapá, Amazonas, Mato Grosso, Pará, Roraima and Rondônia (IPT 2017). Batches of wood of the same species can present different values of their properties (Pletz *et al.* 2006), because of edaphoclimatic factors (Ribeiro and Zani Filho 1993; Romagnoli *et al.* 2014; Huda *et al.* 2014; Csordós *et al.* 2014; Cuecuecha *et al.* 2015; Coral *et al.* 2017) are inherent to the site where they were cultivated (Rodrigues *et al.* 2008). Studies to determine the physical and mechanical properties of wood, from different sites of Brazil, must be developed to verify its technological feasibility for use as raw material for timber structures.

Almeida and Dias (2016) determined strength in compression parallel to the grain ($f_{c0}$) and embedment parallel to the grain ($f_{e0}$): 44.5 MPa and 33.9 MPa, respectively, for a Cupiúba batch from Amazon Forest, with moisture content around 12%. Density of this batch, estimated by Almeida and Dias (2016), was 0.89 g/cm³.

Anjos and Sousa (2015) studied the moisture gain curve and the hygroscopic equilibrium content in Cupiúba wood specie from the state of Pará (Brazil), submitted to thermal treatments at different temperatures (140 ºC, 160 ºC, and 180 ºC). Anjos and Sousa (2015) concluded that hygroscopic equilibrium content and moisture gain curve imposed reduction of the hygroscopicity of the analyzed batch.

Jesus *et al.* (2015) determined characteristic strength values in compression ($f_{c0,k}$), in tension ($f_{t0,k}$), and in shear ($f_{v0,k}$) parallel to the grain: 38.39 MPa, 43.71 MPa, and 6.74 MPa, respectively. The mean value of the modulus of elasticity in compression parallel to the grain ($E_{c0,m}$) was 13,882 MPa. The batch of the Cupiúba wood specie studied by Jesus *et al.* (2015) presented 0.82 g/cm³ and came from the north of state of Mato Grosso (Brazil). Other studies pertaining to the physical and mechanical properties of Cupiúba wood species from different extraction sites have been carried out (Oliveira and Sales 2002; Dias and Lahr 2004; Faria *et al.* 2008; Nicolas *et al.* 2008; Sales *et al.* 2011; Tomppo *et al.* 2016; Tiita *et al.* 2017; Yamasaki *et al.* 2017).

The possibility of estimating wood mechanical properties, especially those from native forests, is highly interesting to scientific and technological communities. Usually, these estimations are carried out by regression models adopting, as estimator, another known wood property. Density is one parameter that can be used as an estimator of wood mechanical properties (Dias and Lahr 2004; Almeida *et al.* 2014; Riggio *et al.* 2014; Christoforo *et al.* 2015; Almeida *et al.* 2015; Zeider *et al.* 2015; Nocetti *et al.* 2015; Almeida *et al.* 2016; Missanjo and Matsumura 2016; Almeida *et al.* 2017b; Christoforo *et al.* 2017; Bader *et al.* 2017).

The aim of this research was to investigate the influence of different procurement sites of the Cupiúba wood species on its physical and mechanical properties. Knowing the properties of wood for one of the extraction sites, it was investigated whether the mean properties of all specimens, came from three different sites, are equivalent to the mean properties of each batch. In addition, this research also evaluated, with the aid of ANOVA of the regression models, the possibility of estimating strength, stiffness, and some physical wood properties as function of density.

## EXPERIMENTAL

### Materials

In this research, three homogeneous batches of Cupiúba, from different extraction sites at Brazil (certified areas): Caracaraí (*Ca*), State of Roraima (01º48'58"N; 61º07'41"W); Bonfim do Sul (*Bo*), State of Roraima (03º21'36"N; 59º49'59"W); and Cláudia (*Cl*), State of Mato Grosso (11º30'55"S; 54º53'29"W) were used. All specimens were seasoned at 12% moisture content, a reference value adopted by ABNT NBR 7190 (1997). Tests were carried out in Wood and Timber Structures Laboratory (LaMEM), Department of Structural Engineering (SET), São Carlos School of Engineering (EESC), University of São Paulo (USP) and Laboratories of the Federal University of Minas Gerais (UFMG) and São Paulo State University (UNESP). Statistical analysis was realized in the Federal University of São Carlos, using BioEstat5.3® software (Mamirauá Institute, Belém, PA, Brazil), all Brazilian institutions. AMSLER universal testing machine (Alfred J Amsler Company, Schaffhausen, Switzerland), 250 kN capacity, was used to carry out the tests to mechanical properties determination.

