BASIC DENSITY AND SCALING OF JUVENILE AND MATURE WOOD IN *PINUS CARIBAEA* TREES

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The objective of the present study was to evaluate the density, and delimit the transition age and the volume proportion of wood types in *Pinus caribaea* trees. Trees from two genetic materials (A and B) were selected from a 20-year-old *P. caribaea* plantation. Disks from the base were used to determine the age of wood segregation and disks from different axial position – to determine the basic density and volume of juvenile, transition and mature wood in the trees. The density of the wood decreased from the base to the tree top. The juvenile wood corresponded to the beginning of the cambium activity until the eighth ring, the rest being characterized as transition wood and no mature wood was found in the 20-year-old *P. caribaea* trees. The proportion of juvenile wood volume in the genetic materials A and B was 58.57% and 80.51%. Transition wood was found up to 17.3 meters height of the trees.

Keywords: tracheid length, trunk analysis, wood quality, xylem

INTRODUCTION

Secondary growth of the cambium produces juvenile, transition and mature wood types.[1,2] Juvenile wood is formed when the stem has a small diameter, the wood has smaller cells, with a thinner cell wall and reduced length.[3] The development of cambium results in the production of cells with larger cell wall and smaller microfibrillar angle.[4] The transition between juvenile and mature wood is gradual, forming the transition wood and the passage between these stages varies as a function of the genetic material,[5,6] environmental[7] and management[8] conditions.

The density of juvenile wood is lower,[9] the microfibrils angle of the S2 layer is larger,[10,11,12] the tracheids are shorter,[13,14] there is volumetric variation for different equilibrium moisture content[15,16] and the mechanical resistance is lower[3] in relation to mature wood. These parameters are important to evaluate the wood quality, and each type of wood is delimited, mainly, by the length of the fibers or tracheids.[17]

The age of the cambium, not of the tree, determines the production of mature wood.[18,19] This production starts at the base, where the cambium is at an advanced stage of production, while the one at the top produces juvenile wood.[20] The juvenile wood, in trees with advanced age, corresponds to a cylinder from the base to the top, and the mature one – to the peripheral areas of the base up to a median height.[5,14] The research reported in the literature so far aiming to delimit the transition age between different wood types[21,22] or assess its quality[23,24] is insufficient to quantify its proportion in the tree.

Thus, the present work has been performed with the objective to estimate the transition age between the juvenile, transition and mature wood, as well as their volumetric proportions, in *Pinus caribaea* trees.

EXPERIMENTAL

Wood samples

Eight *Pinus caribaea* trees, from two genetic varieties (A and B), in plantations with initial spacing of 3 × 3 m and subjected to systematic thinning were harvested (Table 1) in the municipality of Prata, Minas Gerais state, Brazil (19° 18' 25" S, 48° 55' 26" W). The climate of this region is, predominantly, semi-humid tropical with rains concentrated in the summer (December to March) and a dry period in the winter (May to August). The average annual temperature and rainfall are 24 °C and 1,450 mm, respectively.

The wood basic density was determined in two 5 cm thick discs taken from the base and at 25%, 50%, 75% and 100% of the commercial tree height (minimum diameter of 14 centimeters) (Fig. 1), while the juvenile, transition and mature wood – in a disc removed from the base of trees of higher diametric class for each genetic variety. The wood types were quantified by analyzing the growth rings on discs removed at 0.2 m (base), 0.7 m, 1.3 m (DAP) and every two meters of the commercial tree height.

Basic density

The basic density in the axial direction was determined by the ratio between the dry mass and the saturated volume in the disks removed from the base and at 25%, 50%, 75% and 100% of the commercial tree height.[25]

Delimitation of juvenile, transition and mature wood

Samples were taken from earlywood of each growth ring, in disks from the base, and then macerated.[26] Nineteen and 18 growth rings were delimited in the genetic varieties A and B, respectively. The length of the tracheids was measured according to IAWA.[27] The juvenile, transitional and mature wood was delimited by visual analysis of the tracheid length from the pith to bark direction.[6] The zones with high, intermediate or zero increase in the tracheid length were characterized as juvenile, transition and mature wood, respectively.

Volumetric quantification of juvenile, transition and mature wood

The discs, removed from the trunk of the *P. caribaea* trees, were stored in the laboratory for 60 days for drying. After this period, they were sanded to better visualize the growth rings. After preparation, a digital image of each disk was obtained with a Canon Powershot SX60 camera fixed on a tripod to standardize the height.

