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RESEARCH ARTICLE

DELIMITATION OF JUVENILE AND MATURE WOODS OF *Pinus caribaea var. hondurensis* (Sénécl.) W.H. Barrett & Golfari AS A FUNCTION OF THE LENGTH OF THE TRACHEIDS

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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 *Pinus caribeae* var. *hondurensis* with 40 years of age, with diameter class around 30-35 cm, from the plantations of the Fazenda Vale do Rio Grande located at the municipality of Catalão, state of Goiás, Brazil. The regions of juvenile and mature wood were characterized by anatomical studies - length of axial tracheids using discs obtained at the DAP trees, following the recommendations of the International Association of Wood Anatomists. The tracheids 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 tracheids were measured per slide. The juvenile wood region is defined from the pith to the first 50mm radius, whereas the mature zone comprises from 80 mm to the bark, corresponding from the 9th to 17th growth rings, respectively. There was an increasing pattern of tracheids length variation from the pith, followed by a region with stabilization of the value and, finally, a slight increase.

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INTRODUCTION

Planted forests expand about 5 million ha.year^{-1}, covering nowadays a total of 264 million hectares of Earth's surface (Fao, 2014). Several estimates suggest that planted forests account for 1/3 to 2/3 of the global timber demand for industrial purposes (Efiatlantic, 2013). Brazil has one of the largest forest areas in the world, with 463 million hectares, corresponding to 54.4% of country's area (Sfb, 2013). Of these, 7.8 million hectares correspond to planted forests for industrial purposes, with eucalyptus plantations occupying 5.6 million hectares, pinus 1.6 hectares, and acacia, teak, rubber and parica accounting together for 0.59 million hectares (Ibá, 2015). The pine wood presents visible growth rings in their successive depositions of juvenile and mature wood representing one year of vascular cambium activities (Esau, 1974 and Nutto et al, 2012). Wood quality of coniferous from the pith to the bark is not uniform, beginning with juvenile wood, which presents lower specific mass, shorter tracheids, higher lignin content, lower cellulose content and lower mechanical resistance when compared to mature wood (Bendsent, 1978). Some authors observed the occurrence of a gradual increase of the specific mass and the anatomical characteristics in the radial direction of the wood, from the pith to the bark, characterizing the transition from juvenile to mature wood (Bendtsen, 1978; Latorraca and Albuquerque, 2000; Pauleski, 2010; Gatto et al, 2013, Palermo et al. 2013 and Trevisan et al. 2014). The transition between the regions contained by the juvenile and mature wood occurs in a gradual way and, for this reason, its delimitation is difficult (Bendtsen, 1978). Nevertheless, Coneglian et al. (2016) argue that a segmented regression of fiber length is an effective method for such delimitation, yielding two lines to establish the breakpoints of each region of the juvenile and mature wood of *Tectona grandis*. Distinguishing between the juvenile and mature woods of coniferous may be difficult and, in some cases, becomes subjective, establishing a minimum number of growth rings for this transition.

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Overall, transition occurs gradually along growth rings in the pith-bark direction (Szymanski and Tauer, 1991; Zobel and Sprague, 1998). The amount of juvenile wood in the trunk is due to anatomical characteristics next to the physiological growth process of the tree, and there are not many alternatives for the foresters (Passialis and Hiriazakos 2004). Thus, the amount of juvenile wood may undergo changes through genetic improvement and appropriate sylvicultural treatments as well as by changes in the model of trees increment, with slight variations (Zobel and Sprague, 1998; Vidaurre et al., 2011). With few actions, we achieve greater growth of trees, resulting in greater amounts of juvenile wood. As reported by Zobel and Buijtenen (1989) in trees of de *Pinus resinosa* fertilized with nitrogen, the region of juvenile wood increased proportionally in the trunk. Therefore, estimating the age at which the transition from juvenile to mature wood occurs is of great practical importance, since the proportion of juvenile wood in the market in increasing (Gatto et al., 2014; Trianosk et al., 2014). In this sense, this study aimed to delimitate the occurrence of juvenile and adult wood by the length of the tracheids in *Pinus caribeae* var. *hondurensis*, in the radial direction of the wood, from the pith to the bark.