### Methods

*Manufacture of test specimens*

For each homogeneous batch of Cupiúba from different extraction sites (*Ca*, *Bo* and *Cl*), 12 specimens to each properties for wood characterization, according to ABNT NBR 7190 (1997), were prepared. Table 1 shows all tests realized based on requirements of the cited Code (Fig. 1).

**Table 1.** Number of Specimens for Determining Physical and Mechanical Properties of Cupiúba Wood Species from Different Sites

| Properties | Sites | | |
|---|---|---|---|
| | *Ca* | *Bo* | *Cl* |
| Density at 12% of Moisture Content ($\rho_{12}$) | 12 | 12 | 12 |
| Total Radial Shrinkage ($\varepsilon_{r,2}$) | 12 | 12 | 12 |
| Total Tangential Shrinkage ($\varepsilon_{r,3}$) | 12 | 12 | 12 |
| Fiber Saturation Point (*FSP*) | 12 | 12 | 12 |
| Compression parallel to the grain strength ($f_{c0}$) | 12 | 12 | 12 |
| Tension parallel to the grain strength ($f_{t0}$) | 12 | 12 | 12 |
| Tension perpendicular to the grain strength ($f_{t90}$) | 12 | 12 | 12 |
| Shear parallel to the grain strength ($f_{v0}$) | 12 | 12 | 12 |
| Cleavage strength ($f_{s0}$) | 12 | 12 | 12 |
| Modulus of rupture in static bending ($f_M$) | 12 | 12 | 12 |
| Hardness parallel to the grain ($f_{H0}$) | 12 | 12 | 12 |
| Hardness perpendicular to the grain ($f_{H90}$) | 12 | 12 | 12 |
| Toughness (*W*) | 12 | 12 | 12 |
| Modulus of elasticity in compression parallel to the grain ($E_{c0}$) | 12 | 12 | 12 |
| Modulus of elasticity in tension parallel to the grain ($E_{t0}$) | 12 | 12 | 12 |
| Modulus of elasticity in static bending ($E_M$) | 12 | 12 | 12 |

**Fig. 1.** Cupiúba specimen: (a) compression parallel to grain; (b) static bending; (c) cleavage strength

In order to group the different batches of Cupiúba wood species in the strength classes, based on ABNT NBR 7190 (1997), the characteristic strengths values ($f_k$) were calculated using Eq 1, in which $n$ is the number of specimens; $f_1$, $f_2$, and $f_3$ are strength values for each tested specimen.

$$f_k=[(2\cdot((f_1+f_2+f_3+\ldots+f_{(n/2)-1})/([n/2]-1)))-f_{n/2}]\cdot 1{,}10 \tag{1}$$

*Statistical analysis*

Kruskal-Wallis variance analysis (non-parametric test) was used to evaluate the influence of procurement site on physical and mechanical properties, due to the non-fulfillment of the normality in the distribution of the residues for three evaluated properties ($f_{\mathrm{t0}}$, $f_{\mathrm{t90}}$, $f_{\mathrm{H90}}$). Therefore, the adopted level of significance ($\alpha$) of ANOVA was 5%. The null hypothesis ($H_0$) consisted in admitting that the wood property of a set is equivalent (or represents) the same property considering all results of the three extraction sites, and in the difference of means of the two groups (sites) as an alternative hypothesis ($H_1$). Thus, *P*-value of the test higher than the level of 5% of significance implies assuming means equivalence between the two groups (accepting $H_0$), and non-equivalence otherwise (*P*-value <0.05). It should be noted that randomisation data was conducted.

