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ORIGINAL ARTICLE

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Densidade
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sentido base-topo

Radial and longitudinal variation of *Pinus taeda* L. wood basic density in different ages

Variação radial e longitudinal da densidade básica da madeira de Pinus taeda L. com diferentes idades

ABSTRACT: The wood density is one of the parameters that most affect its properties, which makes it knowledge essential for any use indication. However, due to the high variability of this aspect within the tree, its determination shall consider a sampling throughout the stem. Thus, this study aimed to evaluate the longitudinal and radial variations of *Pinus taeda* L. wood density for individuals with different ages. To that end, trees with 8, 14, 18 and 26 years old were cut, and discs with 10, 35, 55 and 75% were removed from the tree total height and another in the height corresponding to the chest height diameter– DBH, taken at a 1.30m. From these, samples were collected in three different positions in the pith-bark direction (next to pith, intermediate and next to bark) to determine the density. A significant density increase was observed for older trees samples. A density reduction from the basis to the top and an increase from the pith to the bark was observed.

RESUMO: *A densidade da madeira é um dos parâmetros mais influentes em suas propriedades, o que torna o seu conhecimento essencial para qualquer indicação de uso. Entretanto, em razão da elevada variabilidade deste aspecto dentro árvore, a sua determinação deve considerar uma amostragem ao longo de todo fuste. Desta forma, o presente trabalho teve como objetivo avaliar as variações longitudinal e radial da densidade da madeira de Pinus taeda L. para indivíduos com diferentes idades. Para isso, foram abatidas árvores com diferentes idades de 8, 14, 18 e 26 anos, sendo retirados discos a 10, 35, 55 e 75% da altura total da árvore e outro na altura correspondente ao diâmetro à altura do peito – DAP, tomada a 1,30 m do solo. Destes foram retiradas amostras em três diferentes posições no sentido medula-casca (próxima à medula, intermediária e próxima à casca) para determinação da densidade. Verificou-se um aumento significativo da densidade para as amostras provenientes de árvores mais velhas. Para os demais parâmetros avaliados, verificou-se redução da densidade da base para o topo e incremento da medula para a casca.*

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1 Introdution

Pinus taeda is a major *Pinus* of the Southern United States. Natural range this species extends from New Jersey to the South Florida and to west Texas and Oklahoma. Introduced in Brazil in the 1950s, in order to replace the *Araucaria angustifolia* wood, it showed excellent adaptation in the South, mainly in Paraná and Santa Catarina States, being widely utilized in this area reforestation. Currently, the *Pinus* genus is highlighted as the second most planted in the country, with approximately two million hectares, only behind the *Eucalyptus* (Elesbão, 2008).

It is necessary to know the wood properties and characteristics in order to opt for the most suitable uses due the species economic importance. The material correct use is related to its physical and mechanical characteristics. The wood is non-exception, becoming important to know its variations in order to predict its behavior in different utilizations (Trevisan et al., 2008). The density is one of the properties that provide more information on wood characteristics, because is related to its strength and rigidity. It is essentially due the cell wall function, the dimensions, and the cells types and, in a lesser extent, the extractable components amount present per volume unit (Panshin & De Zeeuw, 1980).

Density is one of the main factors used in structural wood classification and high quality material selection to be used in foundations or any other use where resistance is essential. This is due the correlation high degree between density and mechanical strength in all wood producing species (Schilling et al., 1997). Thus, from the wood technological utilization point of view, the individual variation study and the variability within the tree diagnosis it is extremely important, both in radial and longitudinal directions (Melo et al., 2013).

According to Vale et al. (2010), the density is one of the most important wood properties, and therefore, the most studied, ranging from 0.13 g cm^{-3} to 1.40 g cm^{-3}. It is directly related to pores empty volume and, consequently, with other physical and mechanical properties. This parameter may be simply defined as the dry weight per saturated volume unit, which is the most usual manner to express this wood physical characteristic.

As mentioned by Melo et al. (2013), this parameter is influenced by diverse factors, varying significantly according to the following aspects: age, origin, spacing, growth rate, genus, species, individuals and even within the same tree. As for the same tree, this variation may occur both in axial direction (basis-top) and in the radial direction (pith-to-bark). Such variations occur due to a complex anatomical combination, physical and chemical factors, which are mainly influenced by tree age, genotype and environmental conditions.

In this sense, the present study aimed to evaluate the variation in *Pinus taeda* wood density to different positions in the stem, in basis-top and pith-to-bark directions to trees with different ages.

