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RADIAL VARIATION OF DENSITY AND DIMENSIONAL STABILITY OF TAUARI (*Couratari oblongifolia* Ducke & R. Knuth.) WOOD

ABSTRACT: Wood is used for furniture, panel making and civil construction. However, the species used are restricted to a small group that is intensively exploited, which poses a risk to the availability of these species in the forest massifs. Thus, it is necessary to carry out studiesin relation to less exploited species, for their inclusion in the market. The objective was to characterize the radial variation of the physical properties of tauari wood. Logs from tauari trees were used, from which 120 specimens were made, subjected to saturation, drying and acclimatization, to obtain data for the calculation of apparent density (ρa) and basic (ρb), porosity (Φ), linear (βl, βt and βr) and volumetric (ΔV) shrinkages and the anisotropy coefficient (T/R). The wood was characterized as moderately heavy (ρb = 0.68 g cm^{-3}), with a moderate tendency to warping and a low anisotropy coefficient (<1.4), indicating that the material has good dimensional stability and can present itself as an alternative to intensely explored species, as it is found in a large part of the Amazon.

KEYWORDS: Wood technology, Wood density, Wood shrinkage.

VARIAÇÃO RADIAL DA DENSIDADE E ESTABILIDADE DIMENSIONAL DA MADEIRA DE TAUARI (*Couratari oblongifolia* Ducke & R. Knuth.)

RESUMO: A madeira é utilizada para movelaria, confecção de painéis e construção civil. Contudo as espécies utilizadas restringem-se a um pequeno grupo que é intensamente explorado, isto oferece risco à disponibilidade dessas espécies nos maciços florestais. Dessa forma é necessária a realização de estudos em relação a espécies menos exploradas para a inclusão das mesmas no mercado. Objetivou-se caracterizar a variação radial das propriedades física da madeira de tauari. Foram utilizadas toras de árvores de tauari, a partir das quais confeccionou-se 120 corpos de prova, submetidos à saturação, secagem e aclimatação, para obtenção de dados para os cálculos de densidade aparente (ρa) e básica (ρb), porosidade (Φ), contrações lineares (βl, βt e βr) e volumétrica (ΔV) e o coeficiente de anisotropia (T/R). A madeira foi caracterizada como moderadamente pesada (ρb = 0,68 g cm^{-3}), com tendência moderada à empenamentos e baixo coeficiente de anisotropia (<1,4), indicando que o material tem boa estabilidade dimensional e pode apresentar-se como alternativa às espécies intensamente exploradas, pois é encontrada em grande parte da Amazônia.

PALAVRAS-CHAVE: Densidade da madeira, Retratibilidade da madeira, Tecnologia da madeira.

VARIACIÓN RADIAL DE LA DENSIDAD Y ESTABILIDAD DIMENSIONAL DE LA MADERA DE TAUARI (*Couratari oblongifolia* Ducke & R. Knuth.)

RESUMEN: La madera se utiliza para muebles, fabricación de paneles y construcción civil. Sin embargo, las especies utilizadas están restringidas a un pequeño grupo que se explota intensamente, lo que representa un riesgo para la disponibilidad de estas especies en bosques masivos. Por ello, es necesario realizar estudios en relación a las especies menos explotadas para su inclusión en el mercado. El objetivo fue caracterizar la variación radial de las propiedades físicas de la madera de tauari. Se utilizaron troncos de árboles de tauari, de los cuales se elaboraron 120 especímenes, sometidos a saturación, secado y aclimatación, para obtener datos para el cálculo de densidad aparente (ρa) y básica (ρb), porosidad (Φ), lineal (βl, βt y βr) y contracciones volumétricas (ΔV) y el coeficiente de anisotropía (T/R). La madera se caracterizó por ser moderadamente pesada (ρb = 0,68 g cm^{-3}), con moderada tendencia al alabeo y bajo coeficiente de anisotropía (<1,4), indicando que el material tiene buena estabilidad dimensional y puede presentarse como una alternativa a especies intensamente exploradas, ya que se encuentra en gran parte de la Amazonía.

PALABRAS CLAVES: Tecnología de la madera, Densidad de la madera, Retratibilidad de la madera.

INTRODUCTION

Wood is a material that is intensively exploited in the Brazilian Amazon, as it is a product used for various purposes (furniture manufacturing, panel making and civil construction) (MELO SILVA et al., 2016). Garapeira (*Apuleia leiocarpa* (Vogel) JK Macbr.), faveira (*Parkia paraensis* Ducke), Jatobá (*Hymenaea courbaril* L.) and cumaru-ferro (*Dipteryx odorata* (Aubl.) Willd.) can be highlighted as noble species for the timber market (MELO et al., 2013a; SILVA et al., 2015; REIS et al., 2019).