The bootstrap simulation technique was used as a way of investigating ANOVA comprehensiveness. This means to generate, by simulation of a small sample, numerous others with the withdrawal and replacement of some of its elements. The assumed null hypothesis was to admit equivalence of the means of each property from an isolated site with the same property, considering all data of three sites (*Ca*, *Bo*, and *Cl*), and the non-equivalence of the two groups as alternative hypothesis. The number of simulations adopted in this investigation was 10000. P-value simulated higher than 5%, which means in accepting, by extrapolation, that the mean of the two groups is equivalent, and not equivalent for *P*-value less than 5%.

*Regression models*

Estimation of the physical and mechanical properties of Cupiúba, using density as independent variable, was evaluated by regression models, according to Eqs. 2, 3, 4 and 5, based on analysis of variance (ANOVA). In Eqs. 2, 3, 4, and 5, $Y$ denotes the dependent variable, which may be a physical or mechanical property; $X$ consists on the independent variable, defined here as the density; "$a$" and "$b$" are the parameters of the models fitted by least squares method.

$$Y = a + b \bullet X \quad [Linear – Lin] \tag{2}$$

$$Y = a \bullet e^{b \bullet X} \quad [Exponential – Exp] \tag{3}$$

$$Y = a + b \bullet ln(X) \quad [Logarithmic – Log] \tag{4}$$

$$Y = a \bullet X^{b} \quad [Geometric – Geo] \tag{5}$$

By ANOVA of the regression models, considered at the 5% significance level ($\alpha$), the null hypothesis formulated consists of the non-representativeness of the tested models ($H_0$: $\beta = 0$), and in the representativeness as an alternative hypothesis ($H_1$: $\beta \neq 0$). $P$-value inferior to the level of significance considered implies accepting $H_0$ and finding that the model tested is not representative; in such cases, variations of $\rho_{12}$ are unable to explain the variations of the estimated property and will be refuted. Otherwise the model tested is representative.

In addition to the use of ANOVA, which allows the user to accept or not to accept the representativeness of the tested models, the coefficient of determination ($R^2$) values were obtained as a way of evaluating the capacity of variations in density to explain the analyzed variable, making it possible to choose (among the models considered to be significant) the best fit. It should be noted that the density was used to estimate the 15 properties studied in this research, as shown in Table 1 (3 physical and 12 mechanical properties), using four different mathematical models (linear, exponential, logarithmic, and geometric), totaling 60 adjustments.

## RESULTS AND DISCUSSION

### Physical and Mechanical Properties of Different batches of Cupiúba wood specie

Tables 2, 3, and 4 present mean ($x_m$), coefficient of variation ($CV$), minimum ($Min$) and maximum ($Max$) values of physical and mechanical properties, and characteristics values ($f_k$) for strength properties to Cupiúba from Caracaraí ($Ca$), Bonfim ($Bo$) and Cláudia ($Cl$), respectively.

Results obtained for the Caracaraí and Cláudia sites to $f_{c0}$ average values were higher than those presented by ABNT NBR 7190 (1997) ($f_{c0}$ = 54.4 MPa), while for the specimens from Bonfim site resulted in lower value.

Tables 2 and 4 show that properties of the batches from Caracaraí and Claudia sites presented more homogeneous values (as example, $f_{t0,k}$ close to 50 MPa), while specimens from Bonfim site resulted in a value close to 40 MPa to $f_{t0,k}$.

Comparing mean of $f_{t0}$, results for Caracaraí and Cláudia sites, specimens showed values around 70 MPa and Bonfim site around 60 MPa, which was close to the value presented by ABNT NBR 7190 (1997), $f_{c0}$ = 62.1 MPa.

