Research, Society and Development, v. 12, n. 9, e7712943146, 2023
(CC BY 4.0) | ISSN 2525-3409 | DOI: http://dx.doi.org/10.33448/rsd-v12i9.43146

Physical and mechanical wood properties of two varieties of *Pinus caribaea*

Propriedades físicas e mecânicas da madeira de duas variedades de *Pinus caribaea*

Propiedades físicas y mecánicas de la madera de dos variedades de *Pinus caribaea*

Received: 08/25/2023 | Revised: 09/12/2023 | Accepted: 09/14/2023 | Published: 09/16/2023

Israel Luiz de Lima
ORCID: https://orcid.org/0000-0002-4868-6414
Instituto de Pesquisas Ambientais, Brasil
E-mail: israellima@sp.gov.br
Maurício Ranzini
ORCID: https://orcid.org/0000-0001-8795-7013
Instituto de Pesquisas Ambientais, Brasil
E-mail: ranzini@sp.gov.br
Wilson José Fioruci
ORCID: https://orcid.org/0009-0007-6784-1604
Instituto de Pesquisas Ambientais, Brasil
E-mail: wilsonfioruci@fflorestal.sp.gov.br
Luís Alberto Bucci
ORCID: https://orcid.org/0000-0001-7311-0778
Instituto de Pesquisas Ambientais, Brasil
E-mail: bucci@sp.gov.br
Eduardo Luiz Longui
ORCID: https://orcid.org/0000-0002-7610-9147
Instituto de Pesquisas Ambientais, Brasil
E-mail: elongui@sp.gov.br
Marcelo Zanata
ORCID: https://orcid.org/0000-0003-0124-187X
Instituto de Pesquisas Ambientais, Brasil
E-mail: marcelo.zanata@sp.gov.br
José Nivaldo Garcia
ORCID: https://orcid.org/0000-0002-8289-9042
Universidade de São Paulo, Brasil
E-mail: jngarcia@usp.br

Abstract
This study aimed to characterize the properties of wood from *Pinus caribaea* var. *hondurensis* and *Pinus caribaea* var *bahamensis*, in 7-year-old individuals, in the municipality of Batatais, State of São Paulo, Brazil. For this, twelve trees of each species/variety were felled, and a 1 m long log was removed from the base of each tree. Samples were taken from the obtained logs to evaluate the physical-mechanical properties of the wood. It was verified that the woods of *Pinus caribaea* var. *hondurensis* and *Pinus caribaea* var. *bahamensis* do not differ significantly from each other for: Apparent density, basic density, compression parallel to the grain, shear parallel to grain, modulus of elasticity, volumetric shrinkage, anisotropy coefficient, radial shrinkage, and tangential shrinkage. The wood of the species/variety *Pinus caribaea* var. *bahamensis* showed a significantly higher modulus of rupture than the variety *Pinus caribaea* var. *hondurensis*. Regarding the use of wood from these species/variety, at a younger age, both showed potential use for different purposes. Since this initial assessment can be used as an indication of pre-selection of wood for the various segments of the timber industry, mainly for uses that do not have many restrictions in structural applications and dimensional variation.
Keywords: Pine; Wood density; Physical-mechanical resistance; Dimensional variation.

Resumo
Este estudo teve como objetivo caracterizar as propriedades da madeira de *Pinus caribaea* var. *hondurensis* e *Pinus caribaea* var *bahamensis*, em indivíduos de 7 anos de idade. Para isso, foram coletadas doze árvores de cada variedade, município de Batatais, estado de São Paulo, Brasil, e destas retiradas uma tora de 1 m de comprimento da base de cada uma das árvores. Das toras obtidas foram retiradas amostras para avaliar as propriedades físicas-mecânicas das madeiras. Foi verificado que as madeiras de *Pinus caribaea* var. *hondurensis* e o *Pinus caribaea* var. *bahamensis* não diferem significativamente entre si para: a densidade aparente, densidade básica, resistência à compressão, cisalhamento, modulo de elasticidade, retração volumétrica, coeficiente de anisotropia, retração radial e retração tangencial. A madeira de *Pinus caribaea* var. *bahamensis* apresentou módulo de ruptura significativamente maior do que a variedade *Pinus caribaea* var. *hondurensis*. Em relação à utilização da madeira desses materiais, em

idade mais jovem, ambos apresentaram potencial de utilização para diversas finalidades, sendo que, essa avaliação inicial pode ser utilizada como o índice de pré-seleção de madeira para os diversos segmentos da indústria madeireira, principalmente para usos que não tenham muitas restrições em aplicações estruturais e de variação dimensional.
Palavras-chave: Pinho; Densidade da madeira; Resistência físico-mecânica; Variação dimensional.

Resumen
Este estudio tuvo como objetivo caracterizar las propiedades de la madera de *Pinus caribaea* var. *hondurensis* y *Pinus caribaea* var *bahamensis*, en individuos de 7 años de edad, en el municipio de Batatais, estado de São Paulo, Brasil. Para ello se talaron doce árboles de cada especie/variedad, y de la base de cada árbol se extrajo un tronco de 1 m de largo. De los troncos obtenidos se tomaron muestras para evaluar las propiedades físico-mecánicas de la madera. Se verificó que los bosques de *Pinus caribaea* var. *hondurensis* y *Pinus caribaea* var. *bahamensis* no difieren significativamente entre sí en: densidad aparente, densidad básica, resistencia a la compresión, resistencia al corte, módulo de elasticidad, contracción volumétrica, coeficiente de anisotropía, contracción radial y contracción tangencial. La madera de la especie/variedad *Pinus caribaea* var. *bahamensis* mostró un módulo de ruptura significativamente mayor que la variedad *Pinus caribaea* var. *hondurensis*. En cuanto al uso de la madera de estas especies/variedades, a edades más tempranas, ambas mostraron potencial de uso para diferentes propósitos, y esta evaluación inicial puede usarse como una indicación de preselección de madera para los distintos segmentos de la industria maderera. principalmente para usos que no tengan muchas restricciones en aplicaciones estructural y de variación dimensional.
Palabras clave: Pino; Densidad de la madera; Resistencia físico-mecánica; Variación dimensional.