However, this can represent a problem, since to meet the commercial demand selective exploitation is practiced, and restricted to a small number of species, resulting in the scarcity or extinction of some forest species (MELO SILVA et al., 2016).

Given this reality, the use of lesser-known species in the forest-based sector becomes evident, since it is possible to find characteristics in them similar to those traditionally used woods, promoting innovation and diversification of forest products, however, information in this regard is incipient (REIS et al., 2019).

Mascarenhas et al. (2021a) mentioned that research related to the physical, chemical and mechanical properties of tropical woods of native species in Brazil can be expanded to support the sizing of this material in a more appropriate way. Tauari wood (*Couratari oblongifolia* Ducke & R. Knuth.) fits into this context, because it presents adequate characteristics for the manufacturing of jambs and doors, and paneling has gained prominence in the Amazon wood industries (COSTA et al., 2011; GARCIA et al., al., 2012).

On the other hand, aspects about the properties of tauari wood are not widely explored and other species also called tauari are grouped, making it difficult to standardize the results (SANTOS et al., 2020). Consequently, few studies report aspects related to the variation of physical and anatomical properties of the wood of tauari species (BERNAL et al., 2011; COIMBRA et al., 2018; CRUZ et al., 2019), especially in relation to radial variation of the wood of the species *Couratari oblongifolia*.

Wood is a heterogeneous material with differences in its properties, among species and within the same species, in radial, tangential and longitudinal directions (TRUGILHO et al., 2015; CRUZ et al., 2021; MASCARENHAS et al., 2021b).

Thus, the objective of this work was to evaluate the radial variation of physical properties (density and shrinkage) of tauari wood in order to provide minimally necessary data for its application.

MATERIAL AND METHODS

RESEARCH LOCATION

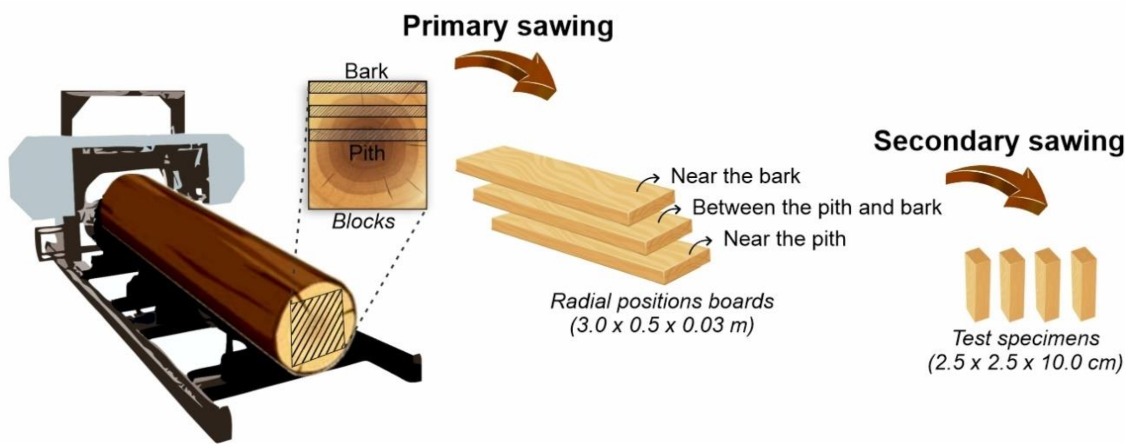
The present study was conducted in the state of Rondônia, where the climate, according to the Köppen-Geiger climate classification, is of the Am type (ALVARES et al., 2013), the annual precipitation is 2.300 mm, average annual temperature of 26 °C. Between the months of November and May, the relative humidity of the air remains between 80 and 90%, and between the months of July and August it is reduced to 75% (MASCARENHAS et al., 2020).

OBTAINING AND PROCESSING WOOD

The wood was obtained from a timber industry in the city of Nova Brasilândia do Oeste - RO, which operates under the legal terms of sustainable management of the Amazon. Two tauari logs were subjected to primary break-down through tangential cuts to obtain boards with dimensions of 3.0 m × 0.5 m × 0.03 m (length × width × thickness). The boards were removed in three radial positions: near the bark, between the pith and bark and near the pith.

After this step, the boards were subjected to secondary unfolding to produce specimens with dimensions of 2.5 cm × 2.5 cm × 10.0 cm (width × thickness × length), according to the guidelines of the ASTM D 143-14 standard (ASTM, 2014), obtaining 20 specimens for each selected board. All sampling procedures are in the scheme shown in Figure 1.