**Table 2.** Physical and Mechanical Properties of Cupiúba Wood Species from Caracaraí (*Ca*)

| Properties | $x_m$ | *CV (%)* | *Min* | *Max* | $f_k$ |
|---|---|---|---|---|---|
| $\rho_{12}$ (g/cm$^3$) | 0.84 | 4.04 | 0.77 | 0.9 | - |
| $\varepsilon_{r,2}$ (%) | 4.17 | 11.85 | 3.26 | 4.88 | - |
| $\varepsilon_{r,3}$ (%) | 7.3 | 6.91 | 6.19 | 7.93 | - |
| *FSP* (%) | 20.96 | 16.43 | 15.36 | 27.51 | - |
| $f_{c0}$ (MPa) | 62.07 | 15.1 | 47 | 74 | 49 |
| $f_{t0}$ (MPa) | 72.8 | 21.78 | 50 | 103 | 54 |
| $f_{t90}$ (MPa) | 3.07 | 24.99 | 2.1 | 5.3 | 2 |
| $f_{v0}$ (MPa) | 17.6 | 12.67 | 14 | 21 | 15 |
| $f_{s0}$ (MPa) | 0.72 | 24.17 | 0.4 | 1 | 0.53 |
| $f_M$ (MPa) | 87.53 | 17.15 | 63 | 114 | 74 |
| $f_{H0}$ (MPa) | 99.8 | 14.55 | 75 | 120 | 80 |
| $f_{H90}$ (MPa) | 68.7 | 10.34 | 57.1 | 80 | 59 |
| *W* (N·m) | 9.12 | 26.23 | 6.03 | 14.67 | - |
| $E_{c0}$ (MPa) | 15976 | 10.56 | 13371 | 19036 | - |
| $E_{t0}$ (MPa) | 14561 | 15.77 | 10958 | 19487 | - |
| $E_M$ (MPa) | 15060 | 13.9 | 11603 | 19344 | - |

The value of $f_{v0,k}$ for Cupiúba wood species from the Caracaraí site presents a higher value ($f_{v0,k}$= 15 MPa), while the batches from Bonfim and Claudia sites presents $f_{v0,k}$ nearly to 13 MPa. For this property the characteristic values are similar.

The mean values to $f_{v0}$, determined for the specimens of the Caracaraí, Bonfim, and Claudia sites, were 17.6 MPa, 16.18 MPa, and 16.83 MPa, respectively, all above the average value presented by ABNT NBR 7190 (1997), $f_{v0}$ = 10 MPa.

The characteristic value of the modulus of rupture in static bending for batches from Caracaraí and Claudia sites presented values equal to 74 MPa and 60 MPa, respectively. By comparison, the batch from Bonfim site presented $f_{M,k}$ = 47 MPa.

It should be noted that the total radial shrinkage ($\varepsilon_{r,2}$) of the Cupiúba wood species was smaller than the total tangential retraction ($\varepsilon_{r3}$), results that are in agreement with statements made by some authors (Dias and Lahr 2004; Del Menezzi 2006; Melo *et al.* 2010). Regarding the strength classes, a difference is observed when comparing all different sites. Cupiúba wood species from Caracaraí, Bonfim, and Cláudia were classified as C40, C30, and C50, respectively. These values are above that established by ABNT NBR 7190 (1997) that introduces Cupiúba in the C30 strength class, independent of the site from which the wood is extracted.

