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Apparent density of wood determined by two different methods in *Pinus caribaea* var. *hondurensis* and *Pinus tecunumanii*

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ABSTRACT: The aim of this study was to compare the apparent wood density obtained by two different methods in populations of Pinus caribaea var. hondurensis and Pinus tecunumanii, both 50 years old, located in Itirapina, SP. For this purpose, five trees of each species were selected. From each tree, two discs of 7 cm thickness were removed in the diameter at breast height (DBH) region. To determine the apparent density by the gravimetric method, samples were collected at five different positions, from pith to bark, on one of the discs. The other disc was used to obtain the radial profile of apparent wood density, using the X-ray Densitometry method. The results revealed that the apparent density did not differ significantly between the species. Variations in apparent density were observed from pith to bark in the trunks of both species, with a tendency of increasing density towards the bark. Furthermore, positive correlations between radial position and apparent density were observed in both species. The methodologies used to obtain the apparent density showed a high correlation between them, allowing for estimates with good precision. It is worth noting that the apparent density obtained by the gravimetric method showed significantly higher values than the X-ray densitometry method.

Densidade aparente da madeira determinada por dois métodos diferentes em *Pinus caribaea* var. *hondurensis* e *Pinus tecunumanii*

RESUMO: O objetivo deste estudo foi comparar a densidade aparente da madeira, obtida por dois métodos distintos, em populações de *Pinus caribaea* var. *hondurensis* e *Pinus tecunumanii*, ambos com 50 anos de idade, localizados em Itirapina, SP. Para isso, foram selecionadas cinco árvores de cada espécie. De cada árvore, foram retirados dois discos de 7 cm de espessura na região do diâmetro à altura do peito (DAP). Para determinar a densidade aparente pelo método gravimétrico, foram coletadas amostras em cinco posições diferentes, no sentido medula-casca, em um dos discos. O outro disco foi utilizado para obter o perfil radial de densidade aparente do lenho das árvores, utilizando o método de Densitometria de Raios X. Os resultados revelaram que a densidade aparente não difere significativamente entre as espécies. Observou-se variações na densidade aparente no sentido medula-casca dos troncos das árvores de ambas as espécies, com uma tendência de aumento da densidade no sentido da medula para a casca. Além disso, em ambas as espécies, foram observadas correlações positivas entre a posição radial e a densidade aparente. As metodologias utilizadas para obter a densidade aparente mostraram uma alta relação entre elas, possibilitando estimativas com boa precisão. Vale ressaltar que a densidade aparente obtida pelo método gravimétrico apresentou valores significativamente maiores do que o método da densitometria de raios X.

Introduction

In Brazil, between 1960 and 1970, plantations with fast-growing exotic species of the genus *Pinus* were expanded to increase wood stocks in order to supply the industrial timber sector (Shimizu and Sebbenn 2008). Several species of this genus were implanted in Brazil, some of them with good silvicultural potential due to their wide edaphoclimatic adaptation and high productivity, providing wood for various uses, such as sawn wood, panels, laminates, cellulose pulp, paper and resin (Braga et al. 2020, Lorenzi et al. 2018).

Pine plantations occupy 1.9 million hectares and are concentrated in Paraná (37%), Santa Catarina (36%) and São Paulo (7.9%) (IBÁ 2022). Among those species with aptitude for the production of wood for industrial use, we have *Pinus tecunumanii*, which has great potential for commercial plantations due to the good development it already presented (Shimizu and Sebbenn 2008). It comes from Mexico, Guatemala, Belize, Honduras, El Salvador and Nicaragua, and generally grows in regions with altitudes between 600 and 2,600 m (Shimizu and Sebbenn 2008; Nilsson et. al. 2020). In Brazil, this species is cultivated in the Southeast and Midwest regions, in regions above 500 m altitude, where its average annual increment is 15 m^3 /ha (Lorenzi et al. 2018). *Pinus tecunumanii* is characterized by having a yellowish wood of excellent quality for use in civil construction, cellulose pulp, and it can also be used for landscaping in general (Lorenzi et al. 2018, Kronka et al. 2005, Shimizu and Sebbenn 2008). Its wood normally presents internal variation in density, both in the pith-bark direction and in the longitudinal direction of the trunk; however, this variation is smaller than other species of the genus *Pinus* (Shimizu and Sebbenn 2008).

Another species within the Pinus genus, exhibiting promising potential for wood production, is Pinus caribaea var. hondurensis. Originating from Belize, Guatemala, Honduras, and Nicaragua, this species typically thrives across altitudes ranging from sea level up to 850 m. In Brazil, it stands as one of the most widely cultivated species, largely owing to the ease of seed procurement (Kronka et al. 2005). It produces white or yellowish wood, it can be used for resin coating, civil construction and landscaping in general. Its wood is of moderate to low density, but of great general utility in the industrial timber sector (Lorenzi et al. 2018, Santos et al. 2018).

Despite the existing information, more studies are still essential, especially those referring to the quality of wood from pine species, with emphasis on the density of the wood, which helps in determining the potential for commercial use. In the production of wood for industrial use, the aim must be to obtain better quality, which implies the incorporation of new parameters for evaluating the suitability of wood for solid use. However, wood density continues to be the main parameter for assessing its quality, as it determines the amount of water mass that is removed during drying, also affecting diffusion through the woody material. High wood density values generally imply slower water loss due to less voids (Latorraca et al. 2000, Yang and Liu 2018).

