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Anatomical characteristics of *Tectona grandis* L.f. from different sites in Mato Grosso state

Características anatômicas de *Tectona grandis* L.f. de sítios distintos do estado do Mato Grosso

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Abstract

The anatomical characteristics of the wood are influenced by the quality of the sites of the material provenance, which, consequently, leads to alterations in its physical and mechanical properties. The aim of this paper was to assess and characterize the organoleptic and anatomical properties of the teak (*Tectona grandis*) from different sites in the state of Mato Grosso, Brazil. Regarding the anatomical characteristics the length, width, diameter and the thickness of the wall for fiber were assessed; the length and diameter of the vessels; the length, width and frequency of the rays. The results obtained showed that the organoleptic properties do not present variations between the different sites. The effect of the site, where the teak plantation is established, produced significant variations in the parameters of the fibers (length, width of the fiber, lumen diameter and thickness of the wall) and in the rays (length, width and frequency). However, no significant vessel-related changes were seen.

Keywords: Wood anatomy; Teak; Provenance

Resumo

As características anatômicas da madeira são influenciadas pelas qualidades dos sítios de procedência do material, que por consequência leva a alterações em suas propriedades físicas e mecânicas. O objetivo deste trabalho foi avaliar e caracterizar as propriedades organolépticas e anatômicas da madeira de teca (*Tectona grandis*), proveniente de diferentes sítios do Estado do Mato Grosso, Brasil. Para as características anatômicas foram avaliados comprimento, largura, diâmetro e espessura da parede para fibra; comprimento e diâmetro dos vasos; comprimento, largura e frequência dos raios. Os resultados mostraram que as propriedades organolépticas não apresentaram diferenças entre os diferentes sítios. O efeito sítio, no qual estão estabelecidos os plantios de teca produziram variações significativas nos parâmetros das fibras (comprimento, largura da fibra, diâmetro do lume e espessura da parede) e nos raios (comprimento, largura e frequência). No entanto, não foram evidenciadas mudanças significativas relacionadas aos vasos.

Palavras-chave: Anatomia da madeira; Teca; Procedência

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Introduction

Native of Asia, the teak (*Tectona grandis* L.f.) has its natural distribution in India, Myanmar, Thailand and Laos. This tree species was established in the state of Mato Grosso in the 1960s. The first planting was of experimental character, pursuing the silvicultural knowledge as well as the adaptability in the region. The commercial planting emerged from the positive outcomes, currently presenting 70 thousand hectares planted in the state, corresponding to 90% of teak plantations in Brazil (TAKIZAWA, 2018). Teak wood presents, as its highlight, its natural durability, dimensional stability, physical-mechanical properties, beauty and aesthetic (SILVA *et al.*, 2010), combining strength and lightness it is considered a high-quality wood due to its excellent properties (FAO 2009).

The wood is constituted by different cellular structures, which, depending on its configuration, performs specific functions in the plant. The precise knowledge of the wood cellular types characteristics allows researchers to determine the most appropriate processing and use conditions of the forest species (RODRIGUEZ-ANDA *et al.*, 2017). Therefore, the comprehension of wood anatomical properties may provide a starting point for several investigations when the goal is to know its operation, associative behavior and its relation with the environment (BHAT; PRIYA, 2004). The wood presents variations between individuals from the same species and from different ones, these variations become more remarkable, especially considering the provenance, age and quality of the site (THULASIDAS; BHAT, 2012). According to Gonçalez *et al.* (2009), the formation of the wood starts in the photosynthetic process, restricted to the assimilation, by part of the trees, of water and carbon dioxide transformed into organic substances. This growth is immensely influenced by environmental factors: climatic, edaphic and topographical. The interaction of these factors with the plants expresses the quality of the site, causing trees from the same species to present different growth rates due to the site they are from. Spurr (1952) posits that the quality of the site is the total sum of the edaphic, biological and climatic factors. The plants are affected by all of these factors acting whether jointly or independently. Studies show that the sites influence the quality of the wood, modifying its coloration, physical and mechanical properties, as well as its anatomical properties (MOYA *et al.*, 2009; ANISH *et al.*, 2015; RODRIGUEZ-ANDA *et al.*, 2017).