**Table 3.** Physical and Mechanical Properties of Cupiúba Wood Species from Bonfim (*Bo*)

| Properties | $x_m$ | CV (%) | Min | Max | $f_k$ |
|---|---|---|---|---|---|
| $\rho_{12}$ (g/cm$^3$) | 0.81 | 3.55 | 0.78 | 0.87 | - |
| $\varepsilon_{r,2}$ (%) | 3.77 | 6.02 | 3.33 | 4.2 | - |
| $\varepsilon_{r,3}$ (%) | 7.57 | 9.15 | 6.76 | 8.71 | - |
| *FSP* (%) | 20.86 | 23.28 | 15.44 | 29.98 | - |
| $f_{c0}$ (MPa) | 47.73 | 25.59 | 35 | 71 | 33 |
| $f_{t0}$ (MPa) | 60.09 | 36.85 | 38 | 99 | 38 |
| $f_{t90}$ (MPa) | 3.33 | 27.05 | 2.3 | 5 | 3 |
| $f_{v0}$ (MPa) | 16.18 | 18.5 | 11 | 21 | 13 |
| $f_{s0}$ (MPa) | 0.61 | 26.38 | 0.3 | 0.9 | 0.39 |
| $f_M$ (MPa) | 65.64 | 25.44 | 45 | 102 | 47 |
| $f_{H0}$ (MPa) | 78.18 | 17.14 | 65 | 106 | 68 |
| $f_{H90}$ (MPa) | 54.99 | 15.42 | 47.3 | 71.6 | 52 |
| *W* (N·m) | 9.59 | 43.26 | 4.98 | 18.2 | - |
| $E_{c0}$ (MPa) | 12061 | 23.19 | 8564 | 18642 | - |
| $E_{t0}$ (MPa) | 12180 | 26.23 | 8976 | 18383 | - |
| $E_M$ (MPa) | 11773 | 25.58 | 8589 | 19353 | - |

**Table 4.** Physical and Mechanical Properties of Cupiúba Wood Species from Cláudia (*Cl*)

| Properties | $x_m$ | CV (%) | Min | Max | $f_k$ |
|---|---|---|---|---|---|
| $\rho_{12}$ (g/cm$^3$) | 0.84 | 2.77 | 0.81 | 0.88 | - |
| $\varepsilon_{r,2}$ (%) | 4.59 | 9.61 | 3.86 | 5.32 | - |
| $\varepsilon_{r,3}$ (%) | 7.57 | 6.93 | 6.78 | 8.53 | - |
| *FSP* (%) | 21.33 | 11.87 | 17.64 | 25.04 | - |
| $f_{c0}$ (MPa) | 57.42 | 13.84 | 49 | 74 | 51 |
| $f_{t0}$ (MPa) | 70.58 | 19.41 | 49 | 90 | 50 |
| $f_{t90}$ (MPa) | 3.6 | 24.12 | 2.4 | 5.1 | 3 |
| $f_{v0}$ (MPa) | 16.83 | 18.76 | 10 | 21 | 13 |
| $f_{s0}$ (MPa) | 0.71 | 23.67 | 0.5 | 1 | 0.48 |
| $f_M$ (MPa) | 75 | 15.15 | 60 | 93 | 60 |
| $f_{H0}$ (MPa) | 89 | 15.52 | 69 | 117 | 77 |
| $f_{H90}$ (MPa) | 70.58 | 16.64 | 54 | 82 | 58 |
| *W* (N·m) | 8.56 | 25.71 | 3.2 | 10.2 | - |
| $E_{c0}$ (MPa) | 12970 | 15.35 | 9964 | 16162 | - |
| $E_{t0}$ (MPa) | 12767 | 26.3 | 7843 | 18275 | - |
| $E_M$ (MPa) | 13217 | 14.75 | 10010 | 16777 | - |

### Statistical Analysis Results

Table 5 presents Kruskal-Wallis ANOVA test results (*P*-values) determined for each property and confronting a site with the set of three sites (*Ca*, *Bo*, *Cl*). The *P*-values underlined were considered significant (*P*-value <0.05).

The Caracaraí and Cláudia sites, analyzed separately, provided results of the properties with 94% equivalence to the set with the properties of Cupiúba from three sites. The same did not occur with wood from Bonfim, where 50% of the properties did not present equivalence with the set involving the three sites.

The non-equivalence of 50% for the Bonfim site batch may be considerable, and in this case, it would be prudent to classify them as non-equivalent, and in this way the extraction site influenced the properties.

Table 6 presents the (*P*-values) of ANOVA to results extrapolated by the bootstrap simulation technique of each property by confronting a site with the set of three sites.

