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*Variation of tracheid biometry and wood properties of **Pinus caribaea** morelet var **caribaea barret and golfari***

*Variación de la biometría de las traqueidas y propiedades de la madera de **Pinus caribaea**
morelet var **caribaea barret y golfari***

*Variação na biometria dos traqueídeos e propriedades da madeira de **Pinus caribaea**
morelet var **caribaea barret e golfari***

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ABSTRACT

The variability of wood properties for a certain species could be influenced by several factors such as: provenance and growth conditions, age, height, growth rate and silvicultural practices. Thus, the objective of the present work is related to the determination of the variations of tracheid biometric characteristics and wood properties of *Pinus caribaea* var *caribaea* Morelet in dependency of the provenance. Thirty 29-year-old trees from three provenances in the province of Pinar del Río, Cuba (Malas Aguas, Cajalbana and Marbajita) are used. The biometry of the tracheid and wood properties are determined from logs obtained at a height of 1.30 m from each tree. Measurements were made in three different radial positions in direction pith to bark. The results obtained allow us to conclude that the biometric dimensions of the tracheid and the physical-mechanical properties vary between provenances and Malas Aguas provenance presents the best indicators. A strong effect of the distance parameter from pith to bark is appreciated in all the studied wood characteristics. As the dimensions of the tracheids increase, the physical and mechanical properties increase. There is an important positive relationship between the strength properties and wood density.

Key words: provenance, variation, anatomy, stiffness, quality.

RESUMEN

La variabilidad de las propiedades de la madera de una determinada especie podría estar influenciadas por varios factores tales como: procedencia y condiciones de crecimiento, edad, altura, tasa de crecimiento y prácticas silviculturales. Así, el objetivo del presente trabajo está relacionado con la determinación de las variaciones de las características biométricas de las traqueidas y propiedades de la madera de *Pinus caribaea* var *caribaea* Morelet en dependencia de la procedencia. Se utilizan 30 árboles de 29 años de tres procedencias en la provincia de Pinar del Río, Cuba (Malas Aguas, Cajalbana y Marbajita). La biometría de las traqueidas y propiedades de la madera se determinan a partir de trozas obtenidas a 1.30 m de altura de cada árbol. Las mediciones se realizaron en tres posiciones



radiales diferentes en dirección médula corteza. Los resultados obtenidos permiten concluir que las dimensiones biométricas de las traqueidas y las propiedades físico-mecánicas varían entre procedencia; resultando Malas Aguas la que presenta los mejores indicadores. Se aprecia un fuerte efecto del parámetro distancia de la médula a la corteza en todas las características de la madera estudiadas. En la medida que aumenten las dimensiones de las traqueidas, se incrementan las propiedades físicas y mecánicas. Existe una importante relación positiva entre la densidad y las propiedades mecánicas de la madera.

Palabras clave: procedencia, variación, anatomía, resistencia, calidad.

RESUMO

A variabilidade das propriedades da madeira de uma determinada espécie pode ser influenciada por diversos fatores como: origem e condições de cultivo, idade, altura, taxa de crescimento e práticas silviculturais. Assim, o objetivo do presente trabalho está relacionado à determinação das variações nas características biométricas dos traqueídeos e propriedades da madeira de *Pinus caribaea* var *caribaea* Morelet dependendo da origem. São utilizadas 30 árvores de 29 anos de três fontes na província de Pinar del Río, Cuba (Malas Aguas, Cajalbana e Marbajita). A biometria dos traqueídeos e as propriedades da madeira são determinadas a partir de toras obtidas a 1,30 m de altura de cada árvore. As medidas foram feitas em três posições radiais diferentes na direção medula-córtex. Os resultados obtidos permitem-nos concluir que as dimensões biométricas dos traqueídeos e as propriedades físico-mecânicas variam entre as origens; Malas Aguas resultando naquele que apresenta os melhores indicadores. Um forte efeito do parâmetro distância da medula à casca é observado em todas as características da madeira estudadas. À medida que as dimensões dos traqueídeos aumentam, as propriedades físicas e mecânicas aumentam. Existe uma importante relação positiva entre densidade e propriedades mecânicas da madeira.

Palavras-chave: origem, variação, anatomia, resistência, qualidade.



INTRODUCTION

Pinus caribaea var. *caribaea* Morelet Barret and Golfari is one of the most important forest species due to the uses made of its wood, being one of those prioritized in reforestation plans in the western and central region of Cuba (Castillo and Mendoza, 2018; Pérez *et al.* 2020).

Oyelere *et al.* (2019), state that the analysis of the anatomical characteristics of wood, such as the determination of the length of tracheids, is a fundamental tool to identify the behavior in use of wood. The dimensional characteristics of tracheids are an element of great importance for the optimal use of wood: variations in wall thickness, lumen diameter or total tracheid diameter have a direct effect on density, shrinkage rate and different mechanical properties (Marqués *et al.*, 2022).

Winck *et al.* (2022), expose that the existence of radial and longitudinal variation in wood properties has been demonstrated; agreeing with Sadiku and Abdulkareem, (2019); Zawadzka & Kozakiewicz (2019) and Liola *et al.* (2021). Variability that is influenced by existing growing conditions in forest ecosystems.

It has been shown that there are variations of wood properties among individual trees from pith to bark, from the base to the top in the longitudinal section of the tree (Sadiku and Abdulkareem, 2019); as well as among individuals of the same species.