The aim of this paper was to characterize the anatomical and organoleptical properties of the teak wood originated from three different sites in the state of Mato Grosso, Brazil. The climate, precipitation, temperature, soil and especially age variables were taken into consideration for a clear distinction between the sites.

Material and methods

The reforestation areas with *Tectona grandis* L.f, subject of the study, are located in Mato Grosso in the cities of Alta Floresta, north region of the state; Cáceres, northwest region; and Nossa Senhora do Livramento in the southwestern region of the capital, Cuiabá. Table 1 describes the climatic conditions of the sites from where the samples were taken and the characteristics of the planting.

Table 1 – Site characteristics of the species *Tectona grandis* applied in the study.

Tabela 1 – Características dos sítios da espécie *Tectona grandis*, utilizadas no estudo.

Site	Climate	Annual precipitation (mm)	Annual average temperature (°C)	Soil type	Tree age (years)
Alta Floresta (AF) 10°02'51" S and 56°20'18" O	Am	2281	26.0	Dystrophic red yellow Argisol	14
Nossa Senhora do Livramento (NS) 16°12'10" S and 50°23'00" W	Aw	1252	25.5	Eutrophic Haplic Planosol	14
Cáceres (CA) 16º 04' 14" S and 57º 40' 44" O	Awi	1301	26.3	Dystrophic red yellow Latosol	16

It was sampled 14 and 16 years old teak plantings in the cities of Alta Floresta (AF), Nossa Senhora do Livramento (NS) and Cáceres (CA), (Table 1). The plantings were established in an area of 1,204.25 ha, subdivided in 49 stands in AF with a 3x2.2 m of spacing; with 1,515 tree/ha and 309 ha in NS, 3x3 m of spacing and 1,111 tree/ha; and in Cáceres, an experimental planting with 1,000 tree/ha with 5x2 m of spacing.

In each of the plantings it was selected 3 trees not harmed by insects with a minimum 15m distance between them, excluding the trees close to the borders of the stands. The trees were sectioned until 2m of height, subsequently unfolded in order to obtain well defined test specimens in the radial, tangential and longitudinal directions, originating test specimens with 50 cm of length and 2 cm of width, these one were sectioned in 30 cm x 2 cm x 2 cm; 10 cm x 2 cm x 2 cm; 5 cm x 2 cm x 2 cm marked in sequence. For this work were used the specimens with dimensions of 10 cm x 2 cm x 2 cm to obtain the specific gravity (COPANT, 1972) and of 5,0 cm x 2,0 cm x 2,0 cm for anatomical characterization.

The macroscopic and microscopic descriptions were carried at the Wood Anatomy sector - Forest Products Laboratory (LPF), which belongs to the Brazilian Forest Service (SFB)/ Brasília - DF.

For the macroscopic test, specimens were polished in cross-sections with sandpaper with granulations varying from 180 to 1000, removing all the roughness, making its characters visible to the naked eye or stereoscope with magnification of 20x, according to the methodology described by the COPANT (1974) standards and Coradin and Muniz (1992).

After the macroscopic description, the test specimens were sectioned (1cm x 2cm),

then immersed in alcohol 50% and glycerin to soften for subsequent histological cuts in radial, transverse and tangential orientations with the aid of a sliding microtome (Leica SM 2010 R) with thickness from 18μm to 30 μm. The sections of the wood were bleached with sodium hypochlorite (50%) and stained with safranin alcoholic (50%) 1:1 and treated in alcoholic series from 50 to 100%, each 10%, preparing the slides with "Entellan" (JOHANSEN, 1940).

To obtain the fibers, the test specimens were sectioned in the longitudinal direction (sticks and wood chips) dissociated according the Franklin method (JOHANSEN, 1940). Afterwards, they were transferred to test tubes with distilled water and then, with maceration solution (hydrogen peroxide 20 vol.) and glacial acetic acid (1:1), taken to the lab oven (50º C, 60h). For the study of the morphology and dimensions assessment, the dissociated cells were stained with safranin and prepared in semi-permanent slides with glycerin and water. The description of the sample microscopic anatomical structure was conducted in accordance with the standards of COPANT (1974), Coradin and Muniz (1992), and IAWA (1989).