1. Introduction

The increased demand for wood has led to a search for new species with silvicultural potential. Among the various species that were introduced as alternatives to hardwoods that were excessively exploited, as well as to supply the high volume of wood consumed in the various segments of the timber sector, we have *Pinus* spp. (Trianoski et al., 2014). The area planted with *Pinus* in Brazil has been increasing significantly, reaching 1,930,055 ha in 2021 and a productivity of 29.7 $m^3.ha^{-1}.year^{-1}$ (Indústria Brasileira de Árvores - IBÁ, 2022).

Among the *Pinus* species planted in Brazil, we have *Pinus caribaea* Morelet, this species covers three natural varieties: *caribaea*, *bahamensis* and *hondurensis* (Kronka et al., 2005). *Pinus caribaea* produces white or yellowish wood, with the possibility of resin extraction (Lorenzi et al., 2018). *Pinus caribaea* presents volumetric shrinkage around 12.9%, tangential shrinkage 7.8% and radial shrinkage 6.3% (Glass and Zelinka, 2021). In Uganda, *Pinus caribaea* wood is used for structural purposes, and even woods that come from plantations that have been burned are used in civil construction works if they do not have many restrictions in terms of mechanical resistance (Zziwa et al., 2020).

Pinus caribaea var. *hondurensis* was one of the most planted species in Brazil, due to the ease of obtaining seeds, the wood has a density classified as being moderate to low and, in general, is very useful for the timber industry (Kronka et al., 2005; Shimizu & Sebbenn, 2008). The initial growth of *Pinus caribaea* var. *hondurensis* is positively influenced by the increase in the variables: precipitation, solar radiation, real evapotranspiration, and relative humidity (Lima et al., 2022).

Pinus caribaea var. *bahamensis* stands out as one of the most important species to produce wood and resin in the southeastern region of Brazil, the wood of this species tends to be denser than the *hondurensis* variety, having a greater physical-mechanical resistance (Shimizu & Sebbenn, 2008). Some aspects must be considered in the production of pine wood for industrial use, such as variations in the proportion of juvenile wood, production age, volume of wood produced from each genetic variety, silvicultural practices, and population management, all these factors affect productivity and wood quality to be produced (Zanuncio et al., 2022).

Wood at a younger age tends to contain a greater proportion of juvenile wood than mature wood, therefore, structural pieces of wood that contain a greater amount of juvenile wood have lower mechanical strength classes. This being the reason why knowledge of the differences between the properties of juvenile and mature wood is so important for the use of mechanically processed wood. Another relevant question is to know the behavior of the dimensional variations of the wood, in which the juvenile and the adult wood behave, and in general, their behavior is slightly different (Vidaurre et al., 2012).

In general, we found that studies on the quality of *Pinus caribaea* wood are still scarce, mainly regarding the use of wood at a younger age, and which also aim to maximize wood production and raise the income of the producers who cultivate it. Therefore, the objective of this work was to characterize the physical and mechanical properties of *Pinus caribaea* wood at a younger age, depending on the variety and to provide basic subsidies for the best industrial use of this wood.

2. Methodology

2.1 Planting area and sampling

The study area is in the municipality of Batatais, São Paulo State, Brazil (20°56′01″S, 47°36′28″W, elevation 880m) (Zanata et al., 2015). According to the Köppen Climate Classification system, climatic type is Cwa, a warm subtropical climate with dry winter, with an average annual temperature of 20°C and an average rainfall of 1569 mm year^{-1} (Alvares et al., 2013). The Brazilian System of Soil Classification and the Pedological Map of São Paulo State indicate that the area under study has soil of medium texture, such as Latosol Red, Red Yellow (LVA31), Dystrophic, in soft wavy relief and Gleissolos in the alluvial floodplains (Santos et al., 2018; Rossi, 2017).

The trees selected for study were from a commercial plantation of 7-year-old *Pinus caribaea* of two varieties: *Pinus caribaea* var. *bahamensis* and *Pinus caribaea* var. *hondurensis*. Trees were planted at a spacing of 3.0 m x 3.5 m, in 22 and 12 hectares, respectively. We selected 24 trees, 12 of each species/variety, trees were selected in the medium DBH (1.3 m from the ground) class, in each species/variety (Table 1).

Table 1 - Diameter at breast height (DBH), total mean height of trees (TH) (standard deviation in brackets) in 7-year-old *Pinus caribaea* two varieties planted in Batatais, São Paulo, Brazil.

Species	Age (year)	DBH (cm)	TH (m)
Pinus caribaea var. *bahamensis*	7	14.26 (3.16)	9.13 (1.46)
Pinus caribaea var. *hondurensis*	7	13.96 (1.83)	9.83 (1.41)

Source: Authors.

Before trees were felled, the geographic North was marked on each stem to standardize sampling. From the chosen trees, the first log of 1 m in length was taken, properly identified, and marked. Subsequently, these logs were transported to the ESALQ/USP sawmill, Piracicaba, SP, where they were unfolded.

From each of the unfolded logs, a central plank 7 cm thick was taken. A batten measuring 4 cm x 4 cm x 1 m was removed from the region close to the bark, then a study was carried out to determine physical and mechanical properties, which specific specimens were removed for each test, and carried out at the Laboratory of Wood Engineering at ESALQ/USP (Figure 1).