A fundamental issue to define the quality of wood for industrial use is to know what proportion of juvenile wood exists in a log and how its variation behaves in the pith-bark direction. This is a characteristic that fundamentally depends on the age of the tree, as well as on the environment and management. However, at the same age and under similar environmental and management conditions, it can be seen that there is great variability in this proportion (Malan 1995, Modes et al. 2019). Pine species, with production cycles longer than 30 years, are economically viable and can be an interesting option for log producers who aim to access specific markets, in which the quality of wood for solid and structural purposes could be even better remunerated (Vivian et al. 2022).

One of the main study techniques for the characterization of wood density is the X-ray densitometry methodology, this technique has the advantage of having a permanent radiographic record of the wood samples and high sensitivity and resolution. Allied to data processing speed and interpretation through radial density profiles, it can be very useful in studies that focus on the proportion of juvenile wood and its variations (Tomazello Filho et al. 2005).

Thus, the objective of this work was to characterize the variation in the pith-bark direction of the apparent density obtained by two different methods in 50-year-old *Pinus caribaea* var. *hondurensis* and *Pinus tecunumanii* woods.

Material and Methods

In this research, wood samples were obtained from experimental planting trees of *Pinus caribaea* var. *hondurensis* and *Pinus tecunumanii*, from the region of Itirapina SP, aged 50 years. The study area is located between latitudes 22°00'S and 22°15'S and longitudes 47°45'W and 48°00'W. The soils are deep quartz sand and hydromorphic (Santos et al. 2018). The climate in the region is tropical with a dry winter (Cwa), featuring an average temperature of 19.3°C. The region boasts an average altitude of 801 meters and an average annual rainfall of 1,377 mm (Alvares et al. 2013).

Samples were collected from five trees of each selected species following the mean diameter at breast height DBH (1.30 m from the ground). From each selected tree, two discs of 7 cm thick at DBH height were removed (Table 1).

Table 1. Average values of diameters at breast height (DBH) and total heights (TH) of trees sampled in populations of 50-year-old *Pinus caribaea* var. *hondurensis* and *Pinus tecunumanii*.

Pinus tecunumanii			*Pinus caribaea var. hondurensis*		
Tree	DBH (cm)	TH (m)	Tree	DBH (cm)	TH (m)
1	27.76	27.00	1	31.69	32.00
2	30.30	30.00	2	21.79	22.00
3	33.30	33.00	3	18.63	19.00
4	21.82	22.00	4	20.38	21.00
5	22.15	23.00	5	26.35	27.00
mean	27.07	27.00	mean	23.77	24.20
standard deviation	5.04	4.64	standard deviation	5.27	5.26

In one of the discs, a representative sample block was removed from the pith region to the bark. From the sample block, five samples measuring 2 cm x 2 cm x 3 cm were taken, representing positions 0, 25, 50, 75 and 100% of the tree's radius, to study the pith-bark variation in apparent density.

Determination of apparent density gravimetric method by direct measurement

For the determination of the apparent density by the gravimetric method by direct measurement (AD_{DM}), the samples of (2 x 2 x 3) cm were dried until they reached 12% of humidity, to obtain the weight of the dry mass. The dimensions of the samples were measured with a digital caliper with a sensitivity of 0.01 mm, and the dry mass was measured on a semi-analytical scale, with a sensitivity of 0.01 g, NBR 7190-4 (ABNT 2022).

X-ray densitometry of the wood of Pinus caribaea var. hondurensis and Pinus with resin extraction to determine apparent density

The other disc obtained was used for the X-ray densitometry study, to obtain the radial profile of the apparent density (AD_{XR}). These procedures were carried out at the Laboratory of Anatomy, Identification and Densitometry of X-rays in Wood of the Escola Superior de Agricultura “Luiz de Queiroz” - University of São Paulo.

To obtain the radial profile of apparent wood density of *Pinus caribaea* var. *hondurensis* and *Pinus tecunumanii*, the cross section of the discs was demarcated and specimens (2.0 cm wide) were cut in diametric alignment (bark-bark). The specimens were glued onto a wooden support and sectioned transversely (1.6 mm thick) using a double parallel circular saw. Then, the wood samples were identified with an ink pen and the resin was extracted using Soxhlet equipment (8 hours in 1:1 alcohol-toluene solution, 8 hours in alcohol, and 8 hours in boiling water). The samples were dried at room temperature and transferred to an acclimatization room and conditioned (20ºC, 60%RH, 24 h) (Amaral and Tomazello Filho 1998). The samples were fitted in a metallic support and transferred to the internal and shielded compartment contained in the equipment, being carried out its calibration and continuous scanning of the radial profile through a collimated X-ray beam, the X-ray values were transformed into apparent density using QMS software. The punctual values of apparent density of the wood were observed together with the image of the cross-section of the wood samples (QMS 1999). After obtaining the values of apparent radial density by the QMS software, an analysis report file was obtained with specific values of apparent density of the wood at every 80 microns, called DAT. Using the Excel software, it was possible to read the DAT file, constructing radial profiles of apparent density of the wood of *Pinus caribaea* var. *hondurensis* and *Pinus tecunumanii* (QMS 1999).

For the purpose of comparing the two methodologies, the average values of the apparent density obtained by X-ray densitometry, corresponding to the positions of samples taken from the disks, these values were considered to obtain the apparent density by the gravimetric method by direct measurement.

Statistical analysis

In the evaluation of the experiment, the variance homogeneity test was initially applied using the Hartley test. Subsequently, analysis of variance was performed and, when a significant difference was observed, Tukey's test and Student's t test were applied for each specific situation to compare means. The F test was used to determine the means that differed from each other, whenever a significant difference was observed at the 5% probability level of the treatments, and Student's t test was applied at the 95% significance level.