The observation and measurement of cell elements were done with the aid of the Olympus BH-2 microscope and Olympus SZX7 stereo microscope with digital camera (DP25), the measurements were taken by the *Image-Pro Plus* software. In the macro and microscopic descriptions, it was used magnification of 4x and 40x, respectively. The determination of fiber dimensions occurred from the semi-permanent slides where 25 fibers were measured with 4x magnifying s for the length and width of the fiber and 100x to measure the lumen diameter. The thickness of the cell wall was determined by the difference between the lumen diameter and the fiber diameter. For the frequency, height and width of the rays, they were measured with 4x magnifying, resorting to the tangential section of the microscopic samples. In the cross-section the elements of the vessels (diameter and length) were the ones to be analyzed (IAWA, 1989), as well as the pores of the intermediate wood and latewood.

For the anatomical parameters, the statistical analysis was performed using the SPSS ® (Statistical Package for the Social Sciences) program and a univariate analysis of variance was performed for origin, age and spacing, and averages were compared by Tukey test at 5% probability, being considered as treatment the origin (local) of the teak.

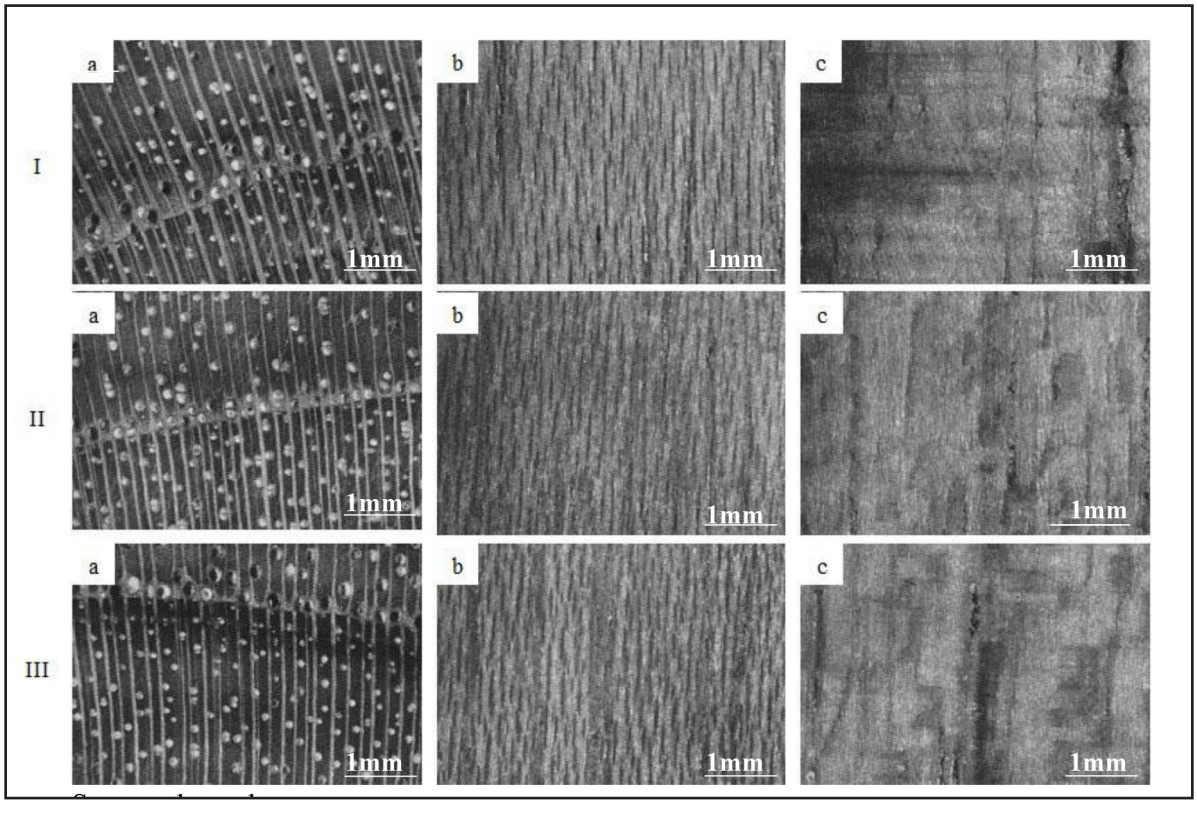
Results and discussion

General characteristics: the wood heartwood and sapwood differ in color, yellowish sapwood and reddish heartwood, noticeable and pleasant smell, bitter taste, rough grain and medium texture. Average basic density of 0.50- 0.65 g.cm^3. It presents a design or pattern highlighted by the axial parenchyma in longitudinal lines and the radial parenchyma and by its distinct growth layers.