Figure 1 - Schematic illustration of wood samples for analysis of physical-mechanical properties.

Source: Authors.

2.2 Wood physical property

Apparent density (ρ_{ap}) - Samples of 2 x 2 x 3 cm were obtained from the battens and dried until they reached 12% humidity, to obtain the apparent density. The dimensions of the samples were measured with a digital caliper with a sensitivity of 0.01 cm, and the mass of the specimen was obtained on a semi-analytical digital scale, with a sensitivity of 0.01 g, following the NBR 7190 standards (ABNT, 1997).

Basic Density (BD) - To obtain the basic density, samples of (3 x 2 x 5 cm) were used, and the hydrostatic balance method was used according to NBR 11941 (ABNT, 2003).

Dimensional variation of wood - The volumetric (β_v), radial (β_r), tangential (β_t) retractions and the anisotropy coefficient (β_t/β_r) were determined using samples (3 x 2 x 5 cm) and according to the NBR 7190 standard (ABNT, 1997).

2.3 Wood mechanical properties

All mechanical tests were carried out with dry samples, in an environment with normalized temperature, until they reached 12% humidity, a standard reference condition, in accordance with the recommendation of NBR7190 (Associação Brasileira de Normas Técnicas - ABNT, 1997).

Compression parallel to the grain (f_{c0}) - To obtain the compression parallel to the grain, 2 x 2 x 3 cm specimens were used, obtained from each batten, in a total of 24 units. Compression tests were carried out in a universal testing machine, according to the adapted NBR 7190 standard (ABNT, 1997).

Shear parallel to grain (f_{v0}) - In obtaining the shear parallel to grain, test specimens with nominal dimensions of 2 x 2 x 3 cm, with 4 cm^2 in the shear area, were used according to the NBR 7190 standard (ABNT 1997).

Static bending - For resistance of the wood to static bending, specimens of 2 x 2 x 35 cm obtained from each batten were used. The tests were conducted in a universal test machine with a load application speed of 10 MPa. A combination of the NBR 7190 standard (ABNT 1997) and ASTM D143–94 (ASTM, 1994) was used, with dimensions (b x h) of 2 x 2 cm for cross section and 30 cm free span (L) and the modulus of rupture (MOR) and modulus of elasticity (MOE) in static bending were tested simultaneously. The test was conducted on the same universal machine.

2.4 Statistical analysis

In the evaluation of the experiment, the variance homogeneity test was initially performed, and, for this, the Hartley test was used. Subsequently, the F test of analysis of variance was carried out according to a completely randomized experimental design. Tukey's test at 5% probability level was applied whenever a significant difference was observed, in some treatment in the F test. Descriptive statistics was also used in data analysis. The data obtained for each variable were statistically analyzed using the SAS® statistical program (SAS Institute Inc., 1999).

3. Results and Discussion

According to the presented results, it was verified that the apparent density, basic density, compression parallel to the grain, shear parallel to grain and MOE did not differ significantly between the varieties of *Pinus caribaea*, but for MOR, wood from the variety *Pinus caribaea* var. *bahamensis* showed significantly greater resistance than the variety *Pinus caribaea* var. *hondurensis* (Tables 2 and 3; Figures 2 and 3).

Table 2 - Analysis of variance of physical properties for *Pinus caribaea* var. *bahamensis* and *Pinus caribaea* var. *hondurensis* for 7 year-old wood.