Table 1
Number of trees harvested (Nr.), age (Id.), diameter at breast height with bark (DBH), average total height (Ht) and average individual volume with bark (Vwb) of *Pinus caribaea* trees of each genetic variety (GV)

GV	Nr.	Age (years)	DBH (cm)	Ht (m)	Vwb (m³)
A	4	20.4	24.8 ± 4.16	20.6 ± 1.32	0.489 ± 0.193
B	4	18.9	28.4 ± 4.37	28.2 ± 2.40	0.771 ± 0.264

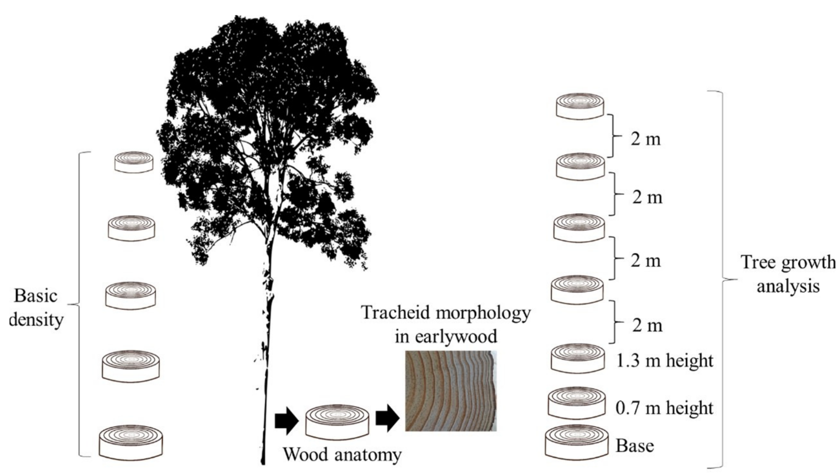

Figure 1: Sampling from the trunk to delimit juvenile, transition and mature wood and to analyze the basic density and growth of *Pinus caribaea* trees

The scale of the images obtained was referenced on transparent graph paper placed on the face of the discs. The number of rings, the sectional area and distance from the edge of each growth ring to the pith, per disc taken at different heights of each tree, were quantified from the images obtained with the Quantum GIS software (Qgis) from the Geographic Information Systems (GIS).[28]

The variables – tracheid length and growth ring – were adjusted in an asymptotic model, which was chosen because they initially increased exponentially, followed by smaller increments until a stabilization trend (Eq. 1):

$$Y = \beta1 + (\beta2 - \beta1) \times \exp(-\exp(\beta3) \times Z) + \varepsilon \quad (1)$$

where Y = tracheid length (µm); Z = ring with the tracheid location; βi = model parameters; and ε = error. The model adjustment was based on the ten largest tracheids per disk position.

The beginning of the increase stabilization in the tracheid length, from the adjusted asymptotic model, was determined with the first derivative in the model. This allows determining the rate of increase in the tracheid length and the growth ring corresponding to the beginning of the stabilization. The volume per wood type was quantified with the dendrometric data from the trunk analysis, after determining the ring corresponding to each kind of wood (juvenile, transition and mature), using the Smalian formula.

Analysis of the results

Density curves, in relation to the axial position, and the tracheid lengths, in relation to cambium age, were generated.

RESULTS AND DISCUSSION

Basic tree density

The basic density of the genetic varieties A and B decreased with the tree height, from 0.420 to 0.553 g.cm^{-3} and 0.368 to 0.468 g.cm^{-3} in the disks removed from the base and the top, respectively (Fig. 2).

The decrease in the basic density of the genetic varieties A and B with the increase in trunk height can be explained by the cambium activity of the tree.[29] The xylem production by the cambium is recent at the top of the tree, with tracheids showing wide lumen and thin cell wall, while the reverse occurred at the base of the tree, where the cambium activity is older, producing larger tracheids and with a thicker cell wall.[14,30,31] Longitudinal tracheids represent more than 90% of softwoods and, therefore, their morphology directly influences wood density.[1] These values are similar to those reported for 20-year-old *P. caribaea* trees, between 0.41 and 0.51 g.cm^{-3} in Goiás state, Brazil.[29,32] The wood basic density from base to top decreased in *Pinus caribaea* var. bahamensis, *Pinus chiapensis*, *Pinus caribaea* var. caribaea, *Pinus caribaea* var. hondurensis, *Pinus massoniana*, *Pinus maximinoi*, *Pinus oocarpa* and *Pinus tecunumanii*.[33,34]

Delimitation of juvenile, transition and mature wood

The tracheid length, along the growth rings, of the genetic varieties A and B was similar (Fig. 2), and, therefore, described with a single asymptotic model. The parameters of the asymptotic model were significant (Table 2), with a residual standard error of 624.0176 (16.19%).

