Scientific Article

INFLUENCE OF MOISTURE CONTENT ON PHYSICAL AND MECHANICAL PROPERTIES OF *Vatairea* SP. WOOD

Heloiza Candeia Ruthes[2*], Fernando Júnior Resende Mascarenhas[3], Larissa Soriani Zanini Ribeiro Soares[4], Vinícius Borges de Moura Aquino[5], Felipe Nascimento Arroyo[2], Iuri Fazolin Fraga[2], André Luis Christoforo[6] and Francisco Antonio Rocco Lahr[7]

[1] Received on 23.07.2021 accepted for publication on 14.12.2021.
[2] Universidade Federal de São Carlos, Programa de Pós-Graduação em Engenharia Civil, São Carlos, SP - Brasil. E-mail: <heloruthes@gmail.com> , <lipe.arroyo@gmail.com> and <iurifraga@outlook.com>.
[3] Universidade de Coimbra, Programa de Pós-Graduação em Engenharia Civil, Coimbra, Portugal . E-mail: <fer.jr.resende@hotmail.com>.
[4] Instituto Federal de Educação e Tecnologia do Triângulo Mineiro, Uberaba, MG - Brasil. E-mail: <larissazanini@iftm.edu.br>.
[5] Isntituto de Engenharia do Araguaia , Santana do Araguaia, PA - Brasil. E-mail: <aquino.vini@hotmail.com>.
[6] Universidade Federal de São Carlos, Departamento de Engenharia Civil, São Carlos, SP - Brasil. E-mail: <christoforoal@yahoo.com.br>.
[7] Universidade de São Paulo, Departamento de Engenharia de Estruturas, São Carlos, SP - Brasil. E-mail: <frocco@sc.usp.br>.
*Corresponding author.

ABSTRACT – The recent interest in constructing high and robust wooden structures has stimulated the investigation of physical and mechanical properties as well as their correlation with other important parameters of the material of tropical species like the *Vatairea* sp., whose popular name is angelim-amargoso, used especially in roof structures with large spans. The Brazilian Standard for wood constructions recommends using linear models to correct or estimate the strength and/or stiffness of wood correlated with moisture content and also provides the classification of hardwoods according to their characteristic strength. However, because wood is a natural, heterogeneous, and anisotropic material, certain properties may not be affected by significant differences in moisture content. Therefore, in this study, the influence of moisture content on fifteen physical and mechanical properties of *Vatairea* sp. wood was investigated through its characterization. The tests were carried out on 12 specimens for each property and two groups: with the moisture content of 12% and at the fiber saturation point. The Anderson-Darling test was performed to verify the results' normality and the analysis of variance (ANOVA) to analyze the influence of moisture content on these properties. In addition, the wood was classified according to the strength classes of the Brazilian Standard, and the strength and stiffness were estimated according to the linear models proposed by the same norm. The estimated results were compared with the experimental ones through the difference calculation and percentual error of the values. It was concluded that most properties were not affected by the moisture content, and the most significant errors obtained in the estimates were for properties that were significantly influenced by the moisture content.

Keywords: Tropical wood; Wood characterization; Brazilian standard model.