2 Materials and Methods

Ten *Pinus taeda* trees were collected for this study. They came from homogeneous plantings with 3.0 × 2.0 m spacing, located in Santa Catarina State, Southern Brazil. The selected individuals were 8, 14, 18 and 26 years old. Three individuals were cut for each age, totalizing twelve trees. In all cases, internal planting trees were selected to avoid the border effect.

After cut, the trees were selected in different heights, with discs remove of 5 cm thick approximately, at 10, 35, 55 and 75% of total tree height, besides a disc removed in height corresponding to the diameter at the base breast - DBH, taken at 1.30 m. The discs were properly identified and send to the laboratory. Six test-bodies were removed from each disc with 1.5 × 1.5 × 5.0 cm, in inner (near pith), intermediate and outer (near bark) portions (Figure 1).

The test-bodies were submerged in water until constant mass (cell walls complete saturation) for density determination, as recommended NBR 11941 (ABNT, 2003). Subsequently, saturated samples volume (obtained from displaced liquid mass) and wood dry weight (obtained after incubator drying at +/–103 °C) was performed for each sample. Each test-body density was determined by the relation between the dry mass and the saturated volume.

An analysis with factorial arrangement was performed to evaluate the results, with three factors: age with four levels (8, 14, 18 and 26 years old); the stem axial position with five levels (10%, DBH, 35, 55 and 75%); and radial position in the stem with three levels (near the pith, intermediate and near the bark). The Scott-Knott test was performed in the analysis and test evaluation at 5% significance to factors and interaction detected as significant by the F test. Regression analysis was also carried out to estimate the wood mean density from the samples density taken in DBH height.

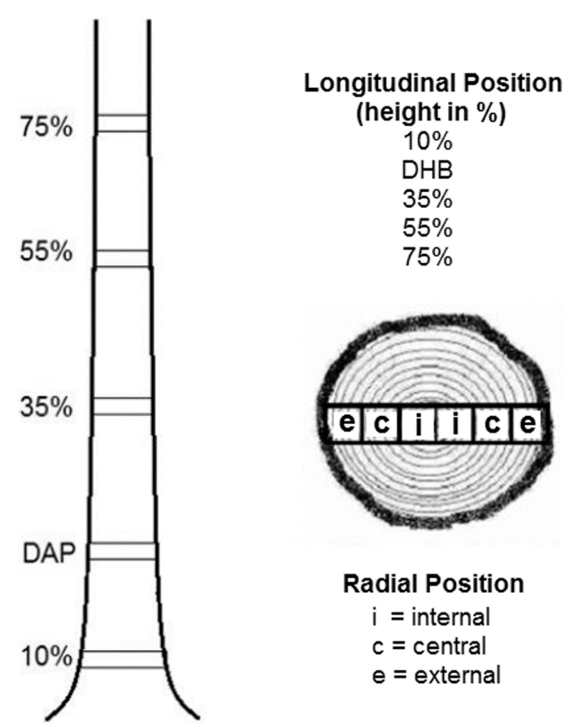

Figure 1. Method used to obtain the samples.

Figura 1. Método utilizado para obtenção das amostras.

3 Results and Discussion

The evaluated factors influence - age, axial and radial position - in wood density may be observed in Figure 2. Regarding to age, there is an increase in wood density over the years. This behavior was also observed by Melo et al. (2010, 2013) for *Araucaria angustifolia* and *Pinus elliottii* woods respectively and, according to these authors, it is a standard performance for coniferous woods. However, this density increase tends to stabilize for mature trees which have reached maturity. This occurs because the older trees produce thicker cell walls, which provides a progressive increase in density. But, when reach maturity; there is thickness stabilization in these cells wall, which provides this parameter stabilization over the years (Conw & Ball, 2001; Corrêa & Bellote, 2011).

A wood density reduction from the tree base distancing was observed for variation in basis-top direction. In studies conducted by diverse authors, among them Hassegawa (2003), Bittencourt (2004), Siqueira (2004) and Mattos et al. (2011), the gymnosperms wood has shown this behavior. There was a pith density increase in axial direction parameter variation for house, behavior already observed for both Pinus genus (Melo et al., 2013) and Eucalyptus genus species (Trevisan et al., 2008). Oliveira & Silva (2003) state to be a similar behavior for species with rapid growth, caused by the good performance of these species in initial growth phase, which provides a more slender cells production and consequently, a wood with lower density in the tree central zone.