The use of the same asymptomatic model for the tracheid length along the growth rings in the genetic varieties A and B established the transition age between the wood type (juvenile, transition and mature) being the same. The greatest increase in the tracheid length in the first eight years of cambium activity characterizes the production of juvenile wood during this period.[6,35] The transition wood was produced from the eighth to the last ring, with a reduced increase in the tracheid length, but without reaching the null value and no mature wood was observed. Silvicultural treatments that favor tree growth, such as thinning and fertilization, can be indicated in eight-year-old stands to improve the wood quality produced.

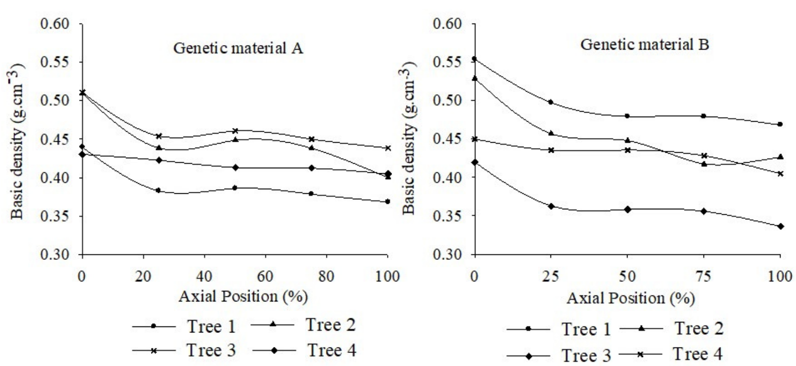

Figure 2: Axial variation of basic density in trees of genetic varieties A and B of *Pinus caribaea* with each line representing a sampled tree;* (Percentage in relation to commercial height (minimum diameter of 14 cm))

Table 2
Parameters, estimate, standard error, t-value and probability (Pr) of the adjustment of the asymptotic model between the tracheid length of the corresponding growth ring

Parameters	Estimate	Standard error	t value	Pr (>|t|)
β_1	4643.40576	44.02254	105.478	$<2e^{-16}$***
β_2	831.06031	113.64920	7.313	$5.02e^{-13}$***
β_3	-1.47277	0.05661	-26.017	$<2e^{-16}$***

***$p < 0.001$

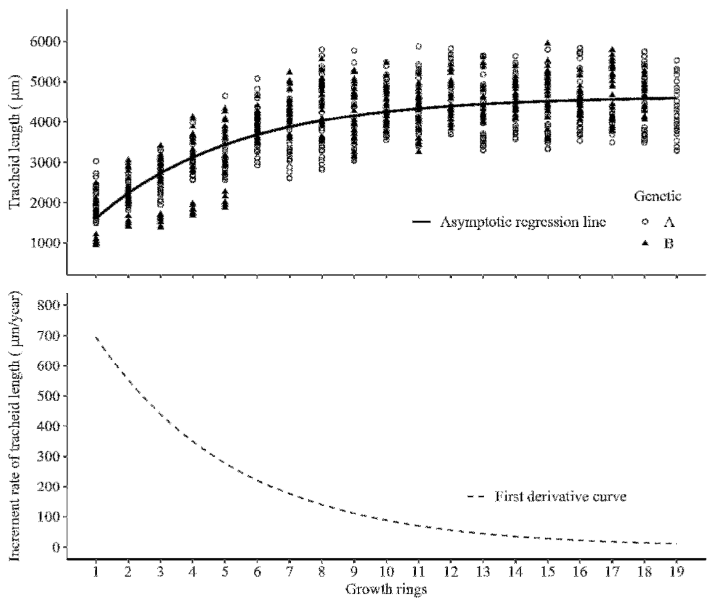

Figure 3: Tracheid length along the radial direction of the genetic varieties A and B, adjusted asymptotic model and increase rate in tracheid length along the growth rings (first derivative) of *Pinus caribaea* trees

The tracheid length was 1700, 3000 and 4000 µm in the first, fourth and eighth years of cambium activity, respectively, with rapid growth during this period, forming the juvenile wood. From the eighth year onwards, the tracheids increase was smaller, but without null values (Fig. 3) and, therefore, this age interval was characterized as transition wood. Mature wood was not observed in any of the materials.