INFLUÊNCIA DO TEOR DE UMIDADE NAS PROPRIEDADES FÍSICAS E MECÂNICAS DA MADEIRA DE Vatairea *SP.*

*RESUMO – O recente interesse pela construção de estruturas altas e robustas em madeira tem estimulado a investigação de propriedades físicas e mecânicas, assim como a correlação delas com outros parâmetros importantes do material de espécies tropicais como o angelim-amargoso (**Vatairea** sp.) utilizada especialmente em estruturas de telhados de grandes vãos. No Brasil, a norma de projetos de madeira recomenda a utilização de modelos lineares para a correção ou estimativa da resistência e/ou rigidez da madeira correlacionada ao teor de umidade, bem como traz a classificação das folhosas segundo sua resistência característica. Entretanto, por ser um material natural, heterogêneo e anisotrópico, certas propriedades podem não ser afetadas por diferenças no teor de umidade. Portanto, nesse trabalho, investigou-se a influência do teor de umidade em 15 propriedades físicas e mecânicas da madeira de **Vatairea** sp., através da sua caracterização. Os ensaios foram realizados em 12 corpos-de-prova para cada propriedade e para dois grupos: com teor de umidade de 12% e no ponto de saturação das fibras. O teste de Anderson-Darling foi empregado para verificar a normalidade dos* *resultados e a análise de variância (ANOVA) para analisar a influência do teor de umidade nessas propriedades. Além disso, classificou-se a madeira segundo as classes de resistência da norma brasileira e estimou-se a resistência e rigidez segundo os modelos lineares propostos pela mesma norma. Os resultados estimados foram comparados com os experimentais através do cálculo da diferença e o erro percentual dos valores. Concluiu-se que a maioria das propriedades não foram afetadas pelo teor de umidade e que os maiores erros obtidos nas estimativas foram para as propriedades que foram influenciadas significativamente pelo teor de umidade.*

Palavras-Chave: Madeira tropical; Caracterização da madeira; Modelo da norma brasileira.

1. INTRODUCTION

The use of wood to manufacture structural elements and structures is widespread, especially in Europe and North America, mainly in buildings with less than six floors and no complexity. However, the wide use of this material for the construction of higher and more robust structures is recent, and the updates in the design codes and new technologies and treatments to improve the material properties have been themselves encouragement for this type of construction (Ramage et al., 2017). Ramage et al. (2017) and Hart and Pomponi (2020) also point out that, although wood cannot be compared to reinforced concrete in terms of compressive strength, it is a less dense material, characteristic that is a good point for its use in large spans, for example.

However, the lack of knowledge about wood species' strength and stiffness properties with potential use in structures contributes to a safer and more conservative design. It is essential to carry out tests of physical and mechanical properties, whose results allow the efficient use of each species, as well as they might be a tool to indicate unsuitable wood for structural use, as emphasized by Lahr et al. (2018).

Several species have been investigated to verify their properties and behavior in response to load carrying. Among them, there is the *Vatairea* sp. wood that belongs to the group of hardwoods, which are heavy and hard woods, with yellowish-brown color and a strong bitter taste. It is found mainly in the north and central-west regions (IPT, 2021). *Vatairea* sp. wood is used mainly in the structure of apparent roofs with high loads and large spans.

Furthermore, Chipaia et al. (2015) did the macroscopic anatomical description of eight wood species from the city of Altamira, Pará State, Brazil. They noted that the *Vatairea* sp. wood presented little distinct growth layers demarcated by thin layers of marginal parenchyma. In this context, acknowledging the physical and mechanical properties of the material for the design of this type of structure becomes important. In Brazil, the characterization of wood is carried out following the guidelines of Brazilian Standard - NBR 7190, Brazilian Association of Technical Standards - ABNT (1997), which also classifies softwoods and hardwoods according to their resistance to standardize the use of wood in structural projects. Conifers are divided into three strength classes: C20, C25, and C30, which have a characteristic compressive strength of about 20 MPa, 25 MPa, and 30 MPa, respectively. Hardwoods or dicots are classified into four different groups: C20, C30, C40, and C60, in which their characteristic strengths are 20 MPa, 30 MPa, 40 MPa, and 60 MPa, respectively.

Because wood is a hygroscopic material used in various environments with different climatic conditions, it has its mechanical properties dependent on moisture content (MC) and, therefore, the relationship between moisture and its properties' importance (Ozyhar et al., 2012). Thus, the relationship between the moisture content of wood from different species and their physical and mechanical properties has been addressed in several studies.

In experimental studies, Beltrame et al. (2010) compare the impact strength of the wood *açoita-cavalo* (*Luehea divaricata*) in the equilibrium moisture content (12%) and saturated in water. The specimens were analyzed for the resistance obtained to the application of load radially and tangentially. The results showed that the samples in the saturated condition presented greater impact resistance when compared to the results obtained for the equilibrium moisture condition.