Figure 1. Scheme of primary sawing of tauari logs (*Couratari oblongifolia* Ducke & R. Knuth.), obtaining blocks, obtaining boards from different radial positions and production of test specimens after secondary sawing.



Fonte: Prepared by the authors.

DETERMINATION OF PHYSICAL PROPERTIES

The specimens were saturated in water until constant mass was observed (fiber saturation point - FSP), at which time the dimensions of the pieces were taken in the radial, tangential and longitudinal directions, with the value of each dimension resulting from the average of three measured on each axis. For the longitudinal direction, two measurements were taken, using a digital caliper.

Then, the specimens were dried in an oven with forced air circulation set at 105 ± 5 °C. When observing constant mass in the anhydrous condition, the dimensions and mass of the pieces were measured as described above.

Subsequently, the specimens were stored in an air-conditioned chamber (relative humidity of 65% and temperature of 25 °C) (USDA, 2010), after the pieces had a constant mass, the dimensions were measured again. All mentioned procedures are provided for in ASTM D 143-14 (ASTM, 2014).

With data on volume under saturated and equilibrium conditions and mass under equilibrium and anhydrous conditions, it was possible to determine the apparent and basic density, based on Equations 1 and 2, respectively.

$$\rho a = \frac{M_{12\%}}{V_{12\%}} \quad \text{Equation 1}$$

$$\rho b = \frac{M_s}{V_i} \quad \text{Equation 2}$$

Where: ρa = Apparent density (g cm^{-3}); $M_{12\%}$ = Mass of the sample in equilibrium moisture (g); $V_{12\%}$ = Sample volume in equilibrium moisture (cm^3); ρb = basic density (g cm^{-3}); Ms = dry mass (g); Vi = initial volume (cm^3).

To calculate the linear shrinkages, the values of the longitudinal, radial and tangential dimensions were applied, in the anhydrous and saturated condition in Equation 3. The coefficient of anisotropy (T/R) was obtained from the ratio between the tangential and radial shrinkages.

$$\beta_{l,t,r} = \left(\frac{d_{l,r,t_{(28)\%}} - d_{l,r,t_{(0\%)}}}{d_{l,r,t_{(28\%)}}}\right) \times 100 \quad \text{Equation 3}$$

Where: βl,t,r= longitudinal, radial or tangential shrinkage (%); $dl,t,r_{(28\%)}$ = longitudinal, radial or tangential dimension of the specimen in saturated condition (cm) and $dl,r,t_{(0\%)}$ = longitudinal, radial or tangential dimension of the specimen in anhydrous condition (cm).

In the calculation of the volumetric shrinkage (Equation 4), the measurements of the volume of the specimens were used, with them in the saturated with water condition and when they were found, in anhydrous form.

$$\Delta v = \left(\frac{V_{28\%} - V_{0\%}}{V_{28\%}}\right) \times 100 \quad \text{Equation 4}$$

Where: Δv = volumetric shrinkage (%); $V_{28\%}$ = volume in saturated condition (cm^3); $V_{0\%}$ = Volume in anhydrous condition (cm^3).

Then, in possession of the basic density values, it was possible to determine the porosity with Equation 5.

$$\Phi = 1 - \left(\frac{\rho b}{1.54}\right) \times 100 \quad \text{Equation 5}$$

Where: Φ = porosity (%); ρb = basic density (g cm^{-3}); ≅ 1.54 is the cell wall density (g cm^{-3}).

STATISTICAL ANALYSIS

The data obtained for the physical parameters of tauari wood were analyzed using descriptive statistics, indicating the values of maximum, average, minimum and coefficient of variation. The results found for the properties evaluated in the different radial positions were submitted to Pearson's correlation ($p<0.01$ and $p<0.05$), indicating the existence of linear relationships between the variables. For this, we used the R software and the Metan package (OLIVOTO; LÚCIO, 2020; R CORE TEAM, 2020).

RESULTS AND DISCUSSION

Regarding ρa, it was observed that the values did not show great variation between the regions near the bark and near the pith (Table 1). In relation to the region between the pith and bark, the observed values of ρa were slightly higher than those found in the other radial positions.

This behavior may be related to the greater amounts of late wood in the position between the pith and bark, which suggests the occurrence of transition wood, delimiting juvenile wood and adult wood (KNAPIC et al., 2007; HIETZ et al., 2013; SALVO et al., 2017). It is expected that in the region near the bark, as it is mostly made up of adult wood, there will be greater density, but this did not happen.