A study of relationships between the evaluated properties was carried out using regression analysis, at a significance level of 95%. The results obtained from the apparent densities were statistically analyzed with the aid of the statistical procedure PROC GLM and PROC REG of the SAS statistical program (SAS 1999).

Results and discussion

Densitometry of Pinus tecunumanii and Pinus caribaea var. hondurensis

Wood images of the densitometric profile of *Pinus tecunumanii* and *Pinus caribaea* var. *hondurensis*, allowed the characterization of the radial variation of the apparent density (Figures 1 and 2).

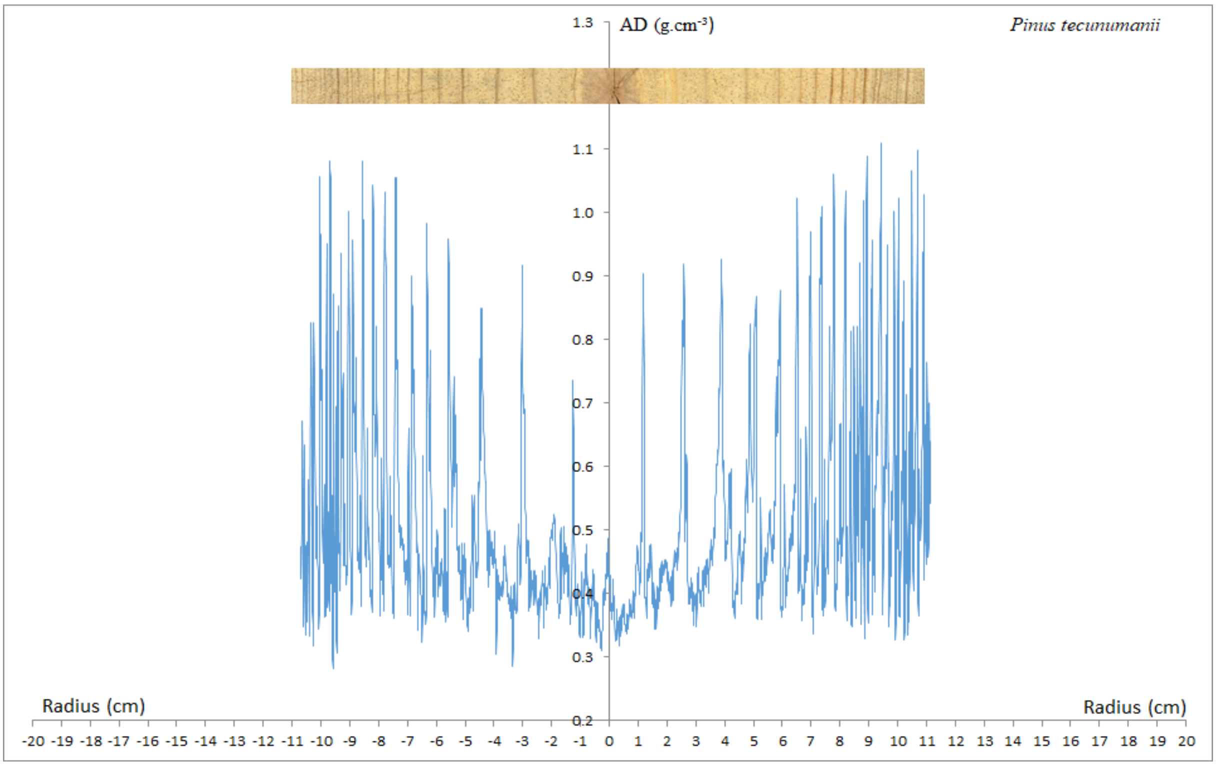

Figure 1. Diametral densitometric profile of the disc of the 50-year-old *Pinus tecunumanii* tree chosen randomly among those sampled.