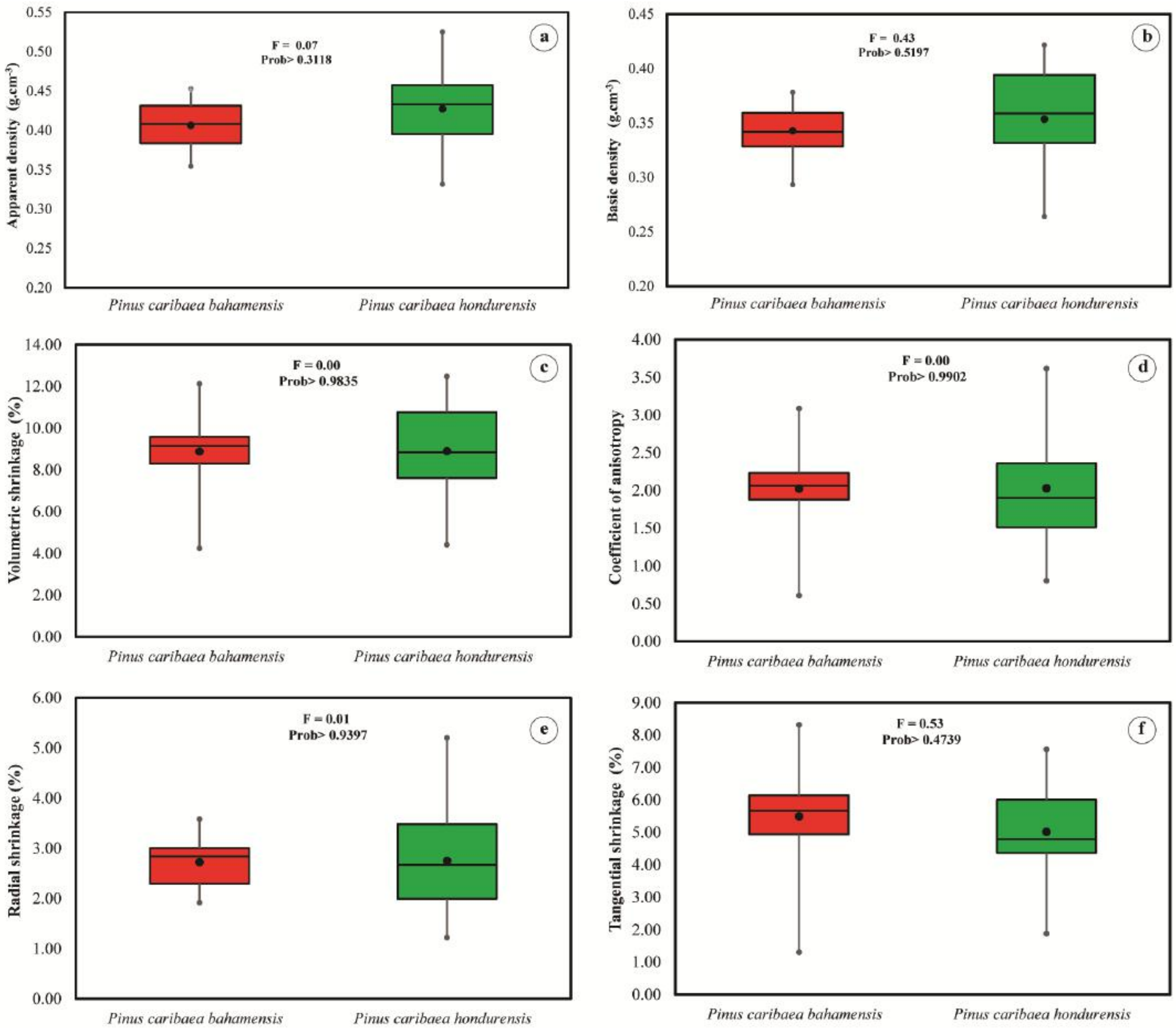
		Mean squares					
Causes of variation	DF	ρ_{ap} ($g.cm^{-3}$)	BD ($g.cm^{-3}$)	β_v (%)	$\beta_t.\beta_r$	β_t (%)	β_r (%)
Species	1	0.0026 $^{n.s.}$	0.0006 $^{n.s.}$	0.0019 $^{n.s..}$	0.0001 $^{n.s..}$	1.3472 $^{n.s.}$	0.0043 $^{n.s.}$
Residual	22	0.0025	0.0015	4.5414	0.5370	2.5377	0.736
	mean	0.42	0.35	8.89	2.03	5.26	2.74
	CV_e (%)	12.03	11.35	23.961	36.14	30,29	31,34
Pinus caribaea* var. *bahamensis	mean	0.41	0.34	8.88	2.03	5.50	2.72
Pinus caribaea* var. *hondurensis	mean	0.43	0.35	8.90	2.03	5.02	2.75

Apparent density (ρ_{ap}), basic density (BD), volumetric shrinkage (β_v), anisotropy coefficient (β_t,β_r), Tangential shrinkage (β_t) and Radial shrinkage (β_r) n.s. = not significant by test F; CV_e= coefficient of experimental variation and DF= degrees of freedom. Source: Authors

Considering the presented values of density and mechanical resistance of the woods, the species of *Pinus caribaea* var. *bahamensis* and *Pinus caribaea* var. *hondurensis,* can be classified as resistance class 20 (C20) NBR 7190 (Associação Brasileira de Normas Técnicas, 1997).

Mean basic density values (Table 2, Figure 2b) were lower than those observed by Trianoski et al. (2013), Zanuncio et al. (2022), Gonçalez et al. (2018) and Loiola et al. (2021), however, these authors evaluated *Pinus caribaea* wood at higher ages, that is, 17, 20, 20 and 25 years old, respectively. However, for wood from *Pinus caribaea* var. *hondurensis* aged 50 years, values very close to those obtained were verified by Lima et al. (2020) for basic density. The apparent density also showed a lower value (Table 2 and Figure 2a) than that observed by Trianoski et al. (2014), for 17-year-old *Pinus caribaea* wood. Therefore, these results obtained for density are probably due to the ages of the youngest of the woods under study.

Figure 2 - Apparent density (a), basic density (b), volumetric shrinkage (c), coefficient of anisotropy (d), radial (e) and tangential (f) shrinkage in 7-year-old *Pinus caribaea* two varieties.



There is a statistically significant difference (P = <0.050). Source: Authors.

For the volumetric shrinkage, coefficient of anisotropy, radial and tangential shrinkage, there were no significant differences between the varieties of *Pinus caribaea* (Table 2 and Figures 2c-f). The mean values obtained for volumetric shrinkage are lower than those observed by Loiola et. al. (2021) and Lima et al. (2020), however, these authors evaluated wood from *Pinus caribaea* var. *hondurensis* aged 14 and 50 years, respectively (Table 2 and Figure 2c). The volumetric retraction values are considered as low, that is, little retraction as specified by Carvalho (1996). In the case of the anisotropy coefficient, the mean values obtained for volumetric shrinkage are higher than those observed by Loiola et al. (2021) (Table 2, Figure 2d). These values are considered high according to Carvalho (1996).

Radial and tangential retractions are considered low by Carvalho (1996). Being lower than those observed by Loiola et. al. (2021) in *Pinus caribaea* wood, aged 14 years (Table 2, Figures 2e-f). Therefore, the values of volumetric, radial, and tangential retraction are considered low. However, the anisotropy coefficient is high, indicating that *Pinus caribaea* var. *hondurensis* and *Pinus caribaea* var. *bahamensis*, at the age of 7 years, may be susceptible to drying defects. This same trend was observed in 13-year-old *Cryptomeria japonica* wood by (Vivian et al., 2023).

