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Review Article

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Longitudinal and Transverse Variation in the Physical Properties of Wood Red Tauari

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ABSTRACT

The objective of this work was to study the fiber length variation, retractability and basic density, in the core-bark direction and along the heig of the red tauari wood (*Cariniana micrantha* Ducke). The stem was evaluated in the discs, from core to bark, corresponding to 0%, 25%, 50%, 75% and 100%. At the commercial height of the tree the evaluation was carried out in the Base, DBH, 50%, 75% and 100%. Three trees were collected and 5 discs of 12 cm of thickness were taken from each tree the heights: Base, DAP, 50%, 75% and 100%. Results indicated that the fiber length increases in the radial direction core-bark and decreases in the longitudinal direction, from base to top. The analysis of the basic density varied in the core-bark direction, with tendency to increase from the position of 50% (heartwood), then decreasing in the sapwood region. Total volumetric and linear contractions decreased in the core-bark direction.

Keywords: basic density, shrinkage, fiber.

1. INTRODUCTION

Wood is one of the most noble products of biomass. Its use is connected since the early times of humanity and with various forms of employment. The most highlighted ones have been for power generation, woodworking, paper and pulp, manufacture of panels and, therefore, in various industrial segments.

According to data from the Institute of Man and Environment in the Amazon, among the States of the Legal Amazon, Pará is the largest producer of tropical wood, followed by Mato Grosso and Rondônia (Pereira et al., 2010).

The Amazon, in conjunction with regions of Central Africa, South-East Asia and Boreal Asia, represent the latest forest areas little modified by anthropic action.

Tauari is a moderately heavy wood (0.55 to 0.60 g/cm^3), yellowish brown heartwood, lighter sapwood with great regular, coarse texture, indistinct odor and taste, easy workability, can receive a good finish of regular polishing (Loureiro et al., 1979).

The wood of *Cariniana micrantha* Ducke can be used in carpentry, in construction in general, cables and tools, boxes, canoes, rowing, musical instruments, toys, crayons, bobbins, spools and mechanical pulp (Loureiro et al., 1979; SUDAM, 1981).

The study for this species was carried out by the need of information of its anatomical and physical properties.

Thus, the present study is justified for the following reasons:

- ✓ The need for information on the physical and anatomical properties (length of fibers, basic density and shrinkage) of red tauari, which has been highlighting within the timber industry;
- ✓ Adding value to the wood originated from native forests, with the incorporation of technological papers qualifying it for various uses;
- ✓ Transfer of information to the furniture manufacture centers and other forest-based industries, as well as to the characteristics and possibilities of use of red tauari wood as basic raw material and strategic for their activities;
- ✓ The physical and mechanical properties of wood have guaranteed great demand in domestic and foreign markets;
- ✓ In 2000, in the state of Amazonas, the tauari wood was the 14th most widely used in the laminate industry (Lima et al., 2005); in 2006, it was already among the 10 most traded in the market of sawn wood and log wood.

Zobel & Van Buijtenen (1989) affirm that the fibers morphological characteristics vary significantly among and within the trees.

The basic wood density is recognized as one of the most important parameters for assessment of their quality, due to being of easy determination and being related to their other characteristics (Shimoyama & Barrichello, 1991).

The wood density is a property much more influenced by genetic inheritance than by environment, as said by (Trugilho et al., 2010).

In the wood characterization, the determination of its density and especially of its variation inside the tree, both in radial direction, from the heartwood to the bark, and in the base-top direction, it is essential as a subsidy to the understanding of its quality.

Therefore, this research aimed to determine anatomical and physical properties of red tauari wood in longitudinal and transversal direction of the stem; check the variation of the basic density in five positions equidistant from the heartwood toward the bark; assess the aspects related with the total wood shrinkage and to evaluate the variation in the length of fibers in five positions equidistant from the heartwood toward the bark at different heights of the stem.

2. MATERIAL AND METHODS

2.1. Data collection

The three red tauari trees, with 13m of commercial height, were collected randomly, in the area of exploitation of the certified forest belonging to company Mil - Madeireira- Ltda, located at Km 227 of the AM-010 in the municipality of Itacoatiara, in the state of Amazonas, in the geographical coordinates 2°43' N 3°04' S and 58°57' W at an altitude of 40m above sea level and were identified in the Laboratory of Wood anatomy of the CPPF - Coordination of Research in Forest Products - INPA. The annual rainfall is about 2,200 mm with lower monthly volume in August to October. The average temperature is 26 °C and the relative humidity is about 80%.

Considering the commercial height of the three red tauari trees, 5 disks of 12 cm thickness were removed from each tree: in the heights, Basis, DAP, 50%,75% and 100%.

These discs were removed with the use of a chainsaw, and packaged in plastic bags to reduce moisture loss and immediately transported to the Laboratory of Wood Physics from the Federal University of Amazonas, where they were submerged in water to prevent loss of moisture and attack of xylophagous bodies.

2.2. Preparation of specimens

The specimens were removed from 15 disks, in three tauari trees, being five for each tree and each disc has been divided into four samples of orthogonal form. In each sample a radius was traced and divided by five positions equidistant in the cross-section of the disks in the direction heartwood-bark corresponding to 0%, 25%, 50%, 75% and 100%, totaling 60 samples and 300 specimens (Figure 1).