The growth pattern of the tracheid length along the growth rings showed only juvenile and transition woods.[36] The absence of regions with zero growth of tracheid length along the growth rings indicates that the production of mature wood will occur after 20-year-old cambium age in *P. caribaea* trees, similar to that reported for *Pinus elliottii*[37] and *Pinus sylvestris*.[38]

However, this differs from that observed for *Pinus sylvestris* L., with juvenile wood production up to 13 years old[39] and the production of mature wood for *Eucalyptus grandis* between 8 and 13 years old,[6,40] confirming the later production of mature wood in *Pinus* species compared to those of *Eucalyptus*. Variations in the juvenile and mature wood production are associated with environmental conditions, in addition to plant genetics[7] and management.[8]

Volumetric proportion of juvenile, transition and mature wood

The proportion of each wood type varied between the genetic varieties, although with the same alternation age between juvenile and transitional wood. The juvenile wood volume corresponded to 58.57% and 80.51% of the total volume, without bark, for the genetic varieties A and B, respectively (Table 3). The growth of the genetic variety B was greater in the early years, increasing the proportion of juvenile wood in its trees. The production of transitional wood started when the trees reached eight years of age when the average volume of the trees from the genetic varieties A and B was 0.074856 m³ or 20.2% and 0.196931 m³ or 32.8% of the total volume of the trees harvested, respectively (Table 3).

Variations in the juvenile wood proportion highlight the importance of studies on wood quality, as the age of production and the volume of each wood type produced can vary with the genetic variety, silvicultural practices and management of the stand, affecting productivity and wood quality.[8,19,41] Practices, such as thinning eight years after planting, reduce competition among remaining trees and increase the volume of transition wood in the evaluated pine stands. The difference in growth between the materials is due to their genetic composition, as all the trees grew on the same site and received the same silvicultural care.

The proportion of juvenile wood increased with tree height, with the presence of transition wood up to the height between 15.3 and 17.3 meters in the genetic varieties A and B, otherwise said, from that height, at the evaluated age, all the wood volume corresponds to juvenile wood (Fig. 4). The proportion of juvenile wood was greater than 50% of the total volume, without bark, in the genetic varieties A and B, from 3.3 meters high and DBH, respectively.

Table 3
Juvenile wood volume (JWV), mean total volume (TV), mean of total volume at eight years (VMT8) and proportion of juvenile wood (mean, maximum and minimum) per *Pinus caribaea* tree of the two genetic varieties (GV) A and B

GV	JWV (m³)	TV (m³)	VMT8 (m³)	Proportion of juvenile wood (%)		
				Mean	Maximum	Minimum
A	0.235981	0.371424	0.074856	58.57	84.37	55.48
B	0.482645	0.599726	0.196931	80.51	85.06	78.90

*The proportion of juvenile wood is given by the transition wood, as only juvenile and transition woods were observed

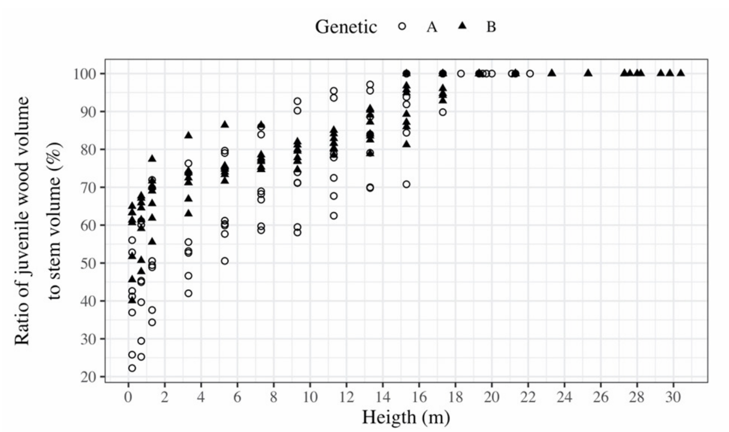

Figure 4: Proportion of juvenile wood in relation to total wood volume without bark, in genetic varieties A and B of *Pinus caribaea*

Genetic variety B showed 100% juvenile wood at heights higher than that of the genetic variety A. Eight growth rings were visualized from that height to the top in the cross-section, showing early cambium activity. The same effect was observed near the base, where the proportion of juvenile wood is above 50% in the genetic variety B at a height lower than in the genetic variety A. The greatest growth in the first years of the genetic variety B resulted in differences in the growth pattern, reflecting the distribution of juvenile and transitional wood in the axial direction. The same effect was recorded for *Robinia pseudoacacia*.[5] This increased the proportion of juvenile wood from the DBH, thus explaining the 100% proportion of juvenile wood at heights greater than in variety A.

CONCLUSION

The increase in the tracheid length shows wood changes during tree growth. The transition between wood types was similar in the two genetic varieties, with juvenile wood from the first to the eighth years of cambium activity and the rest characterized as transition wood, without mature wood. The proportion of juvenile wood was higher in the genetic variety B, with approximately 80%, while this was 58% in the variety A, even with similar transition ages between wood types. This difference in production of each wood type is due to the growth characteristics of the genetic materials. The transition wood was recorded up to 17.3 meters in the two genetic varieties.

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