Likewise, Beltrame et al. (2012) investigated the influence of moisture content on the impact strength of nogueira-pecã (*Carya illinoinensis*) wood from the state of Rio Grande do Sul, Brazil. The specimens were tested in the saturated condition and the equilibrium moisture content (12%), in the radial and tangential directions. The results showed that the resulting impact strength had superior values in the saturated condition and that this property was significantly affected by the moisture content.

To evaluate the influence of moisture content on the strength and elastic anisotropy of wood of the species *Fagus sylvatica* L., Ozyhar et al. (2012) analyzed Young's modulus, Poisson's coefficient, ultimate stress, and toughness in radial, tangential and longitudinal directions. The elastic and strength behavior proved to be dependent on the moisture content, and all parameters studied decreased when the moisture content increased, except for the Poisson's coefficient.

In tests carried out to obtain the apparent density in three samples of 10 different species, with three different moisture conditions: saturated in water, air dry, and in standard climate, seeking to compare four correction models of the property obtained in the samples for a moisture content equal to 12%, Soares et al. (2015) used the Tukey test and analysis of variance to validate the models and demonstrated that they were satisfactory, except for saturated samples.

The influence of moisture content (ranging from 0 to 20%) on the densification process of *Dendrocalamus* asper bamboo samples was studied by Kadivar et al. (2019). The authors also studied the influence of moisture content on bending properties such as modulus of rupture (MOR), modulus of elasticity (MOE), proportionality limit, and specific energy. It was concluded that very low moisture contents (5%) caused fractures in the samples during the densification process. On the other hand, higher moisture contents (20%) caused heterogeneous densification. Regarding the flexural properties, the best results obtained were for the moisture content equal to 10%, in which there was an increase of 56% and 41% of the values of the modulus of elasticity and rupture, respectively, compared to non-densified samples.

However, wood is a natural, heterogeneous, and anisotropic material. Therefore, some properties of strength and stiffness may be little influenced by the material's moisture content. Thus, Lahr et al. (2016) analyzed the influence of moisture content on 15 physical and mechanical properties of jatobá (*Hymenaea stilbocarpa*) wood in two moisture situations: 12% and saturated. The results showed that the mean values of the compressive strength parallel to grain, tensile strength parallel to grain, shear parallel to grain, flexural modulus of strength, and modulus of elasticity in parallel compression were higher for the moisture content of 12 % than when the samples were saturated. In contrast, in apparent density, the opposite was observed. Furthermore, it was concluded that the moisture content was significant in only eight of the fifteen investigated properties.

In this context, there are several other research focused on the analysis of the influence of the moisture content on the physical and mechanical properties of several species (Al-Mahasneh and Rababah, 2007; Anshari et al., 2011; Hering et al., 2012; Jiang et al., 2017; Báder and Németh, 2019; Korkmaz and Büyüksari, 2019; Roszyk et al., 2020).

A linear relationship between stiffness and strength properties and moisture content is considered by NBR 7190 (ABNT, 1997). This fact is evidenced in the equations proposed by the Brazilian code for correcting the values of these properties obtained for a moisture content different from the equilibrium moisture content. When estimating these properties, such models consider the decrease in strength or stiffness with increasing moisture content.

Based on this scenario, this work aims to characterize and classify the *Vatairea* sp. wood through tests accomplished for 15 physical and mechanical properties according to the Brazilian standard. Also, this paper evaluates the influence of moisture content on 15 physical and mechanical properties of *Vatairea* sp., verifies if the linear models of the Brazilian standard consider the moisture content influence and if they can predict the physical and mechanical properties. For this, the properties were estimated through the linear models, and the results were compared to the experimental values.