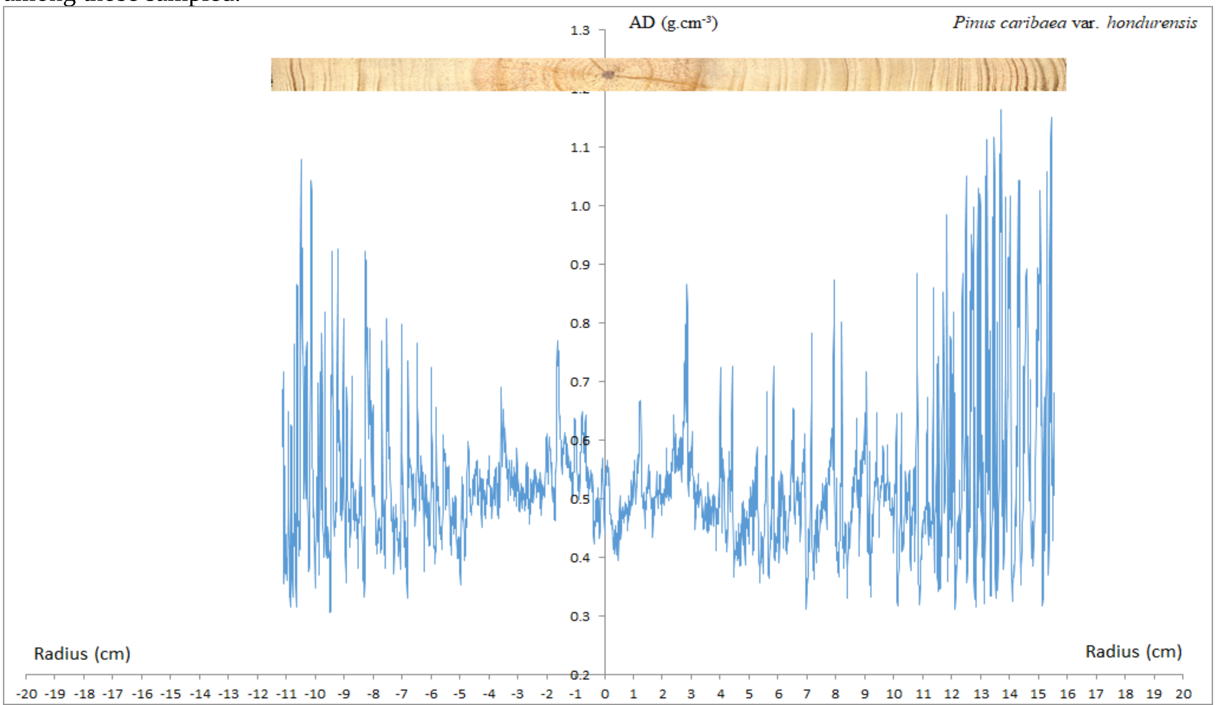

Figure 2. Diametral densitometric profile of the disc of 50-year-old *Pinus caribaea* var. *hondurensis* chosen randomly among those sampled.

According to the apparent density determination, the densitometric profile of the wood of *Pinus tecunumanii* and *Pinus caribaea* var. *hondurensis* was characteristic and revealed a reduction in the density values that coincided with the demarcation of the limits of the growth rings, which is an indication of variations in the anatomical structure of the wood, showing distinct growth rings, constituted by early and late wood, this being of higher apparent density. It can also be seen a trend towards an increase in the specific density value in the pith-bark direction (Figures 1 and 2). Apparent density values of the order of 02-05 g.cm^{-3} and 08-1.2 g.cm^{-3}, for the early and late woods of the growth rings of *Pinus caribaea* var. *hondurensis*, were obtained by Belini et al. (2011), whose values were similar to those observed in Figure 2.

The average values of apparent density obtained by the X-ray densitometry method, for each species, are shown in Figure 3.

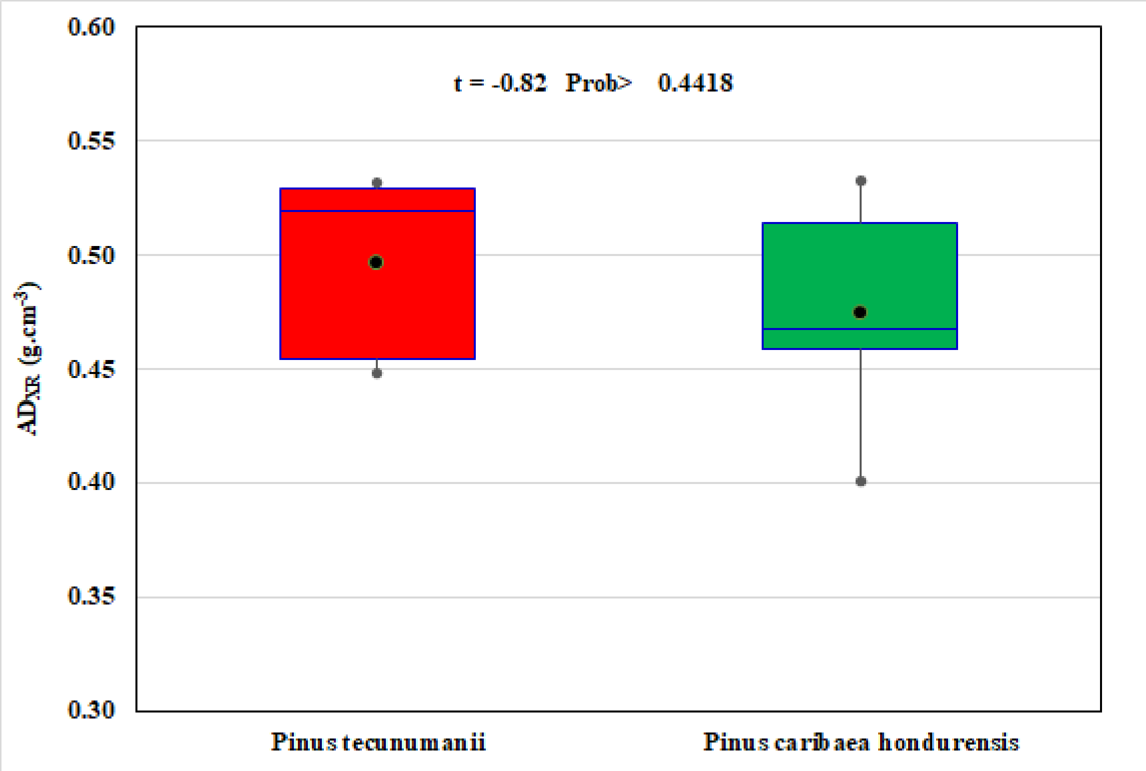

Figure 3. Comparison between the apparent wood density of 50-year-old *Pinus tecunumanii* and *Pinus caribaea* var. *hondurensis* obtained by X-ray densitometry of tree wood.

In the analysis of the average apparent density obtained by X-ray, no significant difference was observed between the Pinus species (Figure 3).

Comparison of methodologies for obtaining Apparent Density

Table 2 shows the analysis of variance performed for apparent density of *Pinus tecunumanii* and *Pinus caribaea* var. *hondurensis*. According to the observed results, there were no significant differences, at a 5% probability level, between the species. However, differences were found between the radial positions on the tree trunk (Table 2). When comparing the methodology, a significant difference was found between the adopted methods (Table 2). It was also observed that the effects of species x methodology x radial position interaction were not significant for apparent density (Table 2). So, there is no dependence between these factors, which demonstrates that the apparent density variation pattern is the same for all treatments (Table 2).

