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RESEARCH ARTICLE

USING SEGMENTED LINEAR REGRESSION TO IDENTIFY JUVENILE AND MATURE WOOD OF *TECTONA GRANDIS*

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ABSTRACT

This study was carried out in order to identify and characterize the transition region between juvenile and mature wood of *Tectona grandis* L.f. with 17 years old, from the PU farm, located at Urutaí, Goiás, Brazil. The regions of juvenile and mature wood were characterized by anatomical studies - length of axial fibers using discs obtained at the DAP trees, following the recommendations of the International Association of Wood Anatomists. The fiber lengths were obtained from a diagnosis and image analysis equipment. A total of five slides were prepared for every 5 mm in the radial direction, and the lengths of six fibers were measured per slide. The results indicate a tendency of sharp and linear increase in fiber length, from the pith until 40 mm radius. The length between 40 mm and 60mm radius remains almost constant and, from this point, fiber length slightly increases until the bark. Therefore, for this species, when the tree is 17 years old, juvenile wood extends from the pith to 40 mm and the mature wood from 60 mm to the bark. Thus, for any use of teakwood, which includes areas of juvenile and mature wood, it is recommended further technological studies.

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INTRODUCTION

Planted forests cover 264 million hectares in the world and their expansion is on average 5 million ha.year^{-1} (Fao, 2014). In 2014, Brazil reached 7.74 million hectares of forests planted for industrial purposes, with eucalyptus plantations occupying 5.56 million hectares, pine trees 1.59 million hectares, and acacia, teak, rubber tree and Anadenanthera accounting for 0.59 million hectares (Ibá, 2015). The forest areas planted with teak reached 65.440 ha in 2010 and an estimated area of 67.329 ha in 2012 (2.8% increase), showing interest in such forest species (Abraf, 2015). These forest plantations provide material for several industrial and domestic purposes, play an important role in sustainable developmentand, contributing to the conservation of native forests (Fao, 2009). Teak belongs to the botanical family Lamiaceae, is a large tree, has a cylindrical trunk, can reach 45 meters in height and 100 cm in diameter under good growing conditions, and does not tolerate shade at any stage of its life cycle (Weaver, 1993; Pandey and Brown, 2000). Teak is one of the most planted and valuable species in the world market due to its excellent physical and mechanical properties such as high natural durability, used in the construction of ships, and production of furniture, luxurious objects and decorative items (Fao, 2009). Teak is native to southern Asia, and today planted due to the high prices of wood in the world market, requiring the reduction of the cutting cycle from 80 to 20-25 years (Flórez *et al.*, 2014). There is a global trend in the management and utilization of planted forests in ever shorter cycles, due to rapid growth, providing commercial trees in a shorter period of time, thus, generating larger amounts of juvenile wood, presenting inferior quality compared of the mature wood (Ballarin and Lara Palma, 2003; Flórez *et al.*, 2014). A tree stores a number of important information in its wood throughout its life, among which, differentiation between juvenile and adult wood. The juvenile wood occurs the central region of the tree, from the pith, forming a cylinder in the center of the tree which extends from the bottom to the top (Zobel and Sprague, 1998;

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Calonego *et al*., 2005). The major differences between juvenile and mature wood from the technological point of view are the changes of the anatomical and physical changes, which take place from the pith/bark. The juvenile wood differs from mature wood by having lower mechanical strength and smaller sized fibers, thinner walls and smaller diameters (Latorraca and Albuquerque, 2000; Lara Palma *et al*., 2010). However, researchers have expressed difficulty in defining the line between juvenile and mature wood, mainly due to the gradual transition of this change, existing variations between species and geographical location (Abdel-Gadir and Krahmer, 1993; Latorraca and Albuquerque, 2000). Thus, it is of great interest to define the approximate age at which the transition of juvenile to adult wood occurs, since the proportion of juvenile wood on the market is growing. This information will enable better estimates of age between the juvenile and adult wood and, consequently, improve the technological use of juvenile wood.

The aims of this study were to delimit the occurrence of juvenile wood of *Tectona grandis* in the pith-bark direction as a function of the radial length, thus contributing to the timber potential in the state of Goiás, Brazil.