2. MATERIAL AND METHODS

The wood samples of the species *Vatairea* sp. from the south of the state of Roraima, Brazil, were supplied by a timber company in the city of São Carlos, in Brazil, in a homogeneous batch of $1m^3$, in pieces with nominal dimensions of 5 cm x 15 cm x 300 cm, (thickness x width x length), in green and air-dry condition.

The specimens were manufactured considering the dimensions specified by NBR 7190 (ABNT, 1997). Two groups of tests were considered: moisture content close to 12% and moisture content close to FSP. In each group, 15 physical and mechanical properties were evaluated (Table 1). For evaluation of each property, 12 specimens were considered. Besides that, 12 specimens were initially performed to determine the FSP, thus resulting in 372 determinations.

The characterization of air-dried and saturated wood was performed according to the guidelines of NBR 7190 (ABNT, 1997), to analyze the influence of moisture content on the physical and mechanical properties (Table 1) of *Vatairea* sp. wood.

Table 1 – Physical and mechanical properties studied.
***Tabela 1** – Propriedades físicas e mecânicas estudadas.*

Acronyms	Meaning
$\rho 12$ (g.cm^{-3})	Apparent density
ρFSP (g.cm^{-3})	Density in the fiber saturation point
ε_{rt} (%)	Total radial shrinkage
ε_{tt} (%)	Total tangential shrinkage
f_{c0} (MPa)	Compression strength parallel to grain
f_{t0} (MPa)	Tensile strength parallel to grain
f_{t90} (MPa)	Tensile strength perpendicular to grain
f_{v0} (MPa)	Shear strength parallel to grain
f_{s0} (MPa)	Cracking strength parallel to grain
f_{tm} (MPa)	Conventional strength in static bending test
E_{c0} (MPa)	Modulus of elasticity in compression parallel to grain
E_{t0} (MPa)	Modulus of elasticity in tensile parallel to grain
E_{tm} (MPa)	Conventional modulus of elasticity in static bending test
f_{h0} (MPa)	Hardness parallel to grain
f_{h90} (MPa)	Hardness perpendicular to grain
W (daN·m)	Tenacity

After that, the values of strength and modulus of elasticity obtained with specimens close to the equilibrium moisture content (12%) were corrected exactly to the equilibrium moisture content, considering Equations (1 and 2), respectively. In Equation (1), f_u is the strength of the samples associated with the moisture content U, and E_u is the stiffness or modulus of elasticity of the sample also associated with the moisture content. NBR 7190 (ABNT, 1997) recommends these expressions for moisture contents ranging between 12% and 20%.

$$f_{12} = f_U \cdot \left[1 + \frac{3 \cdot (U-12)}{100}\right] \qquad \text{Eq.1}$$

$$E_{12} = E_U \cdot \left[1 + \frac{2 \cdot (U-12)}{100}\right] \qquad \text{Eq.2}$$

Once the strength and stiffness values were corrected for the moisture content equal to 12%, (Equation 3) was used to determine the characteristic compressive strength ($f_{c0,k}$). Based on the $f_{c0,k}$, the *Vatairea* sp. wood was classified according to the hardwood strength classes of NBR 7190 (ABNT, 1997), which are: C20, C30, C40, C60. In (Equation 3) f_1, f_2, ..., f_n correspond to the compressive strength values ($f_{c0.12\%}$) in ascending order of the analyzed specimens, with 12 specimens per species.

$$f_{c0,k} = Max\begin{cases} f_1 \\ 0.7 \cdot \dfrac{\sum_{i=1}^{n} f_i}{n} \\ 1.1 \cdot \left[2 \cdot \left(\dfrac{f_1 + f_2 + f_3 + \ldots + f_{(n/2)-1}}{(n/2)-1}\right) - f_{n/2}\right] \end{cases} \qquad \text{Eq.3}$$

The influence of the 12% moisture content and the FSP on the investigated properties (Table 1) of the two groups were statistically analyzed. The analysis of variance (ANOVA) was performed with 5% significance and the Anderson-Darling and multiple comparison tests, also at 5% significance, to verify the normality of the distribution of residuals and equality of variances. The analysis shows that if the P-value is greater than or equal to the significance level, the requirements are met, validating the ANOVA model.