Of these samples the specimens were prepared in dimensions and guidelines recommended by ABNT/NBR 7190 2.0 × 3.0 × 5.0 (ABNT, 1997). It was used in the present study 2 cm (tangential) × 3 cm (radial) × 5 cm (longitudinal) (Figure 1). After manufacturing the specimens were immersed in distilled water for total saturation for a period of 90 days.

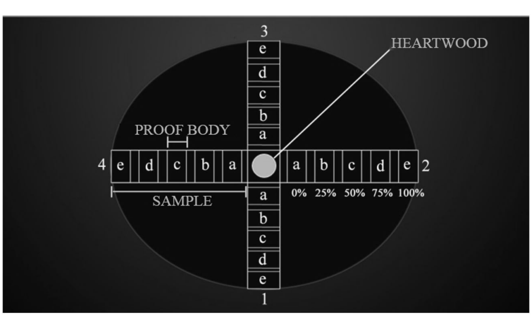

Figure 1. Schematic Representation of the samples taken from the red tauari (*Cariniana micrantha* Ducke). The disc readings were carried out in the following order: a1+a2+a3+A4, with subsequent mean calculation.

2.3. Manufacture of blades for fibers length measurement

To perform the study of the fiber length, a total of 750 slides was manufactured, being 50 blades for each disc, divided into five for each specimen.

The size of the specimens for the fibers analysis were 2 × 3 × 5 cm. These were analyzed in macerated material, for this reason, small portions of each specimen underwent treatments following the recommendations proposed by the Pan American Commission of Technical Standards (COPANT, 1974).

For statistical interpretation of the results of the fibers length ANOVA factorial 5 × 5 was used. The factor is the position in the stem: A1 = Base, A2 = DAP, A3 = 50%, A4 = 75% and A5 = 100%, factor B is the position of the sample toward heartwood-bark: B1 = 0%, B2 = 25%, B3 = 50%, B4 = 75% and B5 = 100% and the three trees are the repetitions.

2.4. Method for obtaining the results of basic density

To determine the basic density the method of maximum moisture content was used according to Smith (1954), using specimens with dimensions of 2 × 3 × 5 cm.

Smith (1955) emphasizes that under the practical point of view, the method of maximum moisture content is entirely satisfactory when the volume of samples varies from 100 to 1,600 cubic millimeters.

In a comparison among various methods of determination of basic density, Scaramuzzi (1966) concluded that the Method of Maximum Moisture Content was the one that provided the lowest standard deviation in relation to immersion in water, in addition to being the fastest and of easier implementation.

Using this method only two weighings are required, one with the sample completely saturated with water and another with the dried sample in an oven at 105 ± 3 °C until constant weight.

In this method the basic density is determined, without, however, obtaining its volume. Therefore the wood sample must be completely saturated. After that, the excess of water must be removed from their surfaces and determine the saturated weight. The dry weight of the samples shall be obtained.

2.5. Method for obtaining the results of shrinkage

For the shrinkage testing specimens removed from the disks in the longitudinal direction and radial of tauari stem were removed, oriented toward base-top and heartwood bark, respectively.

After the saturation, the samples were weighed on a digital electronic scale with a precision of 0.01g, measured linearly with a digital pachymeter accuracy of 0.05 mm and stored in a climate chamber until they reach moisture equilibrium with the environment, around 12%.

After this period the specimens were taken to the greenhouse and the process of artificial drying was started using the temperatures (40 °C to 105 °C) and maintained at a temperature of 105 °C until reaching the wood moisture content of 0%. Throughout this process, the samples were again subjected to successive sessions of weighing and measurement of dimensions. To each session of measurement moisture and dimensions of the samples were calculated.

With these values it was possible to calculate the total linear shrinkage in axial, radial and tangential directions, since perfectly saturated samples until their drying.

The total linear shrinkage was determined in accordance with NBR 7190/97 (ABNT, 1997).

3. RESULTS AND DISCUSSION

3.1. Fibers length

The results of the fibers lengths found in individuals evaluated in this study, reveal a constancy in the fibers length in the direction heartwood-bark. The smallest fibers lengths in the radial direction are in the region that goes from the heartwood to the periphery of the heart and the largest ones are in the sapwood region. It was observed that there was a low variation in radial direction, where the lowest average is 1.465 and the greatest value 1.628, the lowest values for the coefficient of variation, indicating reliability of the collected data (Table 1).

Table 1. Descriptive statistics for the fiber length.

Position in the lumen - Height	Position Heartwood-Bark at the disk	Tree I	II	III	Average	Standard Deviation	Coefficient Variation
Basis	0%	1.710	1.431	1.486	1.542	0.121	7.836
	25%	1.655	1.445	1.517	1.539	0.087	5.660
	50%	1.702	1.434	1.443	1.526	0.124	8.136
	75%	1.665	1.481	1.569	1.572	0.075	4.785
	100%	1.694	1.491	1.489	1.558	0.096	6.176
DAP	0%	1.643	1.43	1.542	1.538	0.087	5.648
	25%	1.655	1.464	1.559	1.559	0.078	4.981
	50%	1.693	1.558	1.593	1.615	0.057	3.549
	75%	1.742	1.522	1.593	1.619	0.091	5.647
	100%	1.720	1.497	1.668	1.628	0.095	5.832
50%	0%	1.668	1.423	1.501	1.53	0.102	6.689
	25%	1.641	1.461	1.569	1.557	0.074	4.773
	50%	1.635	1.442	1.558	1.545	0.079	5.129
	75%	1.665	1.470	1.526	1.554	0.082	5.261
	100%	1.625	1.514	1.614	1.584	0.05	3.154
75%	0%	1.579	1.439	1.410	1.476	0.074	4.986
	25%	1.705	1.477	1.554	1.579	0.094	5.983
	50%	1.745	1.500	1.526	1.590	0.110	6.898
	75%	1.801	1.484	1.58	1.622	0.133	8.174
	100%	1.780	1.486	1.571	1.612	0.123	7.654
100%	0%	1.597	1.437	1.361	1.465	0.098	6.706
	25%	1.619	1.586	1.491	1.566	0.054	3.463
	50%	1.682	1.424	1.563	1.557	0.105	6.770
	75%	1.731	1.428	1.505	1.555	0.128	8.259
	100%	1.678	1.433	1.621	1.578	0.105	6.637
Number of Notes		**250**	**250**	**250**			