MATERIALS AND METHODS

The study was conducted at the Universidade Estadual de Goiás, UEG, Câmpus Ipameri, Goiás, Brazil. The wood used in the experiment was extracted from three 17-year-old trees of *Tectona grandis* with diameter class around 20-25 cm, from the plantations of the PU farm, located at the municipality of Urutaí, state of Goiás, Brazil. From each selected tree, a 50 mm thick disc was taken from each tree, at a height of 1.30 m (DBH), to determine the variation in fiber length in the pith/bark direction. For the preparation of the slides and read the fibers length measurement was withdrawn from the disk of the central region. A sample was removed in the direction of the pith-bark with 10 mm thick. From this sample, 5 mm sub-samples were taken in order to delimit the juvenile wood and the adult. The fibers of each sub-sample (5 mm) underwent the decoupling and staining process, with a total of 5 slides were prepared. From these slides, 6 fiber length were measured randomly for not to damage the cells (fibers), totalizing 30 measurements in each sample, and 2,760 measurements for the three trees (Figure 1).

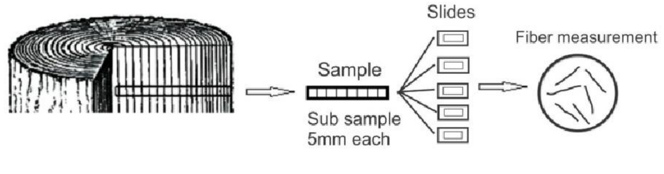

Figure 1. Samples in the radial direction (pith-bark) used to measure the fiber length of wood of 17-year-old *Tectona grandis* trees

The observations and measurements of the fibers were captured in microscope LEICA DM500, coupled to a digital camera ICC 50. The image analysis software LAS EZ 2.0.0 was used to measure and assess the fiber lengths using the micrometer scaleruler at the Laboratory of Phytopathology of the Universidade Estadual de Goiás, Câmpus Ipameri, GO. For determining the juvenile and mature wood and for the anatomical study (fiber length), we used the following methods: The modified Franklin method (Franklin, cited by Taylor, 1975); IAWA standard Committee (1989) and Coradin and Muñiz (1992). The number of fibers measured in each sub-sample was determined based on a statistical test (N test), using the equations (1) and (2).

$$N = \frac{t^2 x S^2}{E^2} \quad (1)$$

Where N = number of replicates, t = the quantile 0.975 of the variable *t*-Student with infinite degrees of freedom, and S^2 = sample variance.

$$E^2 = (0.1\bar{x})^2 \quad (2)$$

Where $\bar{x}$ is the average of the sampled values.

The moment at which a tree fails to produce juvenile wood and begins producing mature wood is not well defined due to the gradual variation in wood properties in the radial direction (pith-bark) (Bendtsen and Senft, 1986). However, there is a point at which such properties become stabilized and decrease. The fiber length data as a function of radial distance were analyzed to define the transition age, using a segmented linear regression, which provides more flexibility on characterizing the different behaviors of fiber lengths. The breakpoints of the adjusted lines were used to mark the moment when lengths of the fibers showed a linear increase, stabilized or decreased. These points marked the juvenile wood area transition wood zone and adult wood area. Statistical analyzes were performed using the R statistical computing environment, version 3.1.2 (www.r-project.org).

RESULTS AND DISCUSSION

Table 1 shows some descriptive statistics for the fiber length of the three trees selected. The fiber length and the coefficients of variation were higher in adult wood, implying greater homogeneity in formation and wood maturation, when compared to the juvenile wood.

Table 1. Descriptive statistics of fiber length (mm) of three trees of *T. grandis*

	Tree 1		Tree 2		Tree 3	
Statistics	Juvenile	Mature	Juvenile	Mature	Juvenile	Mature
Minimum	757.2	923.2	832.9	1144	775.3	1135
Maximum	933.9	1216.8	1103.7	1210	1093.4	1245
Mean	851.2	1063.9	946.6	1197	936.1	1218
Standard deviation	58.9	85.1	100.4	20.5	32.7	32.7
CV %	6.9	8.0	10.6	1.7	11.0	2.7