MATERIAL AND METHODS

The study was conducted at the State University of Goiás (Universidade Estadual de Goiás, UEG), Campus Ipameri – state of Goiás (Lat. 17º 43' 19" S, Long. 48º 19' 35" W, Alt. 773 m). The wood used in the experiment was extracted from three trees of *Pinus caribeae* var. *hondurensis* with 40 years of age, with diameter class around 30-35 cm, from the plantations of the Fazenda Vale do Rio Grande located at the municipality of Catalão, state of Goiás (Lat. 17º 34' 18,90" S, Long. 47º 27' 49,11" O, Alt. 975 m). From each selected tree a 50mm thick disk was taken at a height of 1.30 m of (DBH), to determine the variation in tracheids length in the radial direction, from the pith to the bark. For the preparation of the slides and measurement of tracheid lengths, a diametrical sample was taken from the central region of the disk. From each diametrical sample, a 10-mm-thick strip was removed, from which five 5mm subsamples were removed in the pith-bark direction, to previously distinguish between juvenile and adult wood. After decoupling and staining the tracheids of each subsample (every 5 mm), a total 5 slides were prepared and 6 length measurements were made on each slide. For the measurements, always 6 undamaged tracheids were chosen, making a total of 30 measurements in each sample (by radial position), totaling 2,760 measurements for the three trees, as shown in Figure 1.

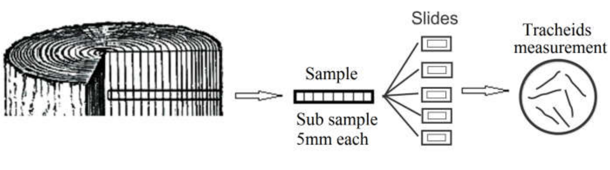

Figure 1. Removal of the samples in the radial direction (pith-bark) for measurement of wood tracheids in the shaft of *Pinus caribeae* var. *hondurensis* at 40 years of age

Digital images of each slide were captured in a LEICA DM500 microscope, coupled to an ICC50 digital camera. The image analysis software LAS EZ 2.0.0 was used to measure tracheid lengths with projection using the micrometer scaleruler at the Phytopathology Laboratory of the Universidade Estadual de Goiás, Câmpus Ipameri, GO.

For the anatomical study (tracheids length and determination of juvenile and adult wood), recommendations of the modified Franklin method (cited by Taylor, 1975) were followed; IAWA standard Committee (1989) and Coradin and Muñiz (1992). The number of tracheids measured in each subsample was determined based on the t statistic (Equation 1).

$$N = (t^2 \times S^2)/E^2 \qquad (1)$$

Where: N = number of replicates; t = tabulated value of Student's t variable; S^2 = sample variance; and $E^2 = (0,1\ x)^2$, where x = the average of the sampled values.

As described by Bendtsen and Senft (1986), due to the gradual variation on wood properties in the radial direction (pith-bark), the point at which a tree fails to produce juvenile wood and begins producing adult wood is not well defined. Nevertheless, there is a point at which such properties stabilize and decrease. For delimiting the transition age, data on tracheids length in function of radial distance were analyzed using the segmented linear regression method, recommended by Coneglian et al. (2016). Such method provides greater flexibility for characterizing distinct behaviors of cell lengths. The breakpoints of the adjusted lines were used to mark when the lengths of the tracheids presents linear increase, stabilized or decreased. These points delimitated the juvenile wood zone, the wood transition zone and the adult wood zone. The statistical analyses were made in the R statistical computing environment, version 3.1.2 (www.r-project.org).

RESULTS AND DISCUSSION

Table 1 shows the mean values, minimum values, standard deviation and coefficient of variation of tracheids length of the three studied trees. Tracheids length and coefficients of variation were lower in the adult wood, suggesting greater homogeneity in their formation and wood maturation, when compared to the juvenile wood.

Table 1. Descriptive statistics of tracheids length (in mm), measured individually by tree

	Tree 1		Tree 2		Tree 3	
Statistics	Juvenile	Mature	Juvenile	Mature	Juvenile	Mature
Minimum	1969	2951	1836	2882	2102	3079
Maximum	2718	3515	2571	3343	2864	3508
Mean	2228	3251	2122	3153	2333	3357
Standard deviation	249.75	131.99	239.39	123.20	262.15	135.56
CV %	11.21	4.06	11.28	3.90	11.23	4.03

Overall, it may be observed a striking pattern of growing variation of tracheids length along the tree radius, increasing length from the pith up to a certain value, followed by a segment with increase and stabilization or stabilization. Thus, an increasing variation pattern of the length from the pith is observed, followed by a segment with a small decrease and, at next, a gradual and stable increase until the bark, as showed in Figures 2, 3 and 4, respectively. The results found here were already expected and are in accordance to other findings for *Pinus elliottii* (Foekel et al., 1975; Palermo, 2013; and Trevisan et al., 2014) and *Pinus taeda* (Tomaselli, 1979; Lara Palma and Ballarin, 2003; Tanabe et al., 2016). When considering the mean values of tracheids length presented in Table 1, an approximate variation from 1836 to 3515 µm is observed, corresponding, respectively, to juvenile and mature woods of *Pinus caribeae* var. *hondurensis* at 40 years of age.