Research carried out by Costa et al. (2017) helps to understand these results. The authors mention that the heartwood contains a large amount of extractives and lignin, making this part of the wood with low permeability, higher natural durability than sapwood and slightly higher density.

Regarding the results obtained for ρb, the values found for the regions near the bark and between the pith and bark were very close, and for the values of the region near the pith, there was a decrease in relation to the previous ones, probably due to the greater amount of juvenile wood. Melo et al. (2010) and Gonçalves et al. (2020) explained that juvenile wood differs from adult wood in that it has lower density, greater microfibrillar angle, higher proportion of reaction wood, thinner cell walls, higher lignin content, lower cellulose content and lower mechanical strength.

Table 1. Values of apparent density (ρa), basic density (ρb) and porosity (Φ) of tauari wood (*Couratari oblongifolia* Ducke & R. Knuth.) in different radial positions.

Values	ρa (g cm^{-3})	ρb (g cm^{-3})	Φ (%)
	Near the bark		
Minimum	0.77	0.65	55.11
Average	0.79	0.67	56.61
Maximum	0.82	0.69	57.62
CV (%)	1.67	1.59	1.22
	Between the pith and bark		
Minimum	0.78	0.65	55.00
Average	0.82	0.68	55.93
Maximum	0.85	0.69	58.00
CV (%)	2.89	1.79	1.41
	Near the pith		
Minimum	0.70	0.58	58.92
Average	0.74	0.62	59.90
Maximum	0.76	0.63	62.37
CV (%)	2.09	1.95	1.31

In general, the values of ρa and ρb found are within the expected range for the species (≥ 0.62 g cm^{-3}) (COSTA et al., 2011; SANTOS et al., 2013). The results obtained for Φ varied around 60% in the region near the pith and around 56% in the regions near the bark and between the pith and bark. These results allow classifying the wood, regardless of the evaluated region, as moderately heavy or heavy (RUFFINATTO et al., 2015).

The highest means for βl were observed, respectively, for the region between the pith and bark, region near the bark and region near the pith (Table 2). In relation to βr, the average of the region near the bark was slightly lower than that obtained for the region near the pith.

In the region between the pith and bark, the highest values for βr were obtained. For both βt and ΔV, the highest means were found for the region between the pith and bark and the lowest for the region near the bark. The values of βt, βt and ΔV allow us to say that tauari wood tends to present medium intensity shrinkages (PEREIRA, 2013; SARGENT, 2019; ELAIEB et al., 2020).

Table 2. Values of linear longitudinal (βl), tangential (βt), radial (βr), volumetric shrinkage (ΔV) and anisotropy (T/R) of tauari wood (*Couratari oblongifolia* Ducke & R. Knuth.) in different radial positions.

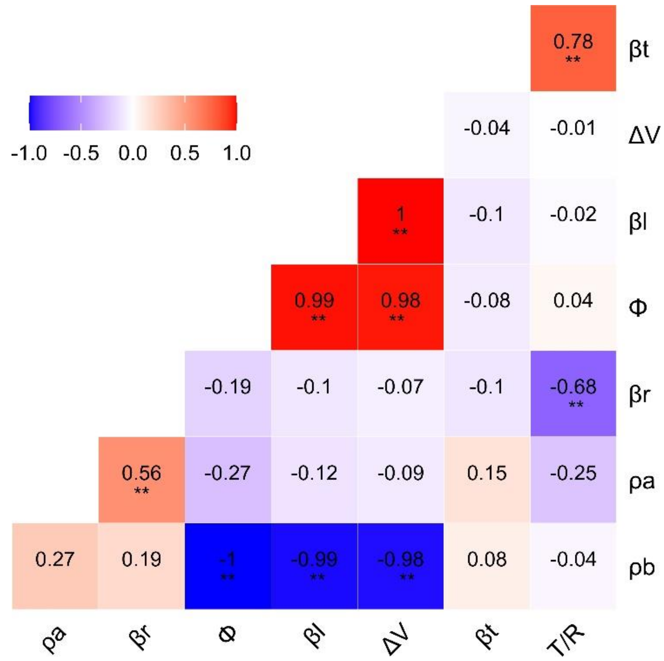
Values	βl (%)	βr (%)	βt (%)	ΔV (%)	T/R
			Near the bark		
Minimum	0.09	4.30	6.15	10.98	1.08
Average	0.33	5.23	6.82	11.99	1.32
Maximum	0.49	6.02	7.35	12.88	1.56
CV (%)	31.81	8.34	5.06	4.33	10.00
			Between the pith and bark		
Minimum	0.12	4.57	6.94	12.21	1.14
Average	0.36	5.61	7.41	12.92	1.34
Maximum	0.88	6.16	7.99	13.71	1.70
CV (%)	54.69	7.38	3.92	3.27	9.97
			Near the pith		
Minimum	0.13	4.90	6.23	11.22	1.08
Average	0.31	5.65	6.97	12.50	1.24
Maximum	0.88	6.28	7.66	13.83	1.54
CV (%)	59.76	7.16	6.05	5.17	7.88