A variation of approximately 757.2 to 1216.8 µm was recorded for the fiber length of juvenile, and mature teak wood with 17 years of age, respectively (Table 1). Note that the average values of juvenile and mature wood are located between 900 - 1600 µm, classified as short fiber (Coradin and Muñiz, 1992). However, this value was lower than the reported by Bhat, Priya and Rugmini (2001) studying 25 and 60 year old *Tectona grandis* individuals (average length of 1168 µm for juvenile wood and 1405 µm for mature wood). The values of the coefficient of variation (CV%) of juvenile teak wood were high (6.9, 10.6 and 11.0 for trees 1, 2 and 3, respectively) when compared with the CV% recorded for mature wood (8.0, 1.7 and 2.7 for the trees 1, 2 and 3). The coefficient of variation recorded for mature wood were higher than the recorded for juvenile wood, and shows a homogeneity and stabilization of the fiber length in the mature wood. The fiber length values recorded in this study were lower than records by Bhat, Priya and Rugmini (2001), studying 25 and 60-year-old *Tectona grandis* individuals, with CV% of 11.00 – 13.00 for juvenile wood and CV% 11.00 – 17.00 for mature wood, respectively. However, the CV% found in this study were similar to those described by Calonego et al. (2005) studying 32-year-old *Corymbia citriodora* with CV% of 3.50 – 18.61 for juvenile wood and CV% 3.20 – 7.77 for mature wood. Lara Palma *et al*. (2010) studying 30-year-old *Corymbia citriodora* also found CV% for juvenile wood of 16.18 – 18.92 and CV% for mature wood of 2.89 – 5.06.

We observed an overall striking pattern of variation in the fiber length along the tree radius, increasing fiber length from the pith up to a certain value, followed by a segment with an increase or stabilization. Two different increasing patterns of fiber length from the pith were observed. Tree 1 presented a segment with a slight fiber decrease from the pith-bark; and trees 2 and 3 exhibited increasing on fiber length from the pith-bark, followed by a stabilization segment (Figures 2, 3 and 4). Lara Palma *et al*. (2010) reported a similar behavior when studying the demarcation of juvenile and mature wood of *Corymbia citriodora*. The radial variation of the wood fiber lengths was used as explanatory variable define juvenile and mature wood zones. Its effect was significant ($p < 0.05$), which can be seen through the fitting of the segmented regression models (Figures 2, 3 and 4). It was possible to distinguish the two areas of juvenile and mature wood, between 40 and 60 mm from the pith to the bark.

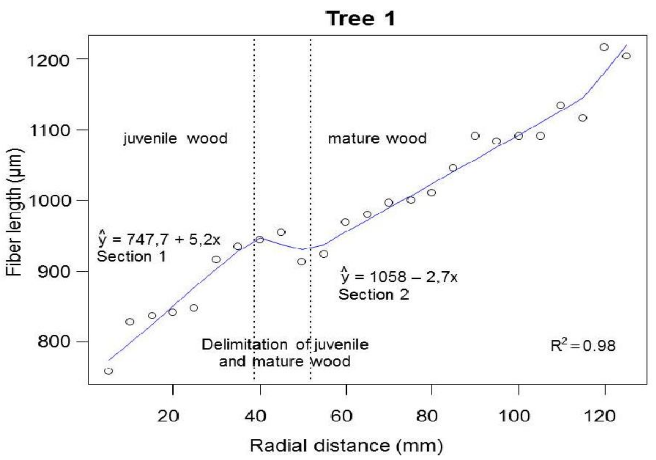

Figure 2. Segmented linear regression of fiber length used to delimit juvenile and mature wood of tree 1 of *Tectona grandis* with 17 years old

Figures 2, 3 and 4 show the equations fitted for fiber length as a function of radial distance, from the pith (mm). The coefficients of determination (R^2) of the models for trees 1, 2 and 3 were, respectively, R^2= 0.98, 0.99 and 0.99. The models present two breakpoints where the regression lines showed an abrupt change. There was a slight decrease in the fiber length in the first breakpoint and, then, a gradual growth from the second point. These breakpoints marked the transition zone between juvenile and mature wood. The fibers lengths showed a sharp and practically linear increase in the radial distance from juvenile wood, which ranged from 40 mm pith to bark. Similar values were reported by Bhat et al. (1989) who concluded that the formation of juvenile wood of *Tectona grandis* extends to 10 years of age.