Table 2. Summary of analysis of variance for apparent density (AD$_{DM}$) of 50-year-old *Pinus caribaea* var. *hondurensis* and *Pinus tecunumanii*.

Causes of variation	DF	Mean squares AD$_{DM}$ (g.cm^{-3})
Species (S)	1	0.0093$^{n.s.}$
Radial position (RP)	4	0.0106**
(S) x (RP)	4	0.0033$^{n.s.}$
Methodology (M)	1	0.0571**

(S) x (M)	1	0.0001 n.s.
(RP) x (M)	4	0.0013 n.s.
(S) x (RP) x (M)	4	0.0009n.s.
Mean		0.51
CV_e (%)		11.04

n.s.: not significant *: significant at the 5% significance level and CVe: coefficient of experimental variation.

It was verified that there was no significant variation for apparent density between the two species under study according to the average values presented for this property (Table 3). Trianoski et al. (2013) observed values of 0.58 $g.cm^{-3}$ and 0.50 $g.cm^{3}$, respectively, in *Pinus tecunumanii* and *Pinus caribaea* var. *hondurensis*, aged 18 years, with these values being higher than those observed in this study at the age of 50 years. However, there are cases in which the interaction of age with environmental factors significantly influenced the wood density values of *Pinus taeda*, with wood density increasing with age (Melo 2015).

Table 3. Means for apparent density (AD) of 50-year-old *Pinus caribaea* var. *hondurensis* and *Pinus tecunumanii*.

Treatment	**AD ($g.cm^{-3}$)**
Pinus tecunumanii	0.52 a
Pinus caribaea var. hondurensis	0.50 a
Radial position (0%)	0.42 c
Radial position (25%)	0.45 c
Radial position (50%)	0.52 b
Radial position (75%)	0.56 ab
Radial position (100%)	0.59 a
Gravimetric method by direct measurement	0.53 a
X-Ray densitometry methodology	0.49 b

Means followed by different letters in the same column differ from each other (at the 5% significance level).

We can consider that these species produce light wood (Zenid 2007). According to the consulted literature, it was to be expected that *Pinus tecunumanii* would present higher density values in relation to *Pinus caribaea* (Trianoski et al. 2013). However, this difference between the species was not significant to the point of being statistically different (Table 3). One possible explanation would be that genetic factors were not influential enough to differentiate the apparent density of wood among the species (Moura et al., 2004).

From the analysis of Table 3, it is possible to observe the variations of the apparent density in function of the radial position. We can see that the values tend to increase from pith to bark, where the lowest values are close to the pith and the highest near the bark. In general, according to the literature, *Pinus* species show an increase in wood density in the pith-bark direction (Souza et al. 2007 and Rios et al. 2018).

The apparent density values obtained by the two methodologies differed significantly, where the values obtained by the gravimetric method by direct measurement were higher than those obtained by the X-Ray densitometry methodology (Table 3). Similar results were obtained in OSB panels of *Pinus taeda* and *Pinus elliottii* var. *elliottii* × *Pinus caribaea* var. *hondurensis*, where the apparent density obtained by the gravimetric method showed significantly higher results than the densitometric method (Surdi et. al. 2014). One of the reasons for the difference between the methodologies would be the fact that in order to determine the apparent density using the X-Ray densitometry methodology, the samples had to go through the process of removing the resin and this could be the cause of the reduction in apparent density values (Surdi et. al. 2014).

In the regression study in order to verify if there is a relationship between the methodologies for obtaining the apparent density separately by species and methodology, it showed that both for *Pinus caribaea* and for *Pinus tecunumanii* the methodologies for obtaining the apparent density have a high relationship between them, being possible to estimate with good precision the apparent density determined by the X-ray densitometry method with the apparent density obtained by the gravimetric method by direct measurement (Figures 4 A and B).