DAP = breast height diameter.

This result is in agreement with studies conducted by Alves & Angyalossy-Alfonso (2002) indicating that the fiber length increases toward heartwood bark Pernía & Melandri (2006) confirm the influence of the fibers growth, related to the positioning on the stem.

Tomazello (1985) and Wilkes (1988) claim that the cambia cells begin to produce, during a certain time, elements with larger dimensions, until they reach their stabilization along the radius. Due to that, there is an increase in the fibers length toward heartwood-bark.

Next to the heartwood the fibers are short, have smaller diameter and have thinner walls and increase rapidly in the area of juvenile wood in the bark direction (Dadswell, 1958; Maeglin, 1987).

The results showed a decrease in the fibers length, along the stem, in the longitudinal direction into the inner layers close to the heartwood. In the outer layers three different behaviors were found:

a) descending to position 50 and from that point rising to the top of the stem;
b) ascending to position 50 and from that point dropping to the top of the stem;
c) ascending to the DAP and descending until the top of the stem.

Silva (1992) studied two timber species from the Amazon where they found increasing fiber length, with some fluctuations, from the heartwood to the periphery, and also increase from the base until it reaches a maximum value then decrease toward the top.

Urbinati et al. (2003), studying *Terminalia ivorensis*, observed an increase in the fibers length in the direction of the top, while the lumen and the thickness of the cells wall showed no differences.

According to Zobel & Van Buijtenen (1989) changes in the fibers length vary among the species, however, the most common is to observe longer fibers at the base of the trees, this variation can be explained by the increase in the proportion of juvenile wood toward the top.

Through the analysis of variance (ANOVA) in factorial scheme, Table 2, performed to verify the existence or not of significant differences between the fiber length in the radial direction of the stem (heartwood-bark) and longitudinal (base-top), resulted not significant, i.e., indicating clearly that there was no statistical difference among the fibers lengths in the radial and longitudinal direction of the tauari stem.

3.2. Basic density

3.2.1. Radial variation

The variation of the basic density, in the tauari radial direction and the values of the density in relation to the positions toward heartwood-shell are presented in Table 3.

In a general way the basic density in the direction heartwood-bark tends to increase from 50% (core) and then decrease, obtaining the lowest values for 100% (sapwood), where it was found in the stem the average of 0.5266 and standard deviation of 0.0245 at the base; in position DAP the average of 0.5264 and standard deviation of 0.0293; in 50% the average of 0.5186 and standard deviation of 0.0214; in 75% the average of 0.5020 and standard deviation of 0.0079 and in position 100% the average of 0.5055 with standard deviation of 0.0209. This was expected, considering that tauari is a species rich in extractive contents, which are mainly located in the duramen.

This behavior of the density in the direction heartwood-bark, approaches with the classification $\underline{c}$ of Panshin & De Zeeuw (1980), in which the density is higher in the heartwood-duramen, which may decrease in the sapwood close to the bark.

Table 2. Analysis of variance for fiber lengths.

Variation Source	GL	SQ	QM	F	P
Radial	4	0.05532	0.01383	1.01	0.412ns
Longitudinal	4	0.02449	0.00612	0.45	0.774ns
Radial × Longitudinal	16	0.03613	0.00226	0.16	1.000ns
Error	50	0.68536	0.01371		
Total	74	0.80131			

ns = not significant to 95% of probability; GL = degree of freedom; SQ = sum of squares; QM = middle square; F = factorial; P = probability.

Table 3. Basic density values.