The Equations (1 and 2) were used to estimate the strength and modulus of elasticity for the equilibrium moisture content through the values obtained experimentally for the FSP moisture content. The experimental and estimated values were compared, measuring the difference and the percentual error between them.

Table 2 – Experimental results of physical and mechanical properties of *Vatairea* sp. wood.
Tabela 2 *– Resultados experimentais das propriedades físicas e mecânicas da madeira de* ***Vatairea*** *sp.*

Properties	MC - 12%		MC - FSP		p-value*	12%/FSP
	$\overline{x}$	CV (%)	$\overline{x}$	CV (%)		
ρ (g.cm^{-3})	0.78	8.20	1.05	7.64	0.000	0.743
ε_{rt} (%)	4.53	20.71	4.35	24.63	0.660	1.042
ε_{tt} (%)	8.53	24.58	8.44	23.75	0.909	1.011
f_{c0} (MPa)	61.21	16.69	41.04	23.00	0.000	1.491
f_{t0} (MPa)	73.89	24.65	52.77	28.43	0.005	1.400
f_{t90} (MPa)	2.73	30.80	2.36	22.08	0.264	1.157
f_{v0} (MPa)	16.36	15.14	11.31	21.50	0.000	1.447
f_{s0} (MPa)	0.61	23.16	0.64	27.83	0.663	0.955
f_{tm} (MPa)	90.67	13.33	72.74	26.60	0.012	1.246
E_{c0} (MPa)	16175	14.77	13627	17.90	0.017	1.187
E_{t0} (MPa)	16315	20.70	14151	22.03	0.117	1.153
E_{tm} (MPa)	15667	16.18	13638	21.91	0.087	1.149
f_{h0} (MPa)	101.19	12.28	66.47	22.11	0.000	1.522
f_{h90} (MPa)	61.62	20.06	45.03	23.18	0.002	1.368
W (daN·m)	0.88	25.25	0.95	22.92	0.404	0.920

*Average values ($\overline{x}$) followed by coefficients of variation (CV); P-value, from ANOVA, evaluated at the 5% level of significance, p-value less than 0.05 implies the non-equivalence of the property means, and equivalence otherwise;
**Valores médios (x) seguidos pelos coeficientes de variação (CV); P-valor, da ANOVA, avaliado ao nível de significância de 5%, p-valor menor que 0.05 implica a não-significância da propriedade e, caso contrário, na significância;*

3. RESULTS

The experimental results obtained found that the FSP was reached with an average moisture content of 18.15%. Regarding the classification of *Vatairea* sp. wood, the characteristic value obtained for the compressive strength parallel to grain was 49.91 MPa (Equation 3); therefore, the wood of this species belongs to the C40 hardwood class according to NBR 7190 (ABNT, 1997).

The results of the characterization of *Vatairea* sp. for the corrected moisture content of 12% and the moisture content corresponding to the FSP equal to 18.15% are displayed in (Table 2). The p-values of ANOVA, the Anderson-Darling, and multiple comparisons tests are also presented in (Table 2). In addition, the average values and de coefficient of variation for the strength and stiffness properties evaluated are shown in (Table 2). The results showed a discrepancy between the linear behavior given by NBR 7190 (ABNT, 1997), where strength and, or stiffness linearly decreases with increasing moisture content (Equations 1 and 2).

The results of strength and stiffness properties estimated by the linear models of the Brazilian standard - NBR 7190 (ABNT, 1997) - at 12% moisture content, starting from the FSP, are shown in (Table 3). The difference and the percentual error between the estimated and experimental values are exhibited in (Table 3).