Macroscopic description (Figure 1): Transverse section, the vessels are present and visible to the naked eye, average tangential diameter (100- 200 μm), porosity in semi-ring porous, some obstructed pores by tyloses) a bundle of solitary, medium and multiple vessels, from circular to oval shape and displayed in a radial chain. Indistinct axial parenchyma to the naked eye, in marginal lines and scarce vasicentric. Radial parenchyma observed under a 20x lens, in the transverse and tangential surfaces, low contrast, fine (< 100 μm), medium (> 1 mm) and numerous (4-12/ mm linear). In the longitudinal plane, the rays are visible under 20x lenses, the vascular lines are regular and stratified. In the longitudinal radial plane, the brightness of the rays is present.

Figure 1 – Photomicrography of *Tectona grandis* wood from three different sites - a) transverse, b) tangential and c) radial section. I - Alta Floresta, II - Nossa Senhora do Livramento and III - Cáceres.

Figura 1 – Fotomicrografia da madeira de *Tectona grandis* de três sítios distintos - a) seção transversal, b) tangencial e c) radial. I - Alta Floresta, II - Nossa Senhora do Livramento e III – Cáceres.



Source: Authors (2019)

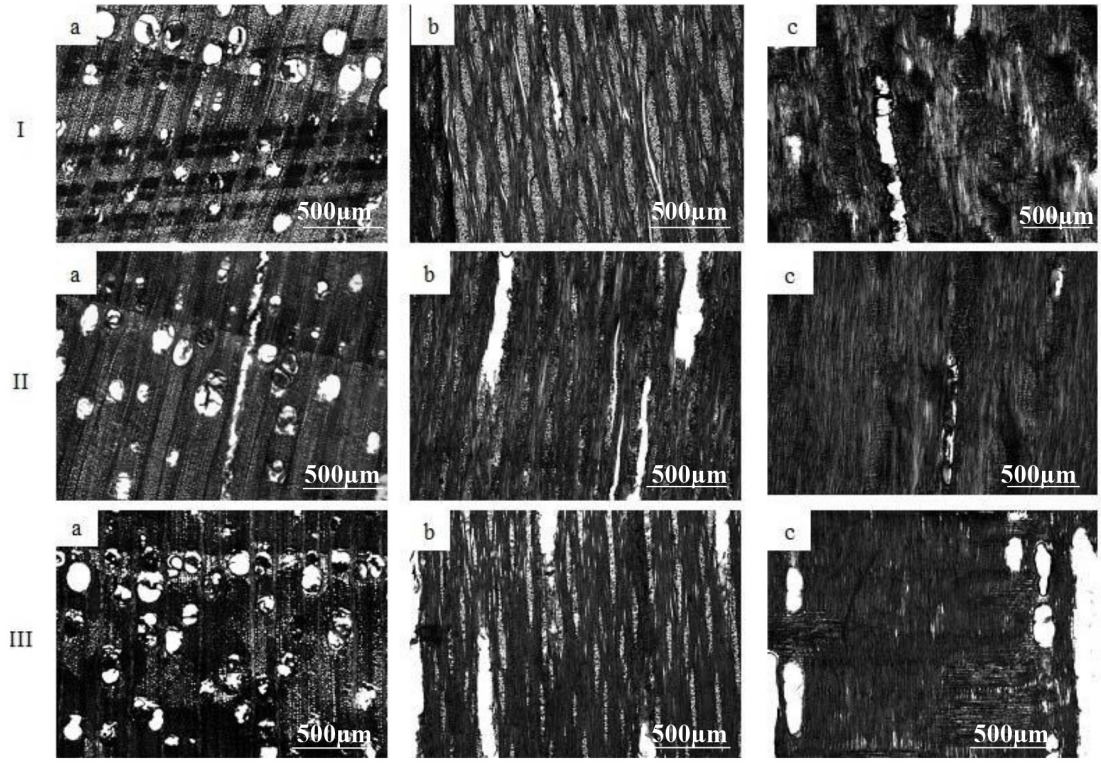
The teak wood, according to the descriptions of Gurmartine and Goudzwaard (2010) and IPT (2018), presents ring-porous, with distinct growth, large pores, visible to the naked eye, oval, most of them solitary and obstructed by tyloses with whitish deposits. While Richter and Dallwitz (2009) described it with the presence of semi- ring porous, such trait presented by fast growing trees, with solitary or multiple pores, scarce and vasicentric paratracheal axial parenchyma, procumbents homogeneous rays. These descriptions match the ones made in this paper, they differ only when it comes to the classification regarding the wood texture. By the observations of the macroscopic characteristics (Fig. 1) there is no occurrence of visual difference in the organoleptic characters from the samples of *Tectona grandis* from the different sites, showing that the occurrence of planting in different sites does not seem to influence this characteristic.