Position in the Stem	Position Heartwood-Bark	Basic density (g/cm³)				
		TREE I	TREE II	TREE III	Average	Standard Deviation
Basis	**0%**	0.5608	0.4947	0.5940	0.5498	0.0506
	25%	0.5896	0.5371	0.6133	0.58	0.0390
	50%	0.5878	0.5333	0.5810	0.5674	0.0297
	75%	0.6050	0.5224	0.5788	0.5687	0.0422
	100%	0.5434	0.4985	0.5380	0.5266	0.0245
	Average	0.5773	0.5172	0.5810		
	Standard Deviation	0.0248	0.0196	0.0277		
DAP	**0%**	0.5618	0.4954	0.5854	0.5475	0.0467
	25%	0.5751	0.5405	0.5739	0.5632	0.0196
	50%	0.5954	0.5389	0.5854	0.5732	0.0302
	75%	0.6062	0.5117	0.5743	0.5641	0.0481
	100%	0.5380	0.4931	0.5481	0.5264	0.0293
	Average	0.5753	0.5159	0.5734		
	Standard Deviation	0.0271	0.0229	0.0152		
50%	**0%**	0.5831	0.5011	0.5306	0.5383	0.0415
	25%	0.6238	0.5384	0.5557	0.5726	0.0451
	50%	0.6231	0.5368	0.5526	0.5708	0.0459
	75%	0.6208	0.5156	0.5844	0.5736	0.0534
	100%	0.5392	0.4964	0.5203	0.5186	0.0214
	Average	0.5980	0.5177	0.5487		
	Standard Deviation	0.0371	0.0195	0.0249		
75%	**0%**	0.5524	0.5845	0.5378	0.5582	0.0239
	25%	0.5916	0.5215	0.5538	0.5556	0.0351
	50%	0.5805	0.5488	0.5604	0.5632	0.016
	75%	0.6066	0.4833	0.5734	0.5544	0.0638
	100%	0.5047	0.4931	0.5083	0.502	0.0079
	Average	0.5672	0.5262	0.5467		
	Standard Deviation	0.0402	0.0414	0.0250		
100%	**0%**	0.6388	0.5654	0.5375	0.5806	0.0523
	25%	0.6390	0.5602	0.5679	0.5890	0.0434
	50%	0.6402	0.5549	0.5600	0.5850	0.0478
	75%	0.6118	0.5199	0.5478	0.5598	0.0471
	100%	0.5272	0.4856	0.5037	0.5055	0.0209
	Average	0.6114	0.5372	0.5434		
	Standard Deviation	0.0486	0.0339	0.0220		

DAP = breast height diameter.

The trees were removed from the same site and had similar DAP and height. Therefore, it is expected to have been influence of environmental conditions. Genetic factors that control the tree shape and growth may have had some contribution in this difference.

The highest value of the density at the duramen agrees with the one observed by Fearnside (1997) which says that the density in the sapwood of Amazon trees is, on average, lower than the duramen. He also reports that some species may have major differences between duramen and sapwood. Trugilho et al. (1990), for example, found for the courbaril (*Hymenea courbaril*) basic density in the sapwood 24.4% lower than in the duramen.

3.2.2. Longitudinal variation

The samples withdrawn in the sapwood near the bark (E-100%) showed a tendency to decrease in basic density in the direction base-top.

It is emphasized here that the sapwood close to the bark is the wood region practically free from extractive contents, and consequently there is no effect of extractive contents in density.

In other positions, still in Table 3 (a-0%; b-25%; c-50% and d-75%) there is a clear trend and probably the extractive content was preponderant in increasing or decreasing the density according to their greater or lesser quantity.

In the trees I and III, there was a greater homogenization in values determined in basic density, i.e., tree I (the lowest value: 0.5047 g/cm^3 - the highest value: 0.6402 g/cm^3) and tree III (the lowest value: 0.5037 g/cm^3 - the highest value: 0.6133 g/cm^3) And it is also observed a general tendency in the trees I and II of increased density in the direction base-top until the position of 50% passing then to the density decrease in the position 50%-75%, followed again by an increase in position 100%, as shown in Table 3. Being this trend close to classification $\underline{d}$ of Panshin & De Zeeuw (1980), i.e., growing from the base to the top, not obeying a uniform pattern of variation.

Figure 2 shows the variation of the basic density along the tauari stem.

It was verified in the tree III a decrease toward the top of the stem presenting higher values at the base of the stem. A similar result was found by Kuroda et al. (1995) where the basic density showed a tendency to decrease at the top, having presented higher values in the base of the stem.

Ferreira (1972), says that there is a great variation of basic density in the longitudinal direction and explanations in the literature are based on the occurrence of reaction wood.

Through the analysis of variance (ANOVA) in factorial scheme, Table 4, performed to verify the existence or not of significant differences between the fiber length in the radial direction of the stem (heartwood-bark) and longitudinal (base-top), resulted not significant in the longitudinal and radial × longitudinal direction, i.e., indicating clearly that there was no statistical difference between the basic density in the radial and longitudinal direction of the tauari stem.

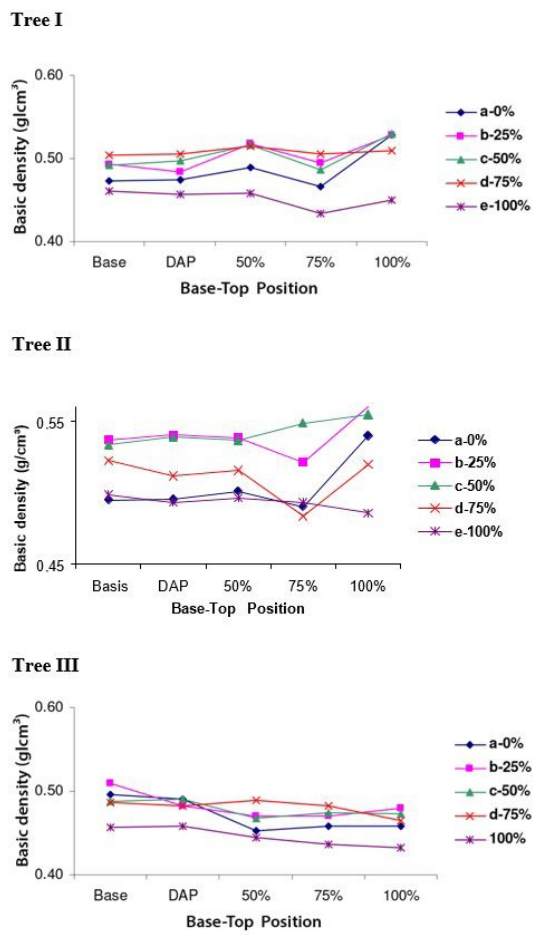

Figure 2. Variation of basic density in the longitudinal top-down direction of the tauari wood (*Cariniana micrantha* Ducke) at 0%, 25%, 50%, 75% and 100% of the heartwood.