In the region near the pith, there was a smaller difference between βt and βr, resulting in a lower anisotropy coefficient (1.24). This is justified because in the central region of the log, the anatomical conditions of the growth rings favor a higher percentage of radial cuts, which provide a more balanced distribution between juvenile wood and late wood, making the transversal shrinkages of the wood less intense (MELO et al., 2010; MONTEIRO et al., 2021).

The anisotropy coefficient is the parameter that represents the variation in the transverse direction, resulting from the dimensional balance in the radial and tangential directions, and is used to classify the quality of the material (TOMASI et al., 2013; MORETTI et al., 2017). Thus, the T/R values found for the regions near the bark and between the pith and bark indicate that tauari wood has moderate dimensional stability (MELO et al., 2013b; MASCARENHAS et al., 2021c).

The correlations observed between ρa, ρb and Φ (Figure 2) may indicate difficulties in drying wood due to the reduction in the flow rate of water from the wood to the atmosphere, as density is inversely proportional to porosity (MONTEIRO et al., 2020; BARAUNA et al. 2021).

Figure 2. Correlations between physical properties of tauari wood (*Couratari oblongifolia* Ducke & R. Knuth.) in different radial positions.



Where: ρa = apparent density (g m^{-3}); ρb = basic density (g m^{-3}); βl = longitudinal shrinkage (%); βt = tangential shrinkage (%); βr = radial shrinkage (%); ΔV = volumetric shrinkage (%); Φ = porosity (%); T/R = anisotropy coefficient; *=significant correlation when $p<0.05$; **=significant correlation when $p<0.01$.

Among linear shrinkages, regardless of radial position, no significant correlation coefficients were observed. There was a significant inversely proportional correlation between βr and T/R and directly proportional between βt and T/R, that is, the smaller the difference between βt and βr, the smaller the T/R ratio (ALMEIDA et al., 2015).

Between Φ, ΔV and ρb, strong correlations were observed. The ρb represents the dry mass content by the maximum wood volume. This dry mass contains around 60% of holocellulose (cellulose + hemicellulose) (ROWELL et al., 2012), which is directly related to the water content that can be adsorbed on the cell wall (SARGENT, 2019).

In other words, in denser woods there will be a greater amount of impregnation water, whose variation, caused by the sorption phenomenon, will provide a more intense volumetric shrinkage or swelling in the cell wall (LEONARDON et al., 2010).

Thus, the dimensional stability parameters evaluated fit the tauari wood to the minimum requirements for the production of furniture and applications that require machining (LOPES et al., 2011; DIAS JÚNIOR et al., 2015). Based on the Ramage et al. (2017), it is possible to say that this material can be used in civil construction in light external and light structural internal applications (frames, rafters and laths). Garcia et al. (2012) reported that tauari wood can be suitable for several purposes, as it has a low tendency to warp and crack.

Note that the properties of the wood studied do not differ from the characteristics of other tropical woods, such as garapeira (*Apuleia leiocarpa* (Vogel) JK Macbr.), faveira (*Parkia paraenses* Ducke), jatobá (*Hymenaea courbaril* L.) and cumaru-ferro (*Dipteryx odorata* (Aubl.) Willd.) (MELO et al., 2013a; REIS et al., 2019).

Taking into account the experimental results (ρb, βr, βt and T/R), especially for the region between the pith and bark, the analyzed wood presented adequate characteristics for the manufacture of laminated panels, structural parts (beams, rafters and slats), artifacts for interior finishing (linings, doors, jambs and baseboards) and tool handles.

CONCLUSION

The physical characterization of tauari wood, under the conditions of study, made it possible to classify it as moderately heavy to heavy and with good dimensional stability, especially in the intermediate region (between the pith and bark).

The application of the wood under study takes place for several purposes, suggesting that it can present itself as an alternative to intensely exploited species, considering that it can be found in a large part of the Amazon.

The scope of the results obtained is limited to the species under study and may vary depending on the origin of the raw material, as the tauari wood comes from native forest management plans. Studies on the properties of lesser-known tropical woods on the market make it possible to determine their potential use, diversifying wood products.

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