Such variation probably occurs due the presence of a juvenile wood zone near the pith, which presents, among other characteristics, short tracheids, while, near to the bark, in turn, this gradient decreases due to plant aging (Trevisan et al, 2014). Values of the coefficient of variation found in the juvenile wood of *Pinus caribeae* var. *hondurensis* indicate higher CV% values for the threes 1, 2 and 3 (11.21, 11.28 and 11.23, respectively), when compared to CV% values of the mature wood (4.06, 3.9 and 4.03, respectively). The observed values for mature wood are considered low in relation to the juvenile wood, suggesting the homogeneity and stabilization of tracheids length in mature wood. Similar values were found in several forest tree species. Bhat, Priya and Rugmini (2001) in *Tectona grandis* of 25 and 60 years of age, CV% varied from 11.00 to 13.00 in juvenile wood, and from 11.00 to 17.00 for mature wood. Still for *Tectona grandis*, at 17 years of age, Coneglian et al. (2016) found CV% values from 6.9 to 11.00 for juvenile wood, and from 8.00 to 1.7 for mature wood. For *Corymbia citriodora*, at 32 years of age, CV% values may range from 3.5 to 18.61 in juvenile wood, and from 3.2 to 7.77 in mature wood (Calonego et al., 2005). Lara Palma et al. (2010) found, also for *Corymbia citriodora*, at 30 years of age, CV% values from 16.18 to 18.92 in juvenile wood, and from 2.89 to 5.06 in mature wood. For *Pinus elliottii* at 30 years of age, Trevisan et al. (2014) found a high coefficient of variation (approximately 17%) of tracheids length between juvenile and adult wood. The radial variation of the wood tracheids length was used as an explanatory variable for delimiting juvenile and mature wood zones. The fittings of the segmented regression models are presented in Figures 2, 3 and 4. Two distinct zones of juvenile and mature wood were distinguished, between 50 and 80 mm from the pith to the bark, corresponding to the 9th and 17th growth rings, respectively.

The coefficients of determination of the fitted models for tracheids length in the trees 1, 2 and 3, were, respectively R^2= 0.98, 0.99 and 0.99. The models presented two breakpoints. There is a stabilization of tracheids growth from the first point, and, in the second breakpoint, tracheids grow gradually, marking the transition zone between juvenile and mature wood. The length of tracheids showed a sharp and almost linear increase in the radial distance of the juvenile wood, which varied from the pith to the first 50 mm of the radius, corresponding to the 9th growth ring in the pith-bark direction.

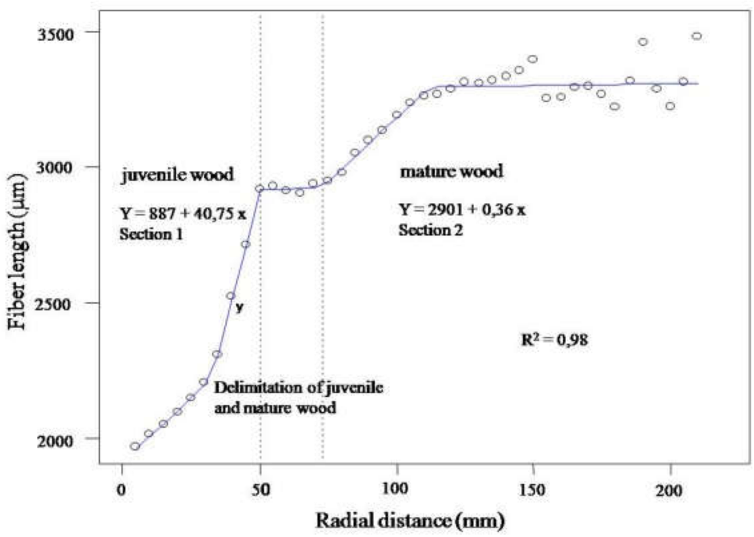

Figure 2. Segmented linear regression to identify juvenile and mature wood of the tree number 1 of *Pinus caribeae* var. *hondurensis* at 40 years of age