Table 4. Analysis of variance for variation of basic density.

Variation Source	GL	SQ	QM	F	P
Radial	4	0.033007	0.008252	5.30	0.001*
Longitudinal	4	0.002413	0.000603	0.39	0.817ns
Radial × Longitudinal	16	0.005826	0.000364	0.23	0.999ns
Error	50	0.077880	0.001558		
Total	74	0.119126			

ns = not significant to 95% of probability; *significant; GL = degree of freedom; SQ = sum of squares; QM = middle square; F = factorial; P = probability.

As it can be observed in Table 4, there was no statistically significant difference in the radial direction, which requires the application of the Tukey test for verification of the differences among means.

The Tukey test for multiple comparisons of mean showed for the density that only the position 100% was statistically different from the others. While these were statistically equal among themselves, i.e., the density of the duramen was statistically higher than the density of the sapwood (Table 5).

3.3. Shrinkage

The results of the coefficients of total or maximum shrinkage of the saturated condition for dry condition of 0% moisture to tauari (*Cariniana micrantha* Ducke), in five positions equidistant from the heartwood, are presented in Table 6.

The values are within the ones cited in the literature for the variation of dimensional and volumetric contraction in different structural directions of wood. According

Table 5. Mean values for basic density in the radial direction of tauari wood (*Cariniana micrantha* Ducke).

Positions	0%	25%	50%	75%	100%
Average	0.5549 b	0.5721 b	0.5718 b	0.5641 b	0.5157 a

Averages followed by the same letter are statistically equal at 5% of probability.

Table 6. Mean values for the coefficients of total retractability and basic density of tauari (*Cariniana micrantha* Ducke).

Position in the Stem	Position Heartwood-bark	Contractions (%)			Ration T/R	Density Basic (g/cm³)
		Tangential	Radial	Volumetric		
Basis	0%	10.26 (9.12)(0.94)	7.16 (15.08)(1.08)	16.70 (6.66)(1.11)	1.46 (13.12)(0.19)	0.54 (7.51)(0.04)
	25%	11.30 (5.75)(0.65)	7.04 (14.71)(1.04)	17.63 (7.52)(1.33)	1.63 (10.46)(0.17)	0.58 (5.49)(0.03)
	50%	11.14 (5.27)(0.59)	6.03 (23.99)(1.45)	15.99 (15.05)(2.41)	1.94 (19.79)(0.38)	0.56 (4.27)(0.02)
	75%	10.71 (10.63)(1.14)	6.56 (6.86)(0.45)	16.81 (9.23)(1.55)	1.63 (5.69)(0.09)	0.56 (6.06)(0.03)
	100%	9.06 (8.92)(0.81)	5.48 (16.33)(0.89)	14.90 (19.16)(2.85)	1.67 (7.54)(0.13)	0.52 (3.80)(0.20)
DAP	0%	10.44 (12.25)(1.28)	7.47 (13.86)(1.04)	17.14 (15.54)(2.66)	1.41 (9.39)(0.13)	0.54 (6.96)(0.03)
	25%	10.57 (8.53)(0.90)	6.91 (15.54)(1.07)	17.24 (10.61)(1.83)	1.55 (8.15)(0.13)	0.56 (2.85)(0.01)
	50%	11.78 (14.05)(1.65)	7.19 (12.35)(0.89)	16.70 (16.72)(2.79)	1.64 (2.27)(0.04)	0.57 (4.29)(0.02)
	75%	11.14 (9.72)(1.08)	7.49 (7.07)(0.53)	16.94 (12.71)(2.15)	1.49 (10.20)(0.15)	0.56 (6.96)(0.03)
	100%	9.05 (15.58)(1.41)	5.33 (17.32)(0.92)	14.00 (20.02)(2.80)	1.70 (6.80)(0.12)	0.52 (4.54)(0.02)
50%	0%	9.42 (1.90)(0.18)	9.27 (28.91)(2.68)	17.34 (4.91)(0.85)	1.09 (24.21)(0.26)	0.53 (6.30)(0.03)
	25%	10.64 (11.34)(1.21)	5.83 (9.27)(0.54)	16.01 (12.59)(2.02)	1.83 (7.51)(0.14)	0.57 (6.44)(0.03)
	50%	10.20 (7.31)(0.75)	6.21 (22.83)(1.42)	15.08 (19.58)(2.95)	1.70 (15.71)(0.27)	0.57 (6.57)(0.03)
	75%	8.97 (24.87)(2.23)	5.52 (37.02)(2.04)	14.19 (30.09)(4.27)	1.77 (25.09)(0.44)	0.57 (7.60)(0.04)
	100%	7.70 (18.52)(1.43)	4.45 (32.93)(1.47)	12.07 (23.92)(2.89)	1.81 (17.51)(0.32)	0.51 (3.38)(0.01)

The values between brackets are the coefficient of variation and standard deviation. DAP = breast height diameter.

Table 6. Continued...