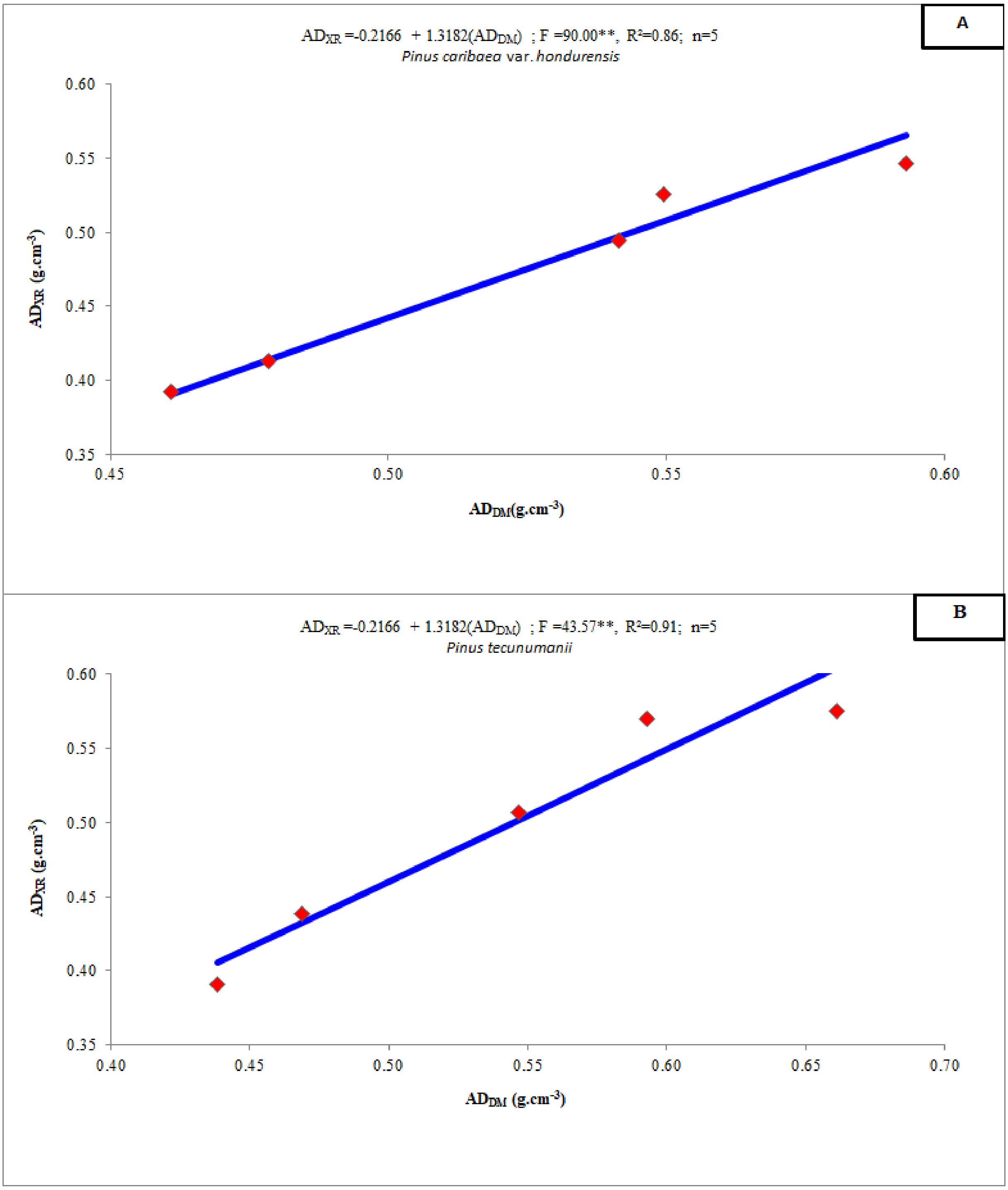

Figure 4. Relations between methodologies for obtaining apparent density in 50-year-old *Pinus caribaea* var. *hondurensis* (A) and *Pinus tecunumanii* (B).

To better explain this tendency of apparent density to increase from pith towards bark, a regression analysis was also performed between radial position (in cm) and apparent density separately by species and methodology (Figures 5A and B).