Compression parallel to the grain showed values of 20.64 MPa and 19.50 MPa for *Pinus caribaea* var. *hondurensis* and *Pinus caribaea* var. *bahamensis*, respectively. However, these values were lower than those observed by Trianoski et. al. (2014) who obtained values of 34 MPa and 30 MPa for *Pinus caribaea* var. *hondurensis* and *Pinus caribaea* var. *bahamensis*, respectively, but aged 17 years (Table 3 and Figure 3a). For shear parallel to the grain, the values obtained (Table 3 and Figure 3b) are lower than the values of 10.38 MPa and 10.64 MPa for *Pinus caribaea* var. *hondurensis* and *Pinus caribaea* var. *bahamensis* 14-year-old obtained by Trianoski et. al. (2014). These values are also lower than the 10.49 MPa of *Pinus caribaea* var. *bahamensis* obtained for 50-year-old wood by Lima et al. (2020).

Table 3 - Analysis of variance of mechanical properties for *Pinus caribaea* var. *bahamensis* and *Pinus caribaea* var. *hondurensis* for 7 year-old wood.

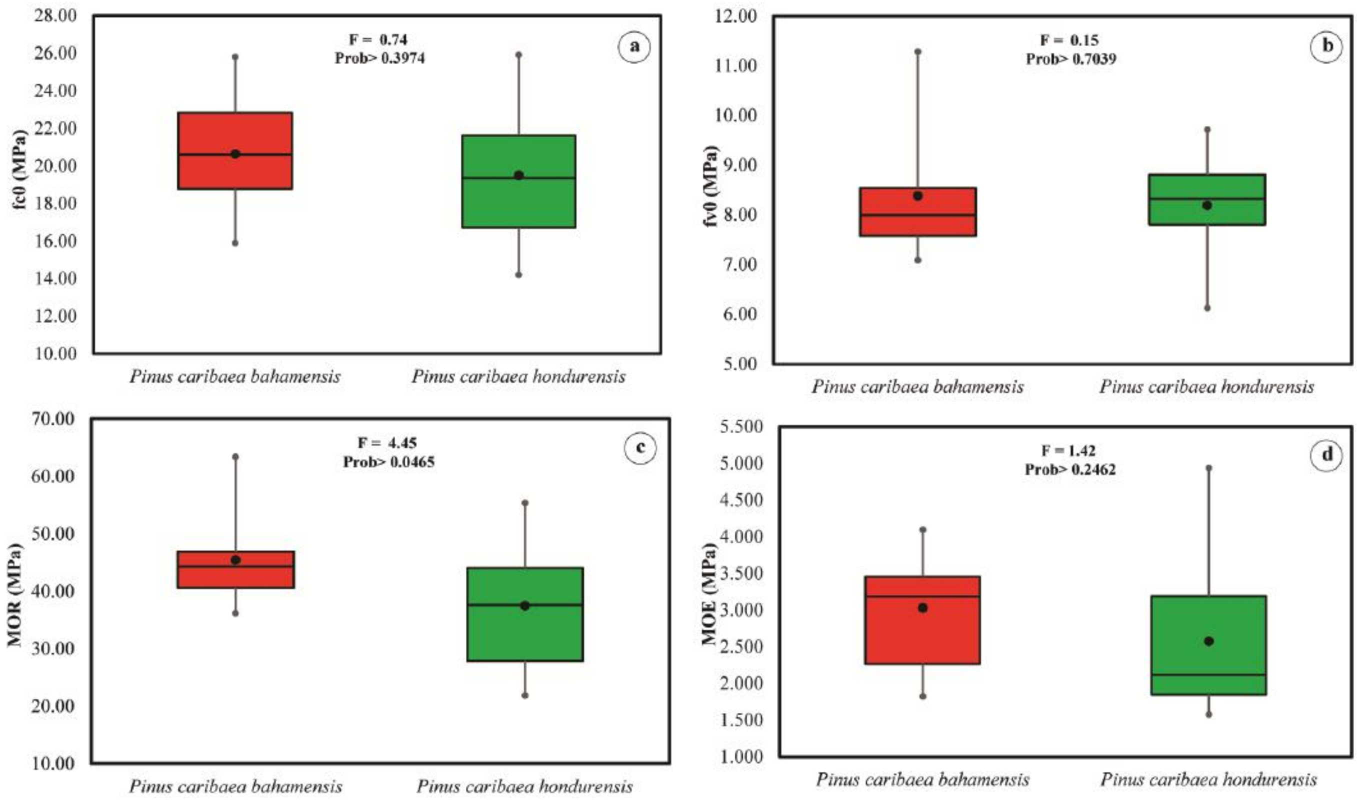
		Mean squares			
Causes of variation	DF	f_{c0} (MPa)	f_{v0} (MPa)	MOR (MPa)	MOE (MPa)
Species	1	7.8204 $^{n.s.}$	0.2289 $^{n.s.}$	377.6266 $^{**.}$	1249897 $^{n.s.}$
Residual	22	10.4985	1.5442	84.8457	880608
	mean	20.07	8.26	41.47	2805
	CV_e (%)	16.14	14.99	22.21	33.45
Pinus caribaea* var. *bahamensis	mean	20.64	8.38	45.43 $^{a.}$	3033
Pinus caribaea* var. *hondurensis	mean	19.50	8.19	37.50 ^{b}	2577

Compression parallel to the grain (f_{c0}), shear parallel to grain (f_{v0}), modulus of rupture (MOR) and modulus of elasticity (MOE); **Significant at 5% level of significance by test F ; n.s. = not significant by test F; Means followed by different letters in the same column differ among themselves by the Tukey test at 5% level of significance; CV_e= coefficient of experimental variation and DF= degrees of freedom. Source: Authors.