Position in the Stem	Position Heartwood-bark	Contractions (%)			Ration T/R	Density Basic (g/cm³)
		Tangential	Radial	Volumetric		
75%	0%	9.88 (8.51)(0.84)	7.38 (35.28)(2.60)	13.10 (14.75)(1.93)	1.51 (32.07)(0.48)	0.55 (3.49)(0.02)
	25%	10.19 (6.10)(0.62)	7.04 (21.52)(1.51)	16.30 (12.99)(2.12)	1.52 (22.71)(0.34)	0.55 (5.16)(0.02)
	50%	10.65 (8.27)(0.88)	8.05 (33.45)(2.69)	17.44 (22.90)(3.99)	1.42 (21.12)(0.30)	0.556 (2.33)(0.01)
	75%	9.87 (21.62)(2.13)	7.21 (26.10)(1.88)	14.78 (30.91)(4.57)	1.39 (13.50)(0.23)	0.55 (9.40)(0.05)
	100%	8.12 (15.56)(1.26)	4.88 (27.64)(1.35)	11.67 (23.64)(2.76)	1.73 (13.21)(0.23)	0.50 (1.29)(0.06)
100%	0%	8.90 (9.67)(0.86)	8.78 (13.22)(1.16)	16.59 (15.87)(2.63)	1.00 (10.23)(0.10)	0.58 (7.36)(0.04)
	25%	9.95 (6.03)(0.60)	9.49 (23.50)(2.23)	17.36 (9.12)(1.58)	1.09 (17.76)(0.19)	0.58 (6.02)(0.03)
	50%	10.36 (5.46)(0.57)	7.87 (13.62)(1.07)	17.34 (5.83)(1.01)	1.34 (14.21)(0.19)	0.58 (6.68)(0.03)
	75%	8.88 (19.77)(1.76)	6.31 (22.86)(1.44)	15.20 (19.0)(2.90)	1.43 (15.25)(0.22)	0.55 (6.87)(0.03)
	100%	8.26 (18.72)(1.55)	5.94 (30.0)(1.78)	13.32 (20.53)(2.74)	1.46 (16.07)(0.23)	0.50 (3.37)(0.01)

The values between brackets are the coefficient of variation and standard deviation. DAP = breast height diameter.

to Galvão & Jankowski (1985) the total contraction for the wood varies by percentage of 2.4-11 to radial direction (R), 3.5-15 for tangential direction (T) and of 6.0-27.0 for shrinkage.

It was also found that the highest and lowest contractions both dimensional and volumetric occurred for the highest and lowest densities respectively (Table 6).

The red tauari wood presented basic density of 0.58 g/cm^{-3}, similar to the values found by (Melo & Camargos, 2016) and IBAMA (1991).

Stamm (1964) experimentally verified the existence of a correlation between the volumetric variation and the wood basic density, in the sense that the higher the basic density the greater the wood volumetric shrinkage.

With some exceptions, the values of the coefficients of variation were low indicating a certain homogeneity among the used samples.

The anisotropic factor is the result of the direct relationship between the tangential and radial contractions. The results of the anisotropy factor are presented in Table 6, where the values between brackets are coefficient of variation and standard deviation.

The analysis of variance in factorial scheme 5 × 5, Table 7, performed to verify the existence or not of significant differences among the contractions in the radial direction of the stem (heartwood-bark) and longitudinal (base-top), resulted not significant in the longitudinal and radial × longitudinal direction, i.e., indicating clearly that there was no statistical difference among the contractions in the radial and longitudinal direction of the tauari stem.

The volumetric contraction values tended to decrease toward heartwood-bark regardless of the position of the sample in the stem. Similar behavior was also observed for the linear contractions in tangential and radial directions.

Only for the anisotropic factor resulted in not significant in the radial, longitudinal and radial × longitudinal direction. In the radial direction for the tangential, radial and volumetric contractions there was statistically significant difference being necessary to use the Tukey test for comparison among the averages (Tables 8, 9 and 10).

Table 7. Analysis of the variances for the physical properties.

ANALYSIS OF VARIANCE FOR THE VARIATION OF THE TANGENTIAL SHRINKAGE					
Variation Source	**GL**	**SQ**	**QM**	**F**	**P**
Radial	4	50.8951	12.7238	5.62	0.001*
Longitudinal	4	19.8361	4.959	2.19	0.084ns
Radial × Longitudinal	16	14.473	0.9046	0.4	0.977ns
Error	50	113.2897	2.2658		
Total	74	198.4939			
ANALYSIS OF VARIANCE FOR THE VARIATION OF THE RADIAL CONTRACTION					
Variation Source	**GL**	**SQ**	**QM**	**F**	**P**
Radial	4	48.2511	12.0626	3.81	0.009*
Longitudinal	4	26.1591	6.5398	2.07	0.099ns
Radial × Longitudinal	16	20.2843	1.2677	0.4	0.976ns
Error	50	158.2144	3.1643		
Total	74	252.9079			
ANALYSIS OF VARIANCE FOR THE VARIATION OF THE VOLUMETRIC CONTRACTION					
Variation Source	**GL**	**SQ**	**QM**	**F**	**P**
Radial	4	129.5631	32.3907	3.19	0.021*
Longitudinal	4	40.8023	10.2005	1.01	0.414ns
Radial × Longitudinal	16	53.0483	3.3155	0.33	0.992ns
Error	50	507.3252	10.1465		
Total	74	730.7389			
ANALYSIS OF VARIANCE FOR THE VARIATION OF THE RATIO T/R					
Variation Source	**GL**	**SQ**	**QM**	**F**	**P**
Radial	4	2.3023	0.5755	0.58	0.675*
Longitudinal	4	5.6274	1.4068	1.43	0.238ns
Radial × Longitudinal	16	20.4445	1.2777	1.3	0.235ns
Error	50	49.2027	0.984		
Total	74	77.577			

ns = not significant to 95% of probability; *significant; GL = degree of freedom; SQ = sum of squares; QM = middle square; F = factorial; P = probability.