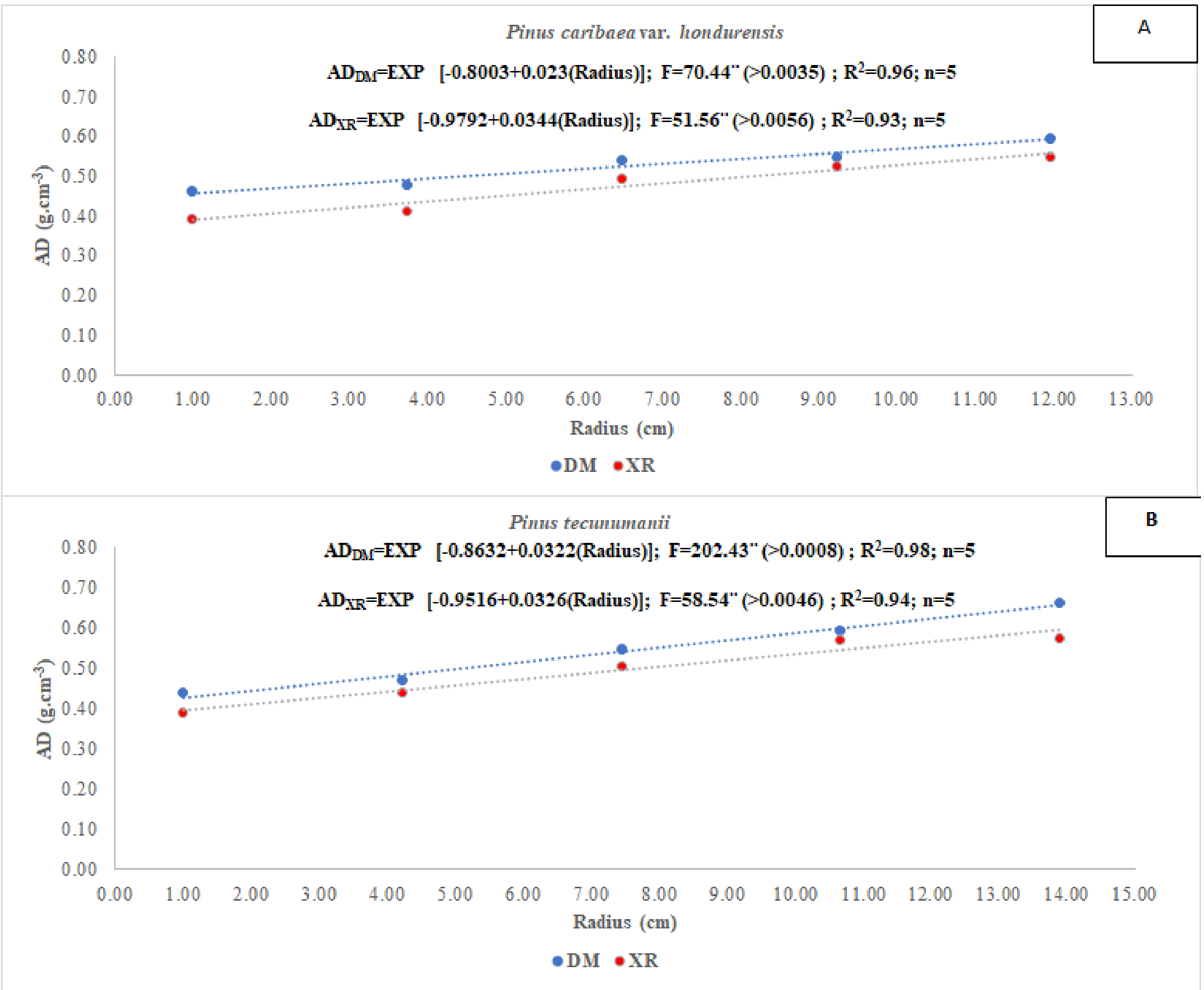

Figure 5. Relationship between radial position (Radius in cm) and apparent density as a function of methodology for 50-year-old *Pinus caribaea* var. *hondurensis* (A) *Pinus tecunumanii* (B).

For both species and methodologies for obtaining the apparent density, it can be seen that there was an increase in the pith-bark direction (Figures 5A, 4B). This can be explained by the proportional increase of mature wood in relation to juvenile wood. The one with low density may be associated with the large presence of juvenile wood (Modes et al. 2019).

For *Pinus taeda*, wood density also increased in the pith-bark direction (Ballarin and Palma 2003; Souza et al. 2007). It has also been found that the density of wood in the radial direction, from the inside to the outside, increased in *Pinus patula* (Rios et al., 2018). This same trend was observed in *Pinus elliottii*, where the radial position significantly influenced the density values, with wood density increasing in the pith-bark direction (Melo et al. 2013). For *Pinus caribaea* var. *hondurensis* density increases in the pith-bark direction, and this occurs due to the decrease in the thickness of the growth rings in the pith-bark direction (Gonçalez et al. 2018). The apparent density of *Pinus caribaea* var. *hondurensis* tends to differentiate over the years, but after a certain age there is a stabilization (Correa and Bellote 2011).

The exponential regression model best represented the relationships between apparent density and radial position (Figures 5A and 4B). As can be seen, we have a strong dependence between radial position and apparent density for both species (Figures 5A and 4B). According to the obtained equations, the apparent density obtained by the two methodologies can be estimated as a function of the radial position.

Conclusions

According to the results presented, it can be concluded that:

Apparent density does not differ significantly between *Pinus tecunumanii* and *Pinus caribaea* var. *hondurensis*;

The apparent density varies from the pith to the bark of the trunks;

For *Pinus caribaea* var. *hondurensis* there are positive correlations between radial position and apparent density;

In relation to *Pinus tecunumanii* there is also a positive correlation: radial position with apparent density;

For *Pinus tecunumanii* and *Pinus caribaea* var. *hondurensis* the apparent density shows a tendency to increase from pith to bark;

The methodologies for obtaining apparent density have a high relationship between them, making it possible to estimate them with good precision, and

The apparent density obtained by the gravimetric method presents significantly higher values than the X-ray densitometry method.

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References

ABNT. Associação Brasileira de Normas Técnicas (2022) *ABNT NBR 7190-4*: Projeto de estruturas de madeira – Parte 4: Métodos de ensaio para caracterização peças estruturais. Rio de Janeiro: ABNT.

Alvares CA, Stape JL, Sentelhas PC, Gonçalves JLM, Sparovek G (2013) Köppen's climate classification map for Brazil. *Meteorologische Zeitschrift*, 22(6): 711-728.

Amaral, ACB, Tomazello Filho, M (1998) Avaliação das características dos anéis de crescimento de *Pinus taeda* pela técnica de microdensitometria de raios X. *Revista de Ciência de Tecnologia*, 6(11/12): 17-23.

Belini UL, Tomazello Filho M, Castro VR, Muniz GIB, Lasso PRO, Vaz CMP (2011) Microtomografia deraios X (microCT) aplicada na caracterização anatômica da madeira de folhosa e de conífera. *Floresta e Ambiente*, 18(1): 30-6.

Braga RC, Paludeto JGZ, Souza BM, Aguiar AV, Pollnow MFM, Carvalho AGM, Tambarussi EV (2020) Genetic parameters and genotype × environment interaction in *Pinus taeda* clonal tests. *Forest Ecology and Management*, 474: e118342.

Corrêa RS, Bellote AFJ (2011) Influência do solo na dimensão dos traqueídeos e densidade da madeira em *Pinus caribaea* var. *hondurensis*. *Pesquisa Florestal Brasileira*, 31(66): 93-102. doi: dx.doi.org/10.4336/2011.pfb.31.66.93.

Goncalez JC, Santos N, Silva Junior FG, Souza RS, De Paula MH (2018) Growth ring width of *Pinus caribaea* var. *hondurensis* and its relationship with wood proprieties. *Scientia Forestalis*, 46(118): 309-317. doi: dx.doi.org/10.18671/scifor.v46n118.16.

IBÁ. Indústria Brasileira de Árvores (2023) Relatório Ibá 2013. São Paulo: Ibá. 90 p. Disponível em:<https://www.iba.org/datafiles/publicacoes/relatorios/relatorio-anual-iba2023-r.pdf. Acesso em: 02 abr. 2024.

QMS. QMS Tree Ring Analyzer Model QTRS-01X. *Users Guide*. Quintek Measurement Systems, Knoxville, TN. 1999.

Kronka FJN, Bertolani F, Ponce RH (2005) *A cultura de Pinus no Brasil*. São Paulo: Páginas & letras. Sociedade Brasileira de Silvicultura. p. 154.