4. DISCUSSION

The FSP value experimentally obtained for the *Vatairea* sp. wood (18.15%) is consistent with the FSP value accomplished by the Almeida (2015) work (17.87%). Both tests were performed according to the specifications of the Brazilian standard for the same species of Brazilian native wood.

The compressive strength parallel to grain was 49.91 MPa; consequently, the *Vatairea* sp. wood

Table 3 – Results of estimating the mean values of strength and modulus of elasticity of *Vatairea* sp. wood.
Tabela 3 *– Resultados da estimativa dos valores médios de resistência e do módulo de elasticidade da madeira de* ***Vatairea*** *sp.*

Properties	$\overline{x}_{exp}$.	$\overline{x}_{est}$.	Dif.=Exp.- Est.	Er. (%)
f_{c0} (MPa)	61.21	48.91	12.30	-20.09
f_{t0} (MPa)	73.89	36.38	37.51	-50.76
f_{t90} (MPa)	2.73	2.79	-0.06	2.23
f_{v0} (MPa)	16.36	13.42	2.94	-17.97
f_{s0} (MPa)	0.61	0.75	-0.14	23.40
f_{tm} (MPa)	90.67	87.61	3.06	-3.37
E_{c0} (MPa)	16175	15487	688.00	-4.25
E_{t0} (MPa)	16315	16469	-154.00	0.94
E_{tm} (MPa)	15667	15648	19.00	-0.12

*Experimental average values ($\overline{x}$_exp) and estimated average values ($\overline{x}$_est); followed by difference and percentual error (Er. (%)).
** Valores médios experimentais (x_exp) e valores médios estimados (x_est) seguidos pela diferença e pelo erro percentual (Er. (%)).*

belongs to the C40 hardwood class according to NBR 7190 (ABNT, 1997). Jesus et al. (2015) also classified the *Vatairea* sp. wood and obtained an average characteristic strength equal to 46.46 MPa, thus also resulting in the C40 strength class.

The characterization results (Table 2) demonstrated that the values obtained for some properties at equilibrium moisture and the FSP do not indicate accordance with the linear model designated by NBR 7190 (ABNT, 1997). According to the linear model, property values tend to be higher as the moisture content increases. However, the values obtained for most properties were higher with the lowest moisture content tested, corroborating with the previous constatation.

Among the properties analyzed, the apparent density (ρ), the resistance to cracking parallel to grain (f_{s0}), and the tenacity (W) presented higher values when saturated than when with a moisture content equal to 12%. The other properties analyzed presented higher values when dry, i.e., with a moisture content equal to 12%.

Concerning the strength properties studied, it was found that the compression strength parallel to grain (f_{c0}) has an average value equal to 61.21 MPa when the moisture content is 12% and equal to 41.04 MPa at the FSP, i.e., the average value is 49.1% higher for dry samples. The same was observed for the tensile strength parallel to grain (f_{t0}) and the shear strength parallel to grain (f_{v0}). Both had a decrease of 40%, and 44.7% of the average strength was observed for the saturated samples, respectively. These results demonstrate compliance with the linear behavior of decreasing strength in the same proportion as the increase in moisture content proposed by the models of NBR 7190 (ABNT, 1997).

The tensile strength perpendicular to grain (f_{t90}) was 15.7% higher for the samples in the equilibrium moisture content. The strength in the static bending test decreased by 24.6% when at the FSP.

Regarding the properties related to stiffness, the modulus of elasticity to compression parallel to grain (E_{c0}) presented an average value of 18.7% higher, with the moisture content equal to 12%. For the modulus of elasticity in the tensile parallel to grain (E_{t0}), there was a decrease of 15.3% in the average value using saturated wood samples. The modulus of elasticity in the static bending test (E_{tm}) resulted in an average of 14.9 % higher in samples with moisture content at the equilibrium point.

The calculated coefficients of variation (Table 2) for the properties in the two studied moisture contents showed lower values for the samples at the FSP than for the relative moisture at the equilibrium point (12%) for the apparent density (ρ), the total tangential shrinkage (ε_{tt}), for the tensile strength in the direction parallel to grain (f_{t0}) and the tenacity (W). Then, analysis of variance (ANOVA) was performed to verify which properties were significantly influenced by the sample's moisture content.