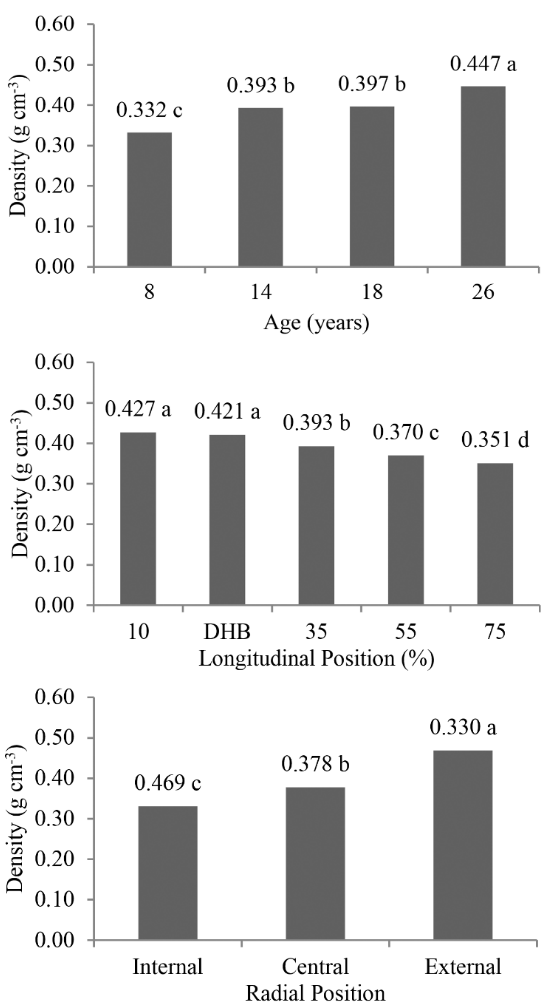

Figure 2. Wood density variability of *Pinus taeda* for old age, longitudinal and radial position.

Figura 2. Variação de densidade da madeira de *Pinus taeda* para os parâmetros idade e posição no tronco nos sentidos longitudinal e radial.

The pattern behavior deployment of *Pinus taeda* wood base density, according to each valuated parameters variation - age, basis-top position and pith-to-bark position - is in Figure 3. In general, directly proportional density increase to age and inversely proportional to height was assessed. Regarding to pith-to-bark, the density was crescent in the stem innermost region (pith) to the outermost region (bark). According to Melo et al. (2010), these results are due to the larger amount of latewood present in the growth ring and in the stem outer positions, which is the main factor responsible for increasing the wood density of coniferous.

The density mean values observed for *Pinus taeda* wood ranged from 0.332 g cm^{-3} for trees with eight years old, up to 0.447 g cm^{-3} adults with 26 years old, approximately. Similar results were observed by Santini et al. (2000), who observed a mean density of 0.410 g cm^{-3} for *Pinus taeda* wood with 13 years old. The same author also observed the mean density of 0.400 g cm^{-3} and 0.410 g cm^{-3} for wood of two other gymnosperms, the *Araucaria angustifolia* and *Pinus elliottii* with 19 and 13 years old, respectively.

A density progressive increase with increasing the trees age was observed for *Pinus taeda* wood. These results corroborate with Oliveira & Silva (2003), who state that over the years, the alterations which occur in the trees wood cells causes substantial changes in its density. Among these alterations may be highlighted changes in the following cellular components: fibers dimensions, cell wall thickness, vessels and parenchyma volume, lumen diameter, ratio between spring and autumn wood and anatomical elements arrangement.

According to the United States Department of Agriculture (USDA, 2010), *Pinus taeda* wood may reach, as adults, a mean density of 0.470 g cm^{-3}, approximately. Based on this study, we might infer that the assessed trees, at 26 years old, were nearing to reach the maturity apex, with a mean density of 0.447 g cm^{-3}. According to Oliveira et al. (2006) this difference may be explained by the tracheids thickness increase due to the trees increasing age.

Table 1 shows the factorial variance analysis performed for the different treatments assessed. The result indicates that the age parameters, longitudinal and radial variation, significantly influenced the *Pinus taeda* wood density. A significant interaction between the parameters, except for triple interaction was also assessed. The interactions detected as significant by F test were unfolded and analyzed separately with Scott-Knott test aid (Tables 2, 3 and 4).