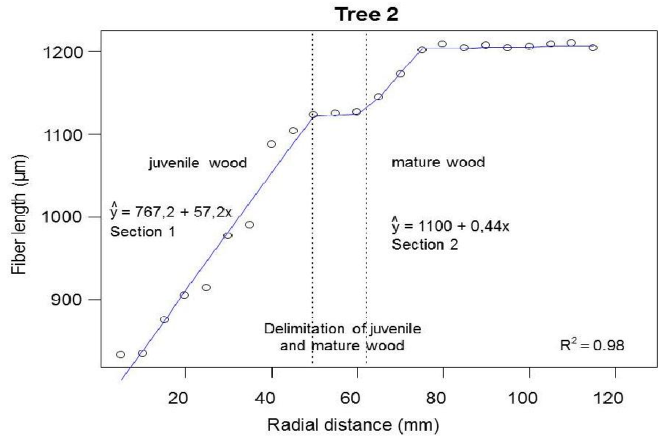

Figure 3. Segmented linear regression of fiber length used to delimit juvenile and mature wood of tree 2 of *Tectona grandis* with 17 years old

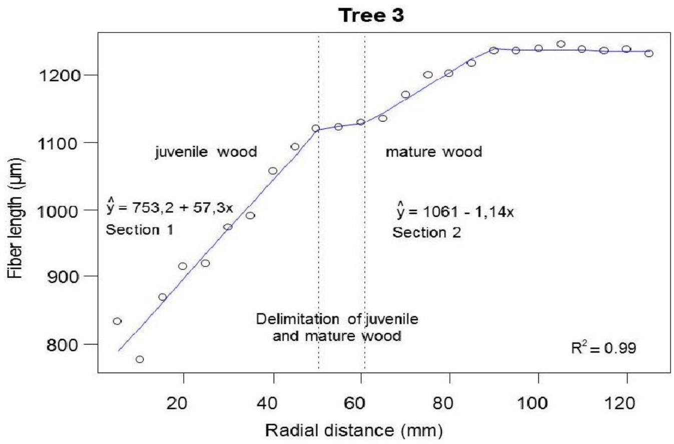

Figure 4. Segmented linear regression of fiber length used to delimit juvenile and mature wood of tree 3 of *Tectona grandis* with 17 years old

In addition, studies with *Eucalyptus citriodora* and concluded that juvenile wood formation is defined from the pith until the first 30 to 40 mm radius, result later ratified the measures to 45-55 mm (Calonego *et al*., 2005 studying juvenile wood of 32-year-old *Eucalyptus citriodora*). The results found in this study of juvenile teak wood were expected in the early years of tree formation and are consistent with other studies conducted to determine the point or transition age from juvenile to mature wood in several species of coniferous and broadleaf species: Bhat, Priya and Rugmini (2001) for *Tectona grandis;* Ballarin and Lara Palma (2003) for *Pinus taeda*; Calonego *et al*. (2005) for *Eucalyptus citriodora*; Gatto *et* al. (2007) for *Luehea divaricata*; Lara Palma *et al*., (2010) for *Corymbia citriodora*; Ramos *et al*. (2011) for *Eucalyptus grandis*; Gatto *et al*., (2012) for *Lueheadi varicata* (açoita-cavalo)*;* Palermo *et al*. (2013) for *Pinus elliottii* and Delucis *et al*. (2013) for *Cedrela fissilis*. The aforementioned species show a pattern of increasing variation in the pith-bark direction, with a tendency of the pith region having juvenile wood. According to this behavior and to the results of the adjusted segmented regression, the region between 40 and 60 mm was considered a transition region, where the region of the wood above 60 mm to the outer end of the trunk was defined in this study as mature wood, because the fiber length tends to stabilize. Similar values were found by Richter *et al*. (2003), characterizing the wood of 20-year-old teak from Ghana as young when located from the pith until 100 mm. The determination of juvenile and mature wood affects directly the uniformity of wood properties, therefore, knowing the transition age is very important for wood quality studies, as it enables separating the different wood according to the characteristics required for each product.

Conclusion

The juvenile wood region can be delimited by assessing the variation of fiber lengths, as it may be used as a measure to predict the different wood maturation stages, with an increase in fiber length in the radial direction (pith-bark direction) of *Tectona grandis* trunks from individuals with 17 years old. Juvenile wood region is defined from the pith until the first 40 mm radius and the mature wood region from 60 mm until the bark. The fiber length increased from the pith, followed by a segment of constant length (stabilization) and finally a slight increase. The fiber length trend confirmed the transverse growth pattern of the species *Tectona grandis*.

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