Table 8. Mean values for tangential contraction in the radial direction of the tauari wood (*Cariniana micrantha* Ducke).

Positions	**0%**	**25%**	**50%**	**75%**	**100%**
Average	10.087 b	10.531 b	10.827 b	9.915 ab	8.445 a

Averages followed by the same letter are statistically equal at 5% of probability.

Table 9. Mean values for radial contraction in the radial direction of the wood of the tauari (*Cariniana micrantha* Ducke).

Positions	**0%**	**25%**	**50%**	**75%**	**100%**
Average	7.456 b	7.261 b	7.055 b	6.617 ab	5.217 a

Averages followed by the same letter are statistically equal at 5% of probability.

Table 10. Mean values for volumetric contraction in the radial direction of the tauari wood (*Cariniana micrantha* Ducke).

Positions	**0%**	**25%**	**50%**	**75%**	**100%**
Average	16.173 b	16.911 b	16.505 b	15.587 ab	13.192 a

Averages followed by the same letter are statistically equal at 5% of probability.

4. CONCLUSIONS

The mean data presented reveal a constancy in the fibers length in heartwood-bark direction, with minor variations. The smallest fibers lengths in the radial direction are in the region that goes from the heartwood to the periphery of the sapwood, evidencing that and the fibers length increase in the radial heartwood-bark direction.

In the longitudinal direction a decrease was noted in the fibers length, along the stem, into the inner layers near the spinal cord, in the outer layers three different behaviors were noticed:

a) Descending to position 50% and from that point rising to the top of the stem;
b) Ascending to position 50% and from that point descending to the top of the stem;
c) Ascending to DAP and descending until the top of the stem.

The fiber length in the radial direction of the stem (heartwood-bark) and longitudinal (base-top), was not significant, indicating clearly that there was no statistical difference among the fibers lengths in the radial and longitudinal direction of the tauari stem (*Cariniana micrantha* Ducke - Lecythidaceae).

In a general way the basic density toward heartwood bark tends to increase from 50% (duramen) and then decrease, obtaining the lowest values for 100% (Sapwood). This was expected, considering that tauari is a species rich in extractive contents, which are mainly located in the duramen.

The minimum values, in a general way, were found in the sapwood near the bark, being these values different among the trees.

The basic density in the duramen region is higher than the basic density in the sapwood region, the samples taken in the sapwood close to the bark (E-100%) showed a tendency to decrease in basic density in the base-top direction.

In the other positions, (a-0%; b-25%; c-50% and d-75%) the extractive content was preponderant upon increasing or decreasing the density according to their greater or lesser quantity.

The analysis of variance was not significant in the longitudinal and radial × longitudinal direction, i.e., indicating clearly that there was no statistical difference between the basic density in the longitudinal and radial × longitudinal direction a of the tauari stem.

Regarding the shrinkage, the largest and smallest dimensional and volumetric contractions both occurred for the highest and lowest densities respectively, only for the anisotropic factor resulted in not significant in the radial, longitudinal and radial × longitudinal direction. In the radial direction for the tangential, radial and volumetric contractions there was statistically significant difference.

In the heartwood-bark direction, volumetric contraction values tended to decrease toward heartwood-bark regardless of the position of the sample in the stem, the extractive contents in greater quantity in the heartwood-duramen region could be responsible for the increase in contraction and improving the wood dimensional stability in this region. This behavior can be directly related with the basic density, which showed higher values in the heartwood region and low in the sapwood.

In the base-top direction, the volumetric and radial contractions showed different behaviors along the stem from the base to the top, the tangential shrinkage tended to diminish despite the increase in DAP and in position 75% of height.

In the direction heartwood-bark, it was found that there was an increase in the anisotropic factor with minimum values in the vicinity of the heartwood and maximum in the region of the heartwood to the sapwood. In the base-top direction, a decrease of the anisotropic factor in positions close to the heartwood was observed, tended to decrease despite an increase in position 75% of the height. In more peripheral positions, it grew from the base to the position 50% and from that point decreased until the top of the stem. The minimum values are in position 100% and maximum at position 50%.

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REFERENCES

Alves ES, Angyalossy-Alfonso V. Ecological trends in the wood anatomy of some Brazilian species. 2. Axial parenchyma, rays e fibres. *IAWA Journal* 2002; 23(4): 391-418. http://dx.doi.org/10.1163/22941932-90000311.

Associação Brasileira de Normas Técnicas – ABNT. *NBR 7190: projeto de estruturas de madeira*. Rio de Janeiro; 1997.

Comisión Panamericana de Normas Técnicas – COPANT. *Descripcion de características generales, macroscópicas de las maderas angiospermas dicotiledôneas*. La Paz; 1974. p. 19.

Dadswell HE. Wood structure variations occurring during tree growth and their influence on properties. *Wood Science* 1958; 1: 11-32.