Modulus of rupture (MOR) values of 45.43 MPa and 37.50 MPa were obtained for *Pinus caribaea* var. *hondurensis* and *Pinus caribaea* var. *bahamensis* (Table 3, Figure 3c), respectively. However, these values are lower than those observed by Trianoski et. al. (2014) of 65 MPa and 62 MPa for *Pinus caribaea* var. *hondurensis* and *Pinus caribaea* var. *bahamensis*, respectively, aged 17 years. They are also smaller than that obtained by Gonçalez et. al. (2018) for *Pinus caribaea* var. *hondurensis* aged 20 years (Table 3, Figure 3c). For the MOE, the values obtained (Table 3, Figure 3d) were lower than 7187 MPa and 7106 MPa for *Pinus caribaea* var. *hondurensis* and *Pinus caribaea* var. *bahamensis*, respectively, obtained from 14-

year-old wood by Trianoski et. al. (2014) and those obtained by Gonçalez et. al. (2018) for *Pinus caribaea* var. *hondurensis* 20 years old.

Figure 3 - Compression parallel to the grain (a), Shear parallel to grain (b), Modulus of rupture (c) and Modulus of elasticity (d) in 7-year-old *Pinus caribaea* two varieties.



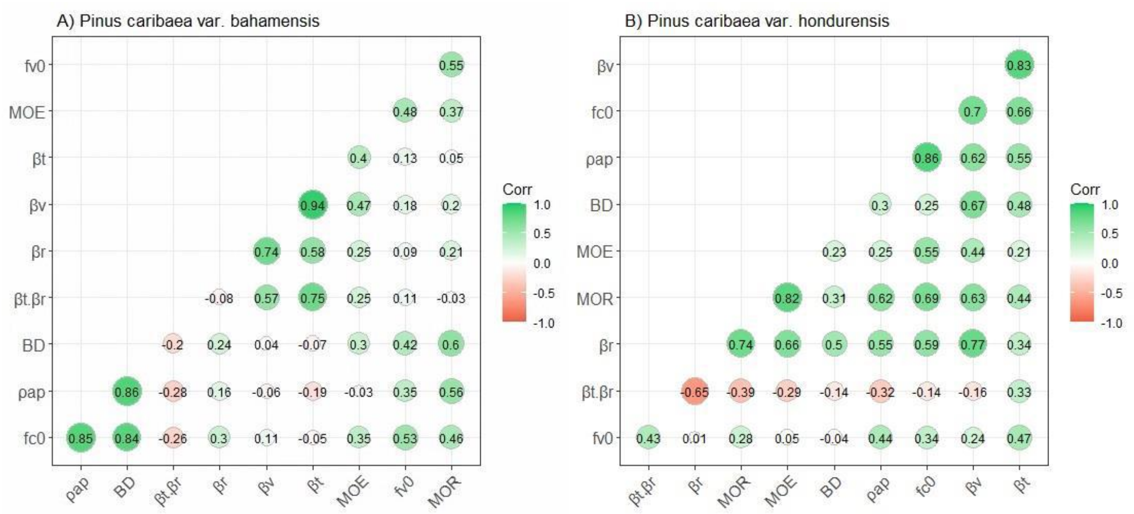
There is a statistically significant difference (P = <0.050). Source: Authors.

The results mentioned above are in line with those of several studies in South Africa with pine wood, aged less than 20 years, and they have repeatedly shown that the main limitation of using pine wood for the structural market is its lack of rigidity. While the flexural strength seems to be sufficient, however, a new approach is needed for the standardization of the structural use of wood produced from younger age pine (Nel et al., 2018). Another factor to be considered would be the fact that the mechanical strength of *Pine* wood has a high positive relationship with the proportion of late wood, which in the case of woods at a younger age, this proportion of late wood is lower (Winck et al., 2023).

In general, according to the results obtained by *Pinus caribaea* for the two varieties at 7 years of age, we can consider that they were very similar to the wood of *Pinus caribaea* var. *hondurensis* aged 50 years evaluated by (Lima et al., 2020), which may be an indication that these physical-mechanical properties of this species begin to stabilize at a young age. The wood of 50-year-old *Pinus caribaea* var. *hondurensis*, confirmed its potential for various uses, such as: the manufacture of panels, light structural use in civil construction and sawmills, which could then be an alternative to supply the demand for raw materials in the industrial sector (Lima et al., 2020). In comparison with *Pinus taeda* wood, the *Pinus caribaea* var. *hondurensis* and *Pinus caribaea* var. *bahamensis* demonstrated a high potential for industrial use, and, in most cases, excellent properties were found, and many times they were superior to the reference species. This wood of these species can then be used for various purposes as a complementary or substitute raw material in forest-based industries, this was also confirmed by (Trianoski et al., 2014).

To better explain the relationships between the physical-mechanical properties of the wood of *Pinus caribaea* var. *bahamensis* and *Pinus caribaea* var. *hondurensis,* Pearson's correlation analyses were performed separately by species (Figures 4A e 4B).

Figure 4 - Pearson’s Correlation Coefficient between the physical-mechanical properties of the wood of *Pinus caribaea* var. *bahamensis* (A) and *Pinus caribaea* var. *hondurensis* (B).



Negative and positive correlations are represented by red and green, respectively. The magnitude of all correlations is represented by color intensity. Apparent density (ρ_{ap}), basic density (BD), volumetric shrinkage (β_v), radial shrinkage (β_r), tangential shrinkage (β_t), anisotropy coefficient ($\beta_t.\beta_r$), compression parallel to the grain (f_{c0}), Shear parallel to grain (f_{v0}), modulus of rupture (MOR) and modulus of elasticity (MOE). Source: Authors.