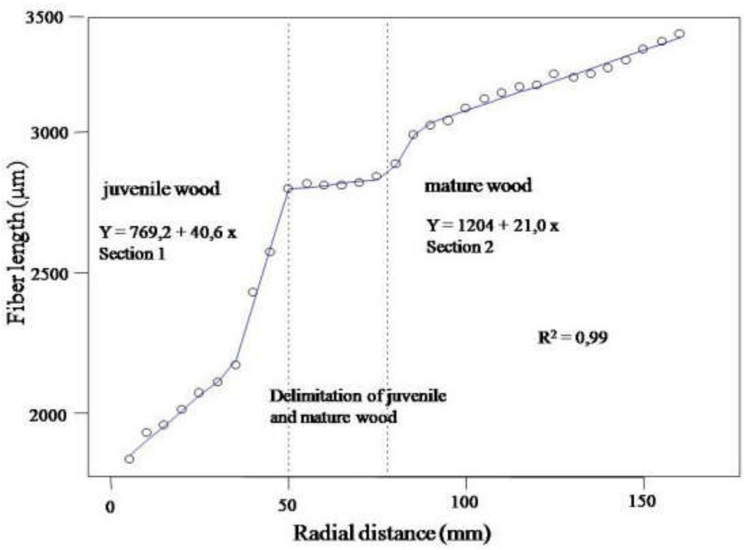

Figure 3. Segmented linear regression for delimitation of juvenile and mature wood of the tree number 2 of *Pinus caribeae* var. *hondurensis* at 40 years of age

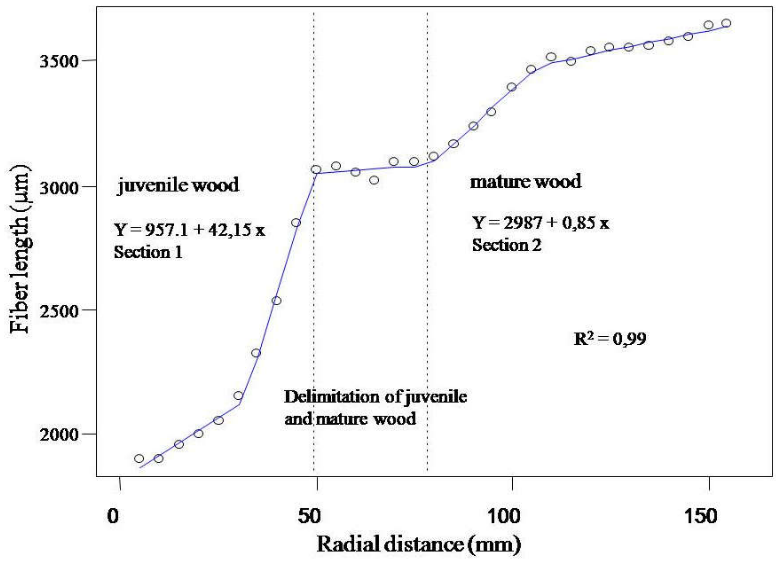

Figure 4. Segmented linear regression for delimitation of juvenile and mature wood of the tree number 3 of *Pinus caribeae* var. *hondurensis* at 40 years of age

According to this behavior and to the fitting of the segmented regression, the transition region was obtained, comprising from 50 to 80mm, which corresponds to the 9th and 17th growth rings, respectively. Therefore, we defined that the mature wood region occurs up to 80 mm, corresponding to the 17th growth ring towards the bark.

The age of demarcation of juvenile and mature wood of *Pinus sp.* was supported by Foelkel et al. (1975), which reported, also based in tracheids length, the transition in the juvenile wood at the 7th and 9th years of tree wood formation in *Pinus elliottii*. In turn, for Mendonça (1982), the maturation age of the same species occurred between the 8th and 11th growth rings. In *Pinus taeda*, such stabilization occurred between the 11th and 13th growth rings for trees with 30 years of age (Zobel, 1971). Zobel e Sprague (1998), also in *Pinus taeda* trees, observed that the juvenile period varied between the 8th and 12th growth rings, based in the tracheids length. The initial wood in *Pinus Patula* and *Pinus taeda* species occurs until the 5th growth ring, and the mature wood occurs after the 14th ring in relation to the pith (Ferreira et al., 1978; Ringo and Klem, 1980; Bendtsen and Senft, 1986). Recently, Palermo et al. (2013) described, also based in the length of tracheids, the transition from juvenile to mature wood at 70mm in relation to the pith for *Pinus elliottii*. The determination of the mature wood interferes directly in the uniformity of wood properties and, consequently, in the use and application of the wood when it is transformed into other products. Therefore, determining the age of demarcation is an important tool in studies regarding wood quality, enabling to distinguish between different woods according to the characteristics needed for each product.

Conclusion

The delimitation of the juvenile wood was achieved by applying the segmented regression of tracheids length, serving as a prediction measure of different wood maturation stages, with increases in tracheids length in the radial direction of the shaft, in the pith-bark direction of *Pinus caribeae* var. *hondurensis* at 40 years of age. The juvenile wood region is defined from the pith to the first 50mm radius, whereas the mature zone comprises from 80 mm to the bark, corresponding from the 9th to 17th growth rings, respectively. There was an increasing pattern of tracheids length variation from the pith, followed by a region with stabilization of the value and, finally, a slight increase.

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