The results of the ANOVA denoted that there was a significant influence of moisture content in the following wood properties: apparent density (ρ), compression strength parallel to grain (f_{c0}), shear strength parallel to grain (f_{v0}), strength in static bending (f_{tm}), modulus of elasticity in compression parallel to grain (E_{c0}), and hardness parallel (f_{h0}) and perpendicular (f_{h90}) to grain (Table 2).

The results of the P-value from ANOVA for the moisture content of the samples did not significantly influence the values of the total radial (ε_{rt}) and tangential (ε_{tt}) shrinkage, the parallel (f_{t0}) and perpendicular (f_{t90}) tensile strength to grain, modulus of elasticity in tensile parallel to grain (E_{t0}), conventional modulus of elasticity in static bending test (Etm) and the tenacity (W). These results show different behavior than the linear model presented by NBR 7190 (ABNT, 1997).

Tenacity (W) increased as there was also an increase in density (ρ) in samples with moisture content relative to the FSP. In this sense, Christoforo et al. (2020) obtained through the analysis of regression models a good correlation between apparent density and toughness in samples with moisture content equal to 12%, in which the increase in density caused an increase in toughness.

In terms of the estimation of strength and stiffness properties, the results demonstrated that the models of NBR 7190 (ABNT, 1997) were not satisfactory for all the properties obtained for *Vatairea* sp. wood characterization.

For the strength properties, it was observed that the most significant errors obtained were for the compressive strength parallel to grain (20.09%), for the tensile strength parallel to grain (50.76%), and the strength in the test of static bending (23.40%), and the moisture content did not significantly influence only the latter according to the analysis of variance performed.

The most significant error in the estimate for stiffness properties was the modulus of elasticity in compression parallel to grain (4.25%). Thus, it was found that the NBR 7190 model (ABNT, 1997) was not satisfactory in estimating the physical and mechanical properties of the wood of *Vatairea* sp.

5. CONCLUSIONS

Based on the results, it was noted that the properties more influenced by moisture content were apparent density, compressive, tensile and shear strength parallel to grain, flexural strength in static bending, modulus of elasticity in compression parallel to grain, and the hardness parallel and perpendicular to grain.

On the contrary, the other properties were not satisfactorily influenced by the moisture content, i.e., the variation of their values in the two studied moisture contents is not a result of the increase in the moisture content. Therefore, it was observed that the Brazilian Standard model was not accurate for the case studied.

The properties that had lower values at the FSP at a rate corresponding to the increase in moisture content and, therefore, are in accordance with the linear model designated by the Brazilian Standard were compressive strength and tensile strength parallel to grain and the shear strength parallel to grain, whose variation was between 40% and 50%.

Density, resistance to cracking parallel to grain, and hardness presented higher values when the moisture content was equal to the FSP. Therefore, the linear model of the Brazilian Standard was not satisfactory for them.

The most significant errors obtained in the estimates of the properties were for the compression strength and tensile parallel to grain, resistance to static bending, and the modulus of elasticity in the compression parallel to grain. Thus, it was found that the linear model adopted by Brazilian Standard was not satisfactory for predicting the properties of the *Vatairea* sp. wood.

AUTHOR CONTRIBUTIONS

Heloiza Candeia Ruthes wrote the paper, obtained and discussed the statistical, experimental, and estimated data.

Fernando Júnior Resende Mascarenhas wrote the article and supported the data analysis.

Larissa Soariani Zanini Ribeiro Soares, Vinicius Borges de Moura Aquino, Felipe Nascimento Arroyo, and Iuri Fazolin Fraga supported the data analysis and the obtaining of experimental results.

André Luis Christoforo and Francisco Antonio Rocco Lahr obtained the experimental results and supported the writing of the paper.

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