The highest positive correlation was observed between apparent density and compression parallel to the grain; basic density and compression parallel to the grain; apparent density and basic density; volumetric shrinkage and radial shrinkage; volumetric shrinkage and tangential shrinkage; tangential shrinkage and anisotropy coefficient from the wood of *Pinus caribaea* var. *bahamensis* (Figure 4A). For the wood of *Pinus caribaea* var. *hondurensis*, the highest positive correlation was observed between apparent density and compression parallel to the grain; volumetric shrinkage and compression parallel to the grain; volumetric shrinkage and radial shrinkage; volumetric shrinkage and tangential; modulus of elasticity and radial shrinkage; modulus of rupture and modulus of elasticity (Figure 4B).

The highest values of correlation coefficients were obtained in the relationship between apparent density and compressive strength, for both species (Figures 4A and 4B). This demonstrates that there is a strong relationship between these properties, indicating that the apparent density can be used as a parameter for estimating the compressive strength. These results are consistent with those observed by Trianoski et al. (2014) for *Pinus caribaea* var. *bahamensis* and *Pinus caribaea* var. *hondurensis*. This same tendency was observed by Mustefago et al. (2019), for *Pinus patula* and *Pinus taeda*. However, a high positive correlation between apparent density and modulus of elasticity was obtained for *Pinus elliotti* by Wen et. al. (2023).

Therefore, we can consider that the varieties of *Pinus caribeae* presented similar physical and mechanical characteristics. Although young pine wood is considered to be of low quality, we can confirm that these varieties have good potential for use in the wood industry. However, it is an abundant material source that is underutilized because its mechanical properties are still not well understood. Even though *Pine* wood at young ages has often been rejected, it has some good mechanical properties that can be combined with structural applications that do not need high strength (Cherry et al., 2022).

Zanuncio et al., (2022) also consider that tropical *Pinus* species at a younger age can be considered promising for plantations on a commercial scale, increasing the supply of wood for the various segments of the timber industry, and even, in some cases, they can produce wood with little dimensional variation and of good mechanical resistance.

Information on the properties of *Pinus* wood at a younger age, as well as the proportion of juvenile wood, can impact forest management, wood classification, decisions about the rotation cycle and the wood processing to be adopted at the sawmill (Rosa et al., 2023). One of the advantages of studying the characteristics of wood at a younger age would be the fact of being able to make an early selection of these materials and use these results as a selection criterion to be adopted in improvement programs of *Pinus* species to produce cellulose and paper, high quality lumber for sawmills and other uses (Wen et al., 2023).

New studies are recommended for *Pinus* species at a younger age, such as the evaluation of wood quality related to climate. According to Da Ros et al., (2021) this research can be essential for genetic improvement programs that seek to use hereditary and economically important traits to select material with adaptability to climate change.

4. Conclusion

Wood properties: apparent density, basic density, compression parallel to the grain, shear parallel to grain, modulus of elasticity, volumetric shrinkage, radial shrinkage, tangential shrinkage, and anisotropy coefficient, evaluated in *Pinus caribaea* var. *hondurensis* and *Pinus caribaea* var. *bahamensis* did not differ significantly from each other.

The wood of the species/variety *Pinus caribaea* var. *bahamensis* has significantly higher resistance to modulus of rupture than the *Pinus caribaea* var. *hondurensis.*

For both *Pinus caribaea* var. *hondurensis* and *Pinus caribaea* var. *bahamensis*, the highest correlation obtained was between apparent density and compressive strength.

Regarding the use of wood from *Pinus caribaea* var. *hondurensis* and *Pinus* caribaea var. *bahamensis*, at a younger age, both have the potential to be used for different purposes that do not have many restrictions in structural applications.

The values obtained for the properties of 7-year-old *Pinus caribaea* var. *hondurensis* and *Pinus caribaea* var. *bahamensis*, can be used for comparative purposes with the species currently used in the timber industry in Brazil for various uses.

Acknowledgments

The authors thank Luis Eduardo Facco (Esalq – USP) for laboratory assistance.

References

Associação Brasileira de Normas Técnicas – ABNT. (1997). NBR 7190 Projeto de estruturas de madeira. ABNT: Rio de Janeiro.

Associação Brasileira de Normas Técnicas – ABNT. (2003). NBR 11941 Madeira: determinação da densidade básica. ABNT: Rio de Janeiro.

Alvares, C. A., Stape, J. L., Sentelhas, P. C., Gonçalves, J. L. M. & Sparovek, G. (2013). Köppen’s climate classification map for Brazil. *Meteorologische Zeitschrift*, 22, 711-728.

American Society for Testing and Materials - ASTM. (1994). Standard methods of testing small clear specimens timber. ASTM D 143-94: Philadelphia.

Carvalho, A. (1996). Denominações convencionais para propriedades da madeira. In: Carvalho, A. Tecnologia das indústrias da madeira III – Na2. http://www.estgv.ipv.pt/paginaspessoais/jqomarcelo/tim3/tim3_tp1_na2.pdf.

Cherry, R., Karunasena, W. & Manalo, A. (2022). Mechanical Properties of Low-Stiffness Out-of-Grade Hybrid Pine—Effects of Knots, Resin and Pith. *Forests*, 13, 927, 2022.

Da Ros, L. M., Thomas, B. R., & Mansfield, S. D. (2021). Wood quality trait associations with climate: Room for improvement in two northern commercial tree species? *Forest Ecology and Management*, 497, 119492.

Gonçalez, J. C., Santos, N., Silva Junior, F. G., Souza, R. S. & De Paula, M. H. (2018). Growth ring width of *Pinus caribaea* var. *hondurensis* and its relationship with wood proprieties. *Scientia Forestalis*, 46, 309-317.

Glass, S. & Zelinka, S. L (2021). Moisture relations and physical properties of wood. In Wood handbook - wood as an engineering material. General Technical Report FPL-GTR-282. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, pp. 1-22.