Microscopic description (Fig. 2): distinct limits in the growth rings, ring porous wood, radially displayed vessels, solitary, large. Vessels/pores with semi- ring porous, radial arrangement, they present solitary vessels, occurrence of radial multiple of 2-3 vessels; tangential diameter from 100 to 200 µm, round shape. Vascular elements 280 - 300 µm of length, short appendix in one of the extremities, simple perforation plates; intervessel pits alternate with opposite tendencies. Libriform fibers, with simple pits, 950- 1111 µm of length, septate distributed uniformly; 26.16 – 32.22 µm of total diameter; 14.96 -17.38 µm of lumen diameter; 5.01-7.42 µm of cell wall thickness, thick and thin. Scarce paratracheal axial parenchyma. Multiseriate rays, homogenous rays, with

all ray cell procumbent, with 61.16 – 77.21 µm of width in the tangential section; number of rays per millimeter varying from 4 to 5 rays, height varying from 5 to 7 mm.

Figure 2 – Photomicrography of the wood *Tectona grandis* from three different sites - a) transverse, b) tangential and c) radial sections. I - Alta Floresta, II - Nossa Senhora do Livramento and III - Cáceres.

Figura 2 – Fotomicrografia da madeira de *Tectona grandis* de três sítios distintos - a) seção transversal, b) tangencial e c) radial, I - Alta Floresta, II - Nossa Senhora do Livramento e III - Cáceres.



Source: Authors (2019)

It was observed with this study significant variation between the teak wood from different sites for the parameters related to the fiber dimensions (Table 2). The results show that there is a site influence when it comes to the spacing and age regarding the fiber length. According to studies presented by Kokutse, Adjonou and Kokou (2009) and Rodriguez-Anda *et al.* (2017), the increase in fiber length occurs with the increase in age. Bhat and Priya (2004) and Thulasidas and Bhat (2012) point that the maturity of the teak is reached between 15 and 25 years of age depending on the location; after this age, the length of the fiber does not vary significantly, corresponding to the result obtained with the fiber length from the site in Cáceres. According to Tienne *et al.* (2009) and Lima *et al.* (2011), in larger spacing the fibers tend to be longer, different from the present study, when it is considered the fiber length from the three sites. The smallest spacing (the site in Alta Floresta) presented longer fiber length. As for the spacing in Cáceres, the biggest among the studied sites, did not present statistical differences with the site with the smallest spacing. That is to say, the lengths of the fibers in the site AF (1110 µm) and CA (1090 µm) were statistically superior to those found in the site NS (950 µm). Chagas *et al.* (2014) working with 4, 6 and 12-year old teak, observed the rates of the fiber lengths in 940, 1120 and