Fearnside PM. Wood density for estimating forest biomass in Brasilian Amazônia. *Forest Ecology and Management* 1997; 90(1): 59-87. http://dx.doi.org/10.1016/S0378-1127(96)03840-6.

Ferreira, M. Variação da densidade básica da madeira de povoamento comerciais de *Eucaliptus grandis* Hill ex Maiden nas idades de 11, 12, 13, 14 e 16 anos. *IPEF* 1972; (4): 65-89.

Galvão APM, Jankowski IP. *Secagem racional da madeira*. São Paulo: Livraria Nobel; 1985.

Instituto Brasileiro de Meio Ambiente e dos Recursos Naturais Renováveis – IBAMA. Laboratório de Produtos Florestais – LPF. *Padronização da nomenclatura comercial brasileira da madeiras tropicais amazônicas*. Brasília; 1991. 59 p.

Kuroda N, Tukau A, Ibrahim WAW. Intra-stem variation of basic density and green moisture content of eight species grown in Sarawak. In: *Wood Anatomy Research: Proceedings of the International Symposium on Tree Anatomy and Wood Formation*; 1995; Tianjin, China. Beijing: International Academic Publishers; 1995. p. 12-19.

Lima JRA, Santos J, Higuchi N. Situação das indústrias madeireiras no Estado do Amazonas em 2000. *Acta Amazonica* 2005; 35(2): 125-132. http://dx.doi.org/10.1590/S0044-59672005000200003.

Loureiro A, Silva MF, Alencar JC. *Essências madeireiras da Amazônia*. Vol. 2. Manaus: INPA; 1979.

Maeglin RR. Juvenile wood, tension wood, and growth stresses effects on processing hardwoods. In: *Appying the Latest Research Hardwoods: Proceedings of the 15th Annual Hardwoods Symposium of the Hardwoods Research Council*; 1987; Memphis. Memphis: Hardwood Research Council; 1987.

Melo JE, Camargos JA. *A madeira e seus usos*. 1. ed. Vol. 1. Brasília: Ministério do Meio Ambiente; 2016.

Panshin AJ, De Zeeuw C. *Textbook of wood technology*. 4th ed. New York: McGraw-Hill; 1980. 722 p.

Pereira D, Santos D, Vedoveto M, Guimarães J, Veríssimo A. *Fatos florestais da Amazônia*. Belém: IMAZON; 2010.

Pernía NE, Melandri JL. Wood anatomy of the *Tribe caesalpinieae* (Leguminosae, Caesalpinioideae) in Venezuela. *IAWA Journal* 2006; 27(1): 99-114. http://dx.doi.org/10.1163/22941932-90000140.

Scaramuzzi G. A comparison of some methods for determining the basic density of increment cores of euramerican poplar hybrids. In: *Proceedings of 6th World Forestry Congress*; 1966; Madrid. Vol. 3. Madrid: FAO; 1966. p. 3454-3459.

Shimoyama VRS, Barrichello LEG. Influência de características anatômicas e químicas sobre a densidade básica da madeira de *Eucalyptus spp*. In: *Anais do Congresso Anual de Celulose e Papel*; 1991; São Paulo. São Paulo: ABTCP; 1991. p. 178-183.

Silva AC. Variação dimensional dos elementos xilemáticos em duas espécies madeireiras da Amazônia. *Acta Amazonica* 1992; 22(2): 261-273. http://dx.doi.org/10.1590/1809-43921992222273.

Smith DM. *A comparison of two methods for determining the specific gravity of small samples of second growth Douglas-Fir*. Madison: U. S. Forest Products Laboratory; 1955. Report no. 2033.

Smith DM. *Maximum moisture content method for determining specific gravity of small wood samples*. Madison: U. S. Forest Products Laboratory; 1954. 8 p.

Stamm AJ. *Wood and cellulose science*. New York: Ronald Press; 1964.

Superintendência do Desenvolvimento da Amazônia – SUDAM. *Grupamento de espécies tropicais da Amazônia por similaridade de características básicas e por utilização*. Belém: SUDAM; 1981. 237 p.

Tomazello M Fo. Estrutura anatômica da madeira de oito espécies de eucalipto cultivadas no Brasil. *IPEF* 1985; 29: 25-36.

Trugilho PF, Arantes MDC, Pádua FA, Almado RP, Baliza AER. Estimativa de carbono fixado na madeira de um clone hibrido *Eucalyptus urophylla* e *Eucalyptus grandis*. *Cerne* 2010; 16: 33-40.

Trugilho PF, Silva DA, Frazão FJL, Matos JML. Comparação de métodos de determinação da densidade básica em madeira. *Acta Amazonica* 1990; 20(0): 307-319. http://dx.doi.org/10.1590/1809-43921990201319.

Urbinati CV, Azevedo AA, Silva EAM, Lisboa PLB. Variação estrutural quantitativa no lenho de *Terminalia ivorensis* A. Chev., Combretaceae. *Acta Botanica Brasilica* 2003; 17(3): 421-437. http://dx.doi.org/10.1590/S0102-33062003000300009.

Wilkes J. Variations inwoodanatomy within species of *Eucalyptus*. *IAWA Bulletin* 1988; 9(1): 13-23. http://dx.doi.org/10.1163/22941932-90000461.

Zobel BJ, Van Buijtenen JP. *Wood variation: its causes and control*. Berlin: Springer Verlag; 1989. (Spring Series in Wood Science). http://dx.doi.org/10.1007/978-3-642-74069-5.