Indústria Brasileira de Árvores - IBÁ. (2023). Relatório anual 2022. https://www.iba.org/publicacoes.

Kronka, F. J. N., Bertolani, F. & Ponce, R. H. (2005). A cultura de *Pinus* no Brasil. Sociedade Brasileira de Silvicultura: São Paulo.

Lima, G. M. L., Gomes, N. S. B., Cunha, T. A. & Figueiredo Filho, A. (2022). Effects of meteorological variables on *Pinus caribaea* growth in different ages at the Amazon region. *Floresta*, 52, 113-121.

Lima, I. L., Oliveira, I. R., Barbosa, J. A. & Ranzini, M. (2020). Variação em propriedades da madeira de *Pinus caribaea* var. *hondurensis* e *Pinus tecunumanii*. *Advances in Forestry Science*, 7, 1231-1247.

Loiola, P. L., Klitze, R. J., Rocha, M. P. & Vidaurre, G. B. (2021). Physical properties of wood *Pinus caribaea* var. *caribaea, Pinus caribaea* var. *Hondurensis* and *Pinus oocarpa* for pencil production. *Floresta*, 51, 354-362.

Lorenzi, H., Bacher, L. B. & Torres, M. A. V. (2018). Árvores e arvoretas exóticas no Brasil: madeireiras, ornamentais e aromáticas. Instituto Plantarum: Nova Odessa.

Nel, A., Malan, F., Braunstein, R., Wessels, C.B. & Kanzler, A. (2018). Sawn-timber and kraft pulp properties of *Pinus elliotti* x *Pinus caribaea* var. *hondurensis* and *Pinus patula* x *Pinus tecunumanii* hybrid and their parent species. *South. For. J. For. Sci.*, 80, 159-168.

Mustefaga, E.C, Hillig, É., Tavares, E.L, Sozim, P.C.L. & Rusch, F. (2019). Caracterização físico-mecânica da madeira juvenil de *Pinus*. *Scientia Forestalis*, 47, 472-481.

Rosa, T. O., Iwakiri, S., Trianoski, R., Terezo, R. F. & Righez, J. L. B. (2023). Influence of juvenile wood proportion on density and modulus of elasticity in softwood boards for structural use: a preliminary study. *Anais da Academia Brasileira de Ciências*, 95, e20200809.

Rossi, M. (2017). *Mapa Pedológico do Estado de São Paulo: revisado e ampliado. São Paulo: Instituto Florestal*. http://www.iflorestal.sp.gov.br.

Santos, H. G., Jacomine, P. K. T., Anjos, L. H. C., Oliveira, V. A., Lumbreras, J. F., Coelho, M. R., Almeida, J. A., Araujo Filho, J. C., Oliveira, J. B., & Cunha, T. J. F. (2018). Sistema brasileiro de classificação de solos. Embrapa: Brasília.

S.A.S. Institute Inc. (1999). SAS Procedures Guide. Version 8 (TSMO). SAS Institute Inc.: Cary.

Shimizu, J. Y. & Sebbenn, A. M. (2008). Espécies de *Pinus* na silvicultura brasileira. In Shimizu, J. Y. *Pinus* na Silvicultura Brasileira. Embrapa: Brasília.

Trianoski, R., Matos, J. L. M., Iwakiri, S. & Prata, J. G. (2013). Variação longitudinal da densidade básica da madeira de espécies de *Pinus* tropicais. *Floresta*, 43, 503-510.

Trianoski, R., Matos, J. L. M., Iwakiri, S. & Prata, J. G. (2014). Avaliação das propriedades mecânicas da madeira de espécies de *Pinus* tropicais. *Scientia Forestalis*, 42, 21-28.

Vidaurre, G. B., Lombardi, L. R., Oliveira, J. T. D. S. & Arantes, M. D. C. (2012). Lenho juvenil e adulto e as propriedades da madeira. *Floresta e Ambiente*, 18, 469-480.

Vivian, M. A., Modes, K. S., Fogliatto, M. M., Schlichting, R. C., Corrêa, R., Grosskopf, É. J. & Júnior, M. D. (2023). Propriedades físicas, químicas e anatômicas da madeira de *Cryptomeria japonica*. *Pesquisa Florestal Brasileira*, 43, 2-10.

Zanata, M., Pissarra, T. C. T., Ferraudo, A. S., Ranzini, M. & Campos, S. (2015). Effect of soil use on the quality of water resource in watershed using multivariate statistical analysis. *Irriga*, 20, 776-789.

Zanuncio, A. J. V., Possato, E. L., Carvalho, A. G., Lopes, O. P., &Castro, V. R. (2022). Basic density and scaling of juvenile and mature wood in *Pinus caribaea* trees. *Cellulose Chem. Technol.*, 56, 473-479.

Zziwa, A., Mukasa, J. & Kizito, S. (2020). Structural suitability of 10-year old *Pinus caribaea* timber with a forest fire history in farm buildings. *AgricEngInt: CIGR Journal Open*, 22, 49-58.

Wen, J., Yi, M., Dong, L., Zhang, L., Liu, S., Yuan, S., Tao, X. & Lai, M. (2023). Early selection efficiency for fiber dimensions and their relationships with growth and wood quality for *Pinus elliottii* Engelm. in southern China. *Journal of Forestry Research*, 2023. https://doi.org/10.1007/s11676-023-01622-5.

Winck, R. A., Winck, L. R., Belaber, E. C., Aquino, D. R., Area, M. C. & Gauchat, M. E. (2023). Colored area, growth-ring width, and latewood percentage in hybrid pine f1 inta-pindo. *Floresta*, 53, 204-213.