**Table 5.** *P*-values for Kruskal-Wallis ANOVA test

| Properties | *Ca* x (*Ca, Bo, Cl*) | *Bo* x (*Ca, Bo, Cl*) | *Cl* x (*Ca, Bo, Cl*) |
|---|---|---|---|
| $\rho_{12}$ | 0.4868 | 0.0275 | 0.196 |
| $\varepsilon_{r,2}$ | 0.9606 | 0.0131 | 0.0217 |
| $\varepsilon_{r,3}$ | 0.4528 | 0.7372 | 0.5855 |
| *FSP* | 0.9606 | 0.6063 | 0.6659 |
| $f_{c0}$ | 0.0986 | 0.0213 | 0.776 |
| $f_{t0}$ | 0.4066 | 0.1571 | 0.6991 |
| $f_{t90}$ | 0.4827 | 0.9904 | 0.4129 |
| $f_{v0}$ | 0.5048 | 0.4194 | 0.823 |
| $f_{s0}$ | 0.5077 | 0.2594 | 0.7554 |
| $f_{M}$ | 0.0527 | 0.0403 | 0.7761 |
| $f_{H0}$ | 0.1696 | 0.0122 | 0.4262 |
| $f_{H90}$ | 0.1437 | 0.0087 | 0.4196 |
| *W* | 0.6425 | 0.792 | 0.433 |
| $E_{c0}$ | 0.0094 | 0.048 | 0.2655 |
| $E_{t0}$ | 0.1638 | 0.2549 | 0.6012 |
| $E_{M}$ | 0.0517 | 0.0319 | 0.838 |

*P*-value results for ANOVA by bootstrap simulation technique, shown in Table 6, indicate that the Caracaraí and Cláudia sites, analyzed separately, continued to provide good results for the properties, with 88% and 94%, respectively, of equivalence to the set with the properties of the Cupiúba of the three sites.

However, the same did not occur with the wood from the Bonfim site, as they continue to provide results of properties with only 56% of equivalence with the set involving the three sites. The adjustment by the bootstrap technique did not significantly improve the equivalence condition, since it increased from 50% to 56%. Therefore it can be concluded, for the three sites of this study, that the representativeness of the wood batch is dependent of the procurement site, a result that is unfavorable to the ABNT NBR 7190 (1997), which makes no mention of possible differences in the values of the physical and mechanical properties of the wood as function of its origin. These differences between sites may be related to the different soils where the trees were cultivated (EMBRAPA 2006), among other edaphoclimatic factors.

**Table 6.** *P*-values for Bootstrap Simulation Technique ANOVA Test

| Properties | *Ca* x (*Ca, Bo, Cl*) | *Bo* x (*Ca, Bo, Cl*) | *Cl* x (*Ca, Bo, Cl*) |
|---|---|---|---|
| $\rho_{12}$ | 0.4993 | 0.0302 | 0.1803 |
| $\varepsilon_{r,2}$ | 0.0986 | 0.013 | 0.0188 |
| $\varepsilon_{r,3}$ | 0.3266 | 0.4001 | 0.4516 |
| *FSP* | 0.0603 | 0.118 | 0.2104 |
| $f_{c0}$ | 0.0977 | 0.0299 | 0.2221 |
| $f_{t0}$ | 0.3998 | 0.2046 | 0.2923 |
| $f_{t90}$ | 0.4939 | 0.03 | 0.3915 |
| $f_{v0}$ | 0.4149 | 0.1781 | 0.4242 |
| $f_{s0}$ | 0.4889 | 0.2303 | 0.321 |
| $f_M$ | 0.0486 | 0.0475 | 0.3344 |
| $f_{H0}$ | 0.148 | 0.0117 | 0.4276 |
| $f_{H90}$ | 0.1504 | 0.0127 | 0.4264 |
| *W* | 0.2715 | 0.4912 | 0.2502 |
| $E_{c0}$ | 0.0083 | 0.0534 | 0.279 |
| $E_{t0}$ | 0.1453 | 0.2802 | 0.399 |
| $E_M$ | 0.0517 | 0.0677 | 0.2949 |

## Regression Models to Estimate Physical and Mechanical Properties

Table 7 presents the best models obtained by property.