In the interaction between age and longitudinal variation of each tree, is clearly verified the density increase for older individuals, regardless the assessed position (Table 2). As density is one of the properties which provides more information on wood characteristics, being directly related to its strength

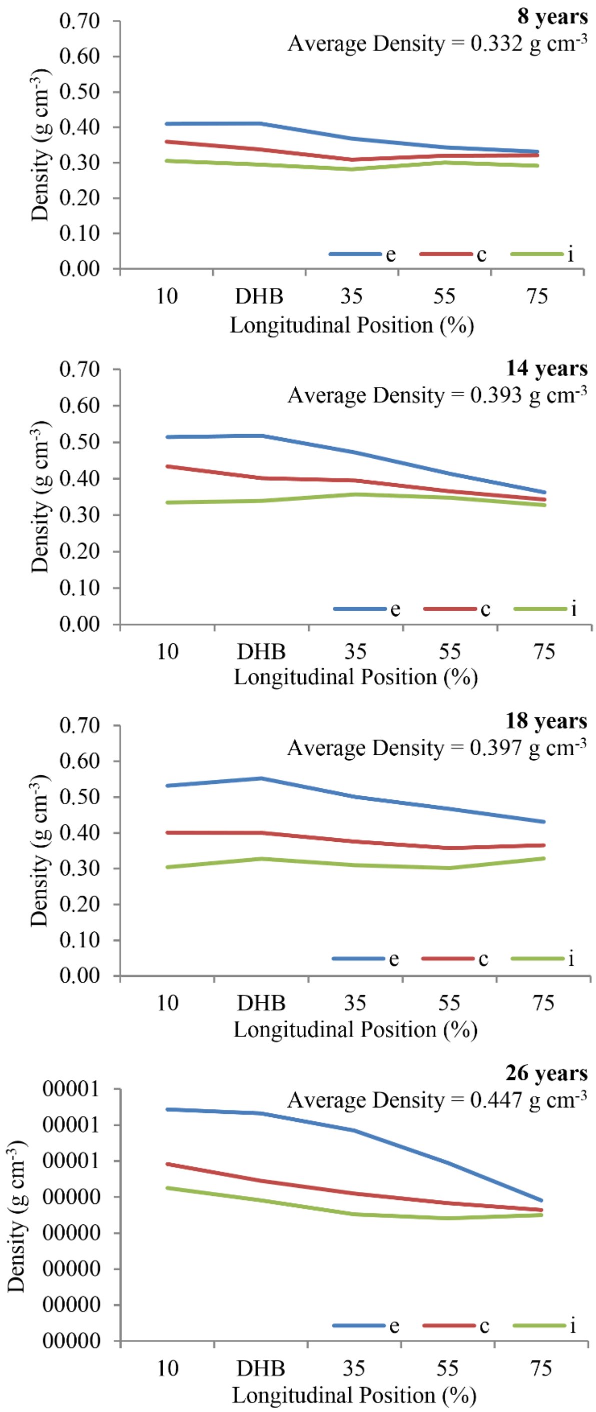

Figure 3. *Pinus taeda* wood density for old age, longitudinal and radial position (e = external; c = central; i = internal).

Figura 3. Densidade básica da madeira de *Pinus taeda* em função da idade e da variação longitudinal e radial (e = externa; c = central; i = interna).

and rigidity, the ideal season cutting shall consider not only planting timber volume, but also its age and therefore, the wood quality (Schilling et al., 1997). As an example, while the lowest density value observed was 0.315 g cm^{-3} (trees with 8 years old; 75% high), the highest value was 0.520 g cm^{-3} (trees with 26 years old; 10% high), 60% higher variation,

Table 1. Fatorial analyses of *Pinus taeda* wood density for factors and interaction evaluated.

Tabela 1. Análise fatorial da densidade da madeira de *Pinus taeda* para os fatores avaliados.

Source of Variation	Degree of Freedom	Mean Square
Age (F1)	3	3.90**
Longitudinal position (F2)	4	1.07**
Radial position (F3)	2	10.75**
Interaction (F1 × F2)	12	0.11*
Interaction (F1 × F3)	6	0.18**
Interaction (F2 × F3)	8	0.22**
Interaction (F1 × F2 × F3)	24	0.02 ns
Treatment	59	0.71**
Residue	120	0.06**
Total	179	

* significant at 5% ($0.01 < p < 0.05$). ** significant at 1% ($p < 0.01$). ns not significant ($p > 0.05$).

variability which may significantly influence the mechanical performance of this species (Santini et al., 2000).

In the interaction analysis between tree ages, the wood variation in radial direction, the density difference between the obtained parts from the stem innermost region (near the pith) with those observed for the outer part (near the bark) was clear for all ages tested (Table 3). For Melo et al. (2010) this result may be referred to the proximity of the growth rings commonly observed in the outer zone of coniferous stem.

The wood density increases rapidly during the juvenile period, grows more slowly in an intermediate phase, until it becomes fairly constant in the tree mature phase. These three distinct phases are present in most fast-growing trees and are mainly responsible for the significant density variation at the pith-to-bark. This pith density increase for bark has been observed and confirmed by diverse authors; among them are Oliveira & Silva (2003), Silva et al. (2004), Trevisan et al. (2008) and Melo et al. (2013). Gatto et al. (2010) also mention that a wood anatomical components brief analysis along these development phases may even be utilized as criteria to define the transition zone between the juvenile and mature woods.