930 µm, respectively. While Lobão *et al.* (2011) found 1500 µm, approximately, of fiber length. Rodriguez-Anda *et al.* (2017), studying anatomical characteristics of teak from 4 sites in Mexico, found significant differences regarding the length of the fibers, which presented a variation in length from 1130 to 830 µm. The aforementioned figures fit the range found with the present study.

Table 2 – Average length, width, diameter of the lumen and thickness of the fiber wall, length and diameter of the vessels, height, width and frequency of the ray from the Tectona grandis wood, from different ages, spacing and provenance.

Tabela 2 – Valores médios do comprimento, largura, diâmetro do lume e espessura da parede de fibras, comprimento e diâmetro dos vasos, altura, largura e frequência dos raios da madeira de Tectona grandis, com diferentes idades, espaçamento e procedência.

Area of study	Fiber length (µm)	Fiber width (µm)	Lumem diameter (µm)	Wall thickness (µm)	Vessels length (µm)	Vessels diameter (µm)	Ray height (µm)	Ray width (µm)	Ray frequency (mm^{-1})
Alta Floresta (14 anos 3 x 2,2 m)	1110a	32.22a	17.38a	7.42a	300.0a	173.16a	950a	77.21a	5.84a
N. S.	950b	28.04b	14.96b	6.54b	290.0a	180.33a	630 b	61.16b	5.12b
Cáceres (16 anos, 5 x 2m)	1090a	26.16b	16.13ab	5.01c	280.0a	180.72a	620 b	66.75b	4.88b

Where: Averages followed by the same letter in the column do not differ significantly by Tukey test at the 5% level of significance.

Still observing Table 2, it is verified that the width of the fiber presents substantial differences between the sites. The site in AF presented higher rates for this parameter compared to the other two sites (NS and CA). In a study developed by Scarparo (2015), the teak presented an average width of 24.60 µm by the age of 12 years in plantings located in the state of Goiás. On the other hand, Chagas *et al.* (2014) found 24.35 µm by the age of 4 years, 20.87 µm by the age of 6 years and 22.99 µm by the age of 12 years for the teak from Santo Antônio do Leverger, in Mato Grosso state. In Costa Rica, Govaere, Carpio and Cruz (2003) found average rates of 25 µm by the age of 8 years. In India, Husen and Pal (2006) verified in 2 month-old, 15 and 30 year-old samples that the fiber width of the teak increased, varying from 0 to 20 µm. It may be noted that the results obtained in this paper demonstrate that the age does not present itself as a key factor for the enhance in the fiber width, as well as in the spacing, such characteristics were confirmed by Silva *et al.* (2007) with *Eucalyptus* fibers in which there is no correlation between the width of the fiber and its age.

The observed results for the lumen diameter (Table 2) demonstrate variability according to the age, going from 14.96 µm to 17.38 µm. In a study led by Chagas *et al.* (2014), the lumen diameter in the teak presented variability according to the age, by the age of 4 years it was 15.71 µm, by the age of 6 it was 11.28 µm and by the age of 12 it was 13.96 µm. Moreover, according to the author, there is no logic explanation to justify this behavior. This variability, in accordance with Gonçalves *et al.* (2007), may be caused by the edaphoclimatic advantages due to the season. Scarparo (2015) found an average rate of 16.4 µm for this species. Moya *et al.* (2009) found a variation of 11- 20 µm in teaks from different sites and ages, then they stated that the rates of the lumen diameter were keep constant with time and with the different types of climate and quality

of the site. As for this study, the biggest lumen diameter was found in the smallest spacing, not following a clear logic of influence on the age or even in the spacing.