Latorraca JVF, Albuquerque CEC (2000) Efeito do rápido crescimento sobre as propriedades da madeira. *Floresta e Ambiente*, 7(1): 279-291.

Lima, IL, Oliveira, IR, Barbosa, JÁ, Ranzini, M (2020) Variação em propriedades da madeira de *Pinus caribaea* var. *hondurensis* e *Pinus tecunumanii*. *Advances in Forestry Science*, 7: 1231-1247.

Lorenzi H, Bacher LB, Torres MAV (2018) *Árvores e Arvoretas exóticas no Brasil*: madeireiras, ornamentais e aromáticas. Nova Odessa: Instituto Plantarum. 464 p.

Malan FS (1995) Eucalipts improvement for lumber production. In: I Seminário Internacional e Utilização da Madeira de Eucalipto para Serraria, Piracicaba, Brasil.

Melo RR (2015) Radial and longitudinal variation of *Pinus taeda* L. wood basic density in different ages. *Revista de Ciências Agrárias*, 58(2): 192-197. doi.editoracubo.com.br/10.4322/rca.1839.

Melo RR, Silvestre R, Oliveira TM, Pedrosa TD (2013) Variação radial e longitudinal da densidade básica da madeira de *Pinus elliottii* Engelm. com diferentes idades. *Revista Ciência da Madeira*, 4(1): 83-92. doi: dx.doi.org/10.15210/cmad.v4i1.4057.

Modes, KS, Ludwig, RL, Vivian, MA, Stolberg, J (2019) Wood quality of *Pinus patula* schltdl & cham for the pulp production. *Revista Árvore*, 43 (2): e430207.

Moura, VPG, Vale, ATD, Isaias, FB (2004) Comparação entre dois métodos de avaliação da variabilidade genética em volume, densidade básica da madeira e matéria seca de *Pinus Tecunumanii* (schwd) Eguiluz e Perry. *Ciência Florestal*, 14(1), 77-84.

Rios PDA, Vieira HC, Pereira GF, Turmina E, Nicoletti MF (2018) Variação radial e longitudinal da densidade básica da madeira de *Pinus patula*. *Pesquisa Florestal Brasileira*, 38(1): 1-5. doi: dx.doi.org/10.4336/2018.pfb.38e201501016.

Santos HG, Jacomine PKT, Anjos LHC, Oliveira VA, Lumbreras JF, Coelho MR, Almeida JA, Araujo Filho JC, Oliveira JB, Cunha TJF (2018) *Sistema brasileiro de classificação de solos*. Embrapa: Brasília (in Portuguese).

Santos W, Silva MSC, Deniz LD, Kieras WS, Shimizu JY, Sousa VA, Aguiar AV (2018) Identificação de procedências e progênies de *Pinus maximinoi* com potencial produtivo para madeira. *Scientia Forestalis*, 46(117): 127-136. doi: dx.doi.org/10.18671/scifor.v46n117.12.

SAS. Statistical Analysis System (1999) *SAS Procedures guide*: version 8 (TSMO). Cary: SAS.

Sebbenn AM, Shimizu JY, Aguiar AV (2008) *Produção de resina de Pínus e melhoramento genético*. In: Shimizu JY. Pínus na silvicultura brasileira. Colombo: Embrapa. p. 49-74.

Sousa RC, Giovanini EP, Lima IL, Florsheim SMB, Garcia JN (2007) Efeito da idade e da posição radial na densidade básica e dimensões dos traqueídeos da madeira de *Pinus taeda* L. *Revista do Instituto Florestal*,19(2): 119-127.

Nilsson O, Hodge G R, Frampton LJ, Dvorak WS, Bergh J (2020). Growth and modulus of elasticity of pine species and hybrids three years after planting in South Africa. *Southern Forests*: a Journal of Forest Science, 82(4), 367-376.

Surdi PG, Bortoletto Jr G, Castro VR, Mendes RF, Almeida NFD, Tomazello Filho M (2014) Relação entre perfil de densidade e ligação interna de painéis OSB de *Pinus* spp. *Floresta e Ambiente*, 21: 349-357.

Tomazello Filho M, Chagas MP, Roque RM (2005) *Manual de aplicação de densitometria de raios X em amostras de madeira, CRAD e CERD*. Piracicaba. 32 p.

Trianoski R, Matos JLM, Iwakiri S, Prata JG (2014) Avaliação das propriedades mecânicas da madeira de espécies de Pinus tropicais. *Scientia Forestalis*, 42 (101): 21-28.

Trianoski R, Matos JLM, Iwakiri S, Prata JG (2013) Variação longitudinal da densidade básica da madeira de espécies de Pinus tropicais. *Floresta*, 43(3): 503-510. doi: d.doi.org/10.5380/rf.v43i3.282 52.

Vivian MA, Dobner Júnior M, Modes KS, Belini UL, Vaz DR (2022) Ciclos de produção de *Pinus taeda* L. com mais de 30 anos: uma alternativa para obtenção de madeira para usos sólidos e estruturais. *Ciência Florestal*, 32(2): 573-596. doi: 10.5902/1980509842430.

Yang L, Liu H (2018) A review of eucalyptus wood collapse and its control during drying. BioResources 13: 2171-2181. doi: doi.org/10.15376/biores.13.1.Y ang.

Zenid GJ (2007) Madeiras e suas características. In: Oliveira JTS, Fiedler NC, Nogueira M (ed). *Tecnologías aplicadas ao setor madeireiro*. Jerônimo Monteiro: Suprema Gráfica e Editora Ltda. p. 129-163.