**Table 7.** *P*-values for Regression Models ANOVA test

| Properties | Model Type | *P*-value | *a* | *b* | Equation | $R^2$ (%) |
|---|---|---|---|---|---|---|
| $\varepsilon_{r,2}$ | *Exp* | 0 | 0.19 | 3.7 | $\varepsilon_{r,2} = a \cdot e^{b \cdot \rho_{12}}$ | 87.22 |
| $\varepsilon_{r,3}$ | *Lin* | 0 | -5.1 | 15 | $\varepsilon_{r,3} = a + b \cdot \rho_{12}$ | 75.60 |
| *FSP* | *Geo* | 0 | 38.8 | 3.5 | $FSP = a \cdot (\rho_{12})^b$ | 72.88 |
| $f_{c0}$ | *Lin* | 0 | -203.5 | 311.2 | $f_{c0} = a + b \cdot \rho_{12}$ | 79.73 |
| $f_{t0}$ | *Geo* | 0 | 202.3 | 6.2 | $f_{t0} = a \cdot (\rho_{12})^b$ | 84.24 |
| $f_{t90}$ | *Lin* | 0 | -19 | 26.7 | $f_{t90} = a + b \cdot \rho_{12}$ | 64.82 |
| $f_{v0}$ | *Lin* | 0 | -42.1 | 70.6 | $f_{v0} = a + b \cdot \rho_{12}$ | 69.57 |
| $f_{s0}$ | *Log* | 0 | 1.4 | 4.1 | $f_{s0} = a + b \cdot \ln(\rho_{12})$ | 78.23 |
| $f_M$ | *Exp* | 0 | 0.63 | 5.7 | $f_M = a \cdot e^{b \cdot \rho_{12}}$ | 73.97 |
| $f_{H0}$ | *Geo* | 0 | 208.9 | 4.6 | $f_{H0} = a \cdot (\rho_{12})^b$ | 87.96 |
| $f_{H90}$ | *Lin* | 0 | -181.3 | 293.6 | $f_{H90} = a + b \cdot \rho_{12}$ | 81.55 |
| *W* | *Lin* | 0 | -46.8 | 66.3 | $W = a + b \cdot \rho_{12}$ | 75.82 |
| $E_{c0}$ | *Lin* | 0 | -44521 | 69837 | $E_{c0} = a + b \cdot \rho_{12}$ | 75.69 |
| $E_{t0}$ | *Lin* | 0 | -51921 | 77974 | $E_{t0} = a + b \cdot \rho_{12}$ | 76.65 |
| $E_M$ | *Lin* | 0 | -40547 | 64565 | $E_M = a + b \cdot \rho_{12}$ | 74.62 |

Table 7 considers the four types of adjustments used in this research for the three sites (single group): $R^2$ is the coefficient of determination; "*a*" and "*b*" are adjusted coefficients by least square method. It should be noted that the adjusted models are estimated by the density ($\rho_{12}$), whose range of values is 0.78 g/cm³ to 0.88 g/cm³.

Regression models were all considered significant by ANOVA ($P$-value <0.05). The adjustments resulted in good approximations, as can be judged by the fact that the values of coefficient of determination were near 70% or greater. This indicates the possibility of estimating the physical and mechanical properties of the Cupiúba as a function of density.

## CONCLUSIONS

1. This study determined the physical and mechanical properties of batches of Cupiúba wood species, obtained from Caracaraí, Bonfim and Cláudia sites. Results indicated some significant divergences. Extraction site influenced wood properties, probably due to edaphoclimatic variables.
2. Cupiúba wood species from three different sites presented strength classes C30, C40, and C50. Therefore, the values were higher than the reference value adopted by ABNT NBR 7190 (1997).
3. Results of the ANOVA evidenced the probability that 50% of the properties of the Bonfim site were not equivalent among the three sites, and even using bootstrap simulation technique the result was equal to 44% of properties with no equivalents. For the other two sites, results presented around 90% of equivalence.
4. Regression models used in this research showed coefficients of determination of approximately 70% or greater, evidencing the possibility of using the density at 12% moisture content as an estimator of physical and mechanical properties of the Cupiúba wood species.

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