Continuing with the analysis of Table 2, the thickness of the fiber walls (EP) presented considerable differences in every age. The thickness of the fiber walls from the site in Alta Floresta proved itself to be larger than the ones from the other sites. It is possible to notice a thinning of the wall according to increase in age. From Rodriguez-Anda *et al.* (2017) point of view, the thinning of the wall thickness according to the age is likely related to the cambium maturation process. Chagas *et al.* (2014) found 4.32 µm for the fiber wall thickness of the teak by the age of 4 years, 4.79 µm by the age of 6, and 4.51 µm by 12 years old. The average rate found by Scarparo (2015) was of 4.1 µm for a 8 year-old teak. In its turn, Rodriguez-Anda *et al.* (2017) found the following wall thickness rates for the teak wood from different sites: 2.8 µm by the age 9 years, 3.5 µm by the age of 15, and 3.2 µm by the 21. In a general manner, the rates of EP found in this study are higher than the ones stated in the aforementioned literature. The provenance sites may be the responsible for these variations.

The length and vessel diameter rates did not show substantial differences, neither with age nor with the spacing. According to Bhat and Priya (2004) analyzing the provenance of the teak wood from three different places in India, they found out that the diameter of the vessels increases until the age of 20 years, after this time, there is a slight decrease. The authors noticed variations in the diameter of the vessels from 162 to186 µm. Rodriguez-Anda *et al.* (2017) found rates for the diameter varying according to the age and site in 127.8 µm by the age of 9 years, 127.3 µm by the age of 15 years, 122.2 µm by the age of 21 years and 120.5 µm by the age 15 years. Chagas *et al.* (2014) observed in their studies the rates of 104.87 µm, 121.08 µm and 168.08 µm, for trees in the ages of 4, 6 and 12 years old, respectively. Richter and Dallwitz (2009) registered for the teak dimensions from 140 to 270 µm regarding the lumen diameter. The dimensions found by this study for the diameter of the vessel fit the aforementioned ranges.

The values of height, width and frequency of the ray (Table 2) show that the age is not determining, once that these characteristics found for the teak by the age of 14 years, which belong to the site in Alta Floresta, are considerably higher than height of the rays found for the teak by the age of 16 years from the site in Cáceres, which, in turn, is similar to the 14 years-old one from the site in Nossa Senhora do Livramento. These results are contrary to the ones presented by Rodriguez-Anda *et al.* (2017) in which the height of the rays proves to be higher with the age. However, according to the authors, the site is the more responsible for this variation. According to Moya *et al.* (2009) the height, width and frequency of the rays show increase in the first years of growth, subsequently they keep themselves constant. This variation in the characteristics of the rays, according to Larson (1994), are influenced by environmental factors that alter the cambium growth rate, which under environmental stress reduce the production of auxins responsible by the divisions of cambium cells, this one also decreases with age.

The average rates for the height and width of the rays found by this study are at the range of (620 to 950 µm) and (61.16 to 77.21 µm), respectively. According to Rehman, Fujiwara and Kamagawa (2005) while studying the teak they found rates from 370 to 1060 µm and from 47 to 78 µm for the same parameter of rays. The height and width of the rays found by Rodrigues-Anda *et al.* (2017) for the teak wood by the age of 9, 15 and 21 years, from different regions in Mexico were, respectively, (700 µm; 560 µm; 550 µm) and (73.1 µm; 64.2 µm; 67.6 µm). It is noticed that the rates for these parameters, found in this study, are at the range indicated by the literature. Still in this regard, it is remarked that for the site in Alta Floresta (smaller spacing) these rates are higher than the one from the other two sites.

Conclusion

This study with teak wood from three different sites in the state of Mato Grosso allows to conclude that the organoleptic properties did not present significant differences between the

sites.

The effect of the climate, precipitation and quality of the site where the plantings were established produce substantial variation in the parameters of the fibers (length, width, lumen diameter and cell wall thickness) and of the rays (length, width and frequency). Nevertheless, no evidence was found of significant change regarding the vessels. It seems that the rainy weather as well as the type of spacing in Alta Floresta were favorable to the formation of the fiber with higher dimensions, besides the presence of higher and larger rays, despite of not always being very substantial.

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