Regarding to the interaction between the variations in the stem, in radial and longitudinal directions, the highest density values were found for samples collected from the basal portion and the outer positions which obtained the highest density values (Table 4). For the internal position, there was non-significant difference to thickness in axial direction. This difference was observed only for external and intermediate position. These results differ from those observed by Melo et al. (2013) for *Pinus elliottii* wood which demonstrated this variation for all positions assessed. Mattos et al. (2011) also verified the same basic density axial variation model decreasing from basis to top, for three conifers species, among them the *Pinus taeda* wood.

A high and significant relation was observed for the correlation between density mean values obtained for each tree and the density observed for samples collected from DBH region, with 0.95 determination coefficients (R^2), which allows estimating

Table 2. Variation of *Pinus taeda* wood density for interaction between old age and longitudinal position.

Tabela 2. Variação da densidade básica de *Pinus taeda* para interação entre os fatores idade e posição longitudinal.

Age (years)	Longitudinal Position (%)				
	10	DHB	35	55	75
8	0.358 cA	0.348 cA	0.320 cB	0.321 bB	0.315 bB
14	0.418 bA	0.420 bA	0.408 bA	0.376 aB	0.345 bB
18	0.412 bA	0.427 bA	0.396 bB	0.375 aB	0.375 aB
26	0.520 aA	0.490 aA	0.449 aB	0.407 aC	0.369 aD

Statistical comparison: lowercase in columns; capital letters in lines.

Table 3. Variation of *Pinus taeda* wood density for interaction between old age and radial position.

Tabela 3. Variação da densidade básica de *Pinus taeda* para interação entre os fatores idade e posição radial.

Age (years)	Radial Position		
	Intenal	Central	External
8	0.294 cC	0.329 cB	0.373 dA
14	0.341 bC	0.382 bB	0.456 cA
18	0.314 cC	0.380 bB	0.497 bA
26	0.371 aC	0.420 aB	0.550 aA

Statistical comparison: lowercase in columns; capital letters in lines.

Table 4. Variation of *Pinus taeda* wood density for interaction between longitudinal and radial position.

Tabela 4. Variação da densidade básica de *Pinus taeda* para interação entre as posições longitudinal e radial.

Longitudinal Position (%)	Radial Position		
	Intenal	Central	External
10	0.342 aC	0.414 aB	0.525 aA
DHB	0.338 aC	0.396 aB	0.529 aA
35	0.325 aC	0.372 bB	0.481 bA
55	0.323 aC	0.356 bB	0.430 cA
75	0.324 aB	0.345 bB	0.379 dA

Statistical comparison: lowercase in columns; capital letters in lines.

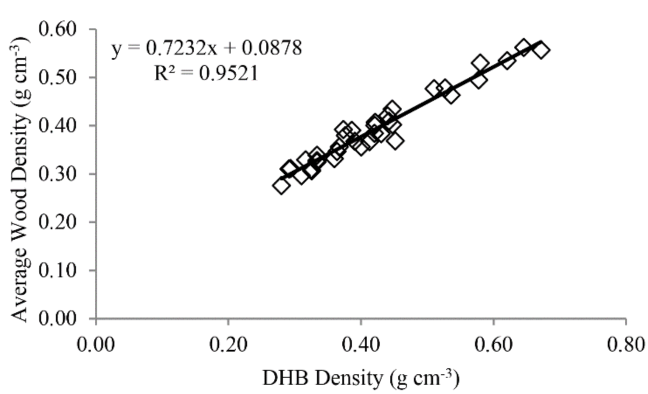

Figure 4. Correlation of average wood density of *Pinus taeda* by density the samples in 1.30 m height obtained.

Figura 4. Correlação entre a densidade média da madeira de *Pinus taeda* e a densidade das amostras obtidas do DAP.

effectively the mean density of these trees utilizing only DBH samples (Figure 4). In studies performed for *Pinus elliottii* wood, Melo et al. (2013) observed similar results.

It would be necessary to remove representative samples along the stem by presenting high variability within the same tree for a specific species density determination. Mendes et al. (1999) highlights that a tree cut procedure of a single sample to estimate the mean density may reduce significantly the sampling effort, without changing the results reliability.

4 Conclusions

The age, axial and radial position and its interactions factors significantly influence the density values for *Pinus taeda* wood; this wood density increases with age; reduces from basis to top; and increases from pith to bark; the DBH samples utilizations may be effectively used for wood mean density estimate.

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