Taking into consideration the aforementioned aspects, the objective of the present work is related to the determination of variations in the biometric characteristics of tracheids and wood properties of *Pinus caribaea* Morelet var *caribaea* Barret and Golfari depending on the origin.



MATERIALS AND METHODS

Determination of the samples

Three provenances of *Pinus caribaea* Morelet var *caribaea* Barret and Golfari have been identified in Pinar del Río, Cuba; which are the following: Cajalbana (CA); Marbajita (MB); belonging to La Palmas municipality; as well as Malas Aguas, Minas de Matahambre municipality; characterized these provenances for being located in the North of Pinar del Río province, Cuba. Figure 1. Table 1 shows the main aspects that define the geographical location of these three provenances (Figure 1) and (Table 1).

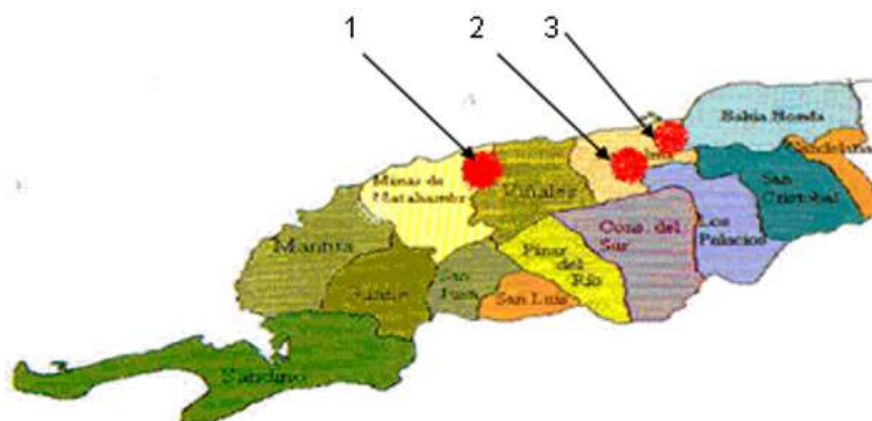


Figure 1. Provenances of the trees of *Pinus caribaea* Morelet var *caribaea* Barret and Golfari

Table 1. - Geographical data of the provenances under study

Symbol	CA	MA	MB
Origin	Cajalbana	Malas Aguas	Marbajita
Latitude	22° 41'	20° 40'	22° 34'
Longitude	83° 34'	83° 45'	82° 32'
Elevation (m)	464	200	150



Sample preparation

A total of 10 trees per source were felled, which were selected completely at random, avoiding edge effects and trees smaller than 20 cm in diameter. At a height of 1.30 m, a 50 cm long log was extracted and numbered. The radial variation of tracheid dimensions as well as the mechanical properties per sample in each log is from the pith to the bark (Figure 2).

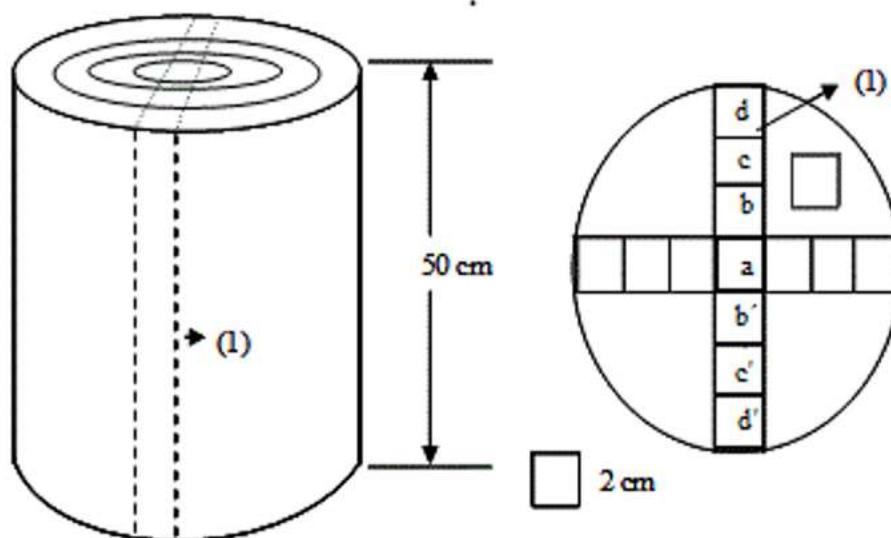


Figure 2. - Sample preparation

Determination of the biometric variation of tracheids in wood of *Pinus caribaea* Morelet var. *caribaea* Barret and Golfari

The quantification of the length, diameter and wall thickness of tracheids is determined by macerating the sampled wood of *Pinus caribaea* Morelet var. *caribaea* Barret and Golfari in a 1:1 solution of glacial acetic acid with hydrogen peroxide. These samples before maceration were stained with Astra Blue. Two lamellae containing 20 fibers per lamella were analyzed and measured for each selected position in the cross section of the log with a Leitz ASM 68K semi-automatic image analyzer.



The mean radial tracheid diameter and mean radial lumen diameter were determined from twice the wall thickness, calculated by subtracting the lumen diameter from the tracheid diameter. Analysis of variance is used to statistically determine the existence of significant differences between the variables analyzed for a significance level of $p < 0.05$; coinciding with the methodology proposed by Vírgen *et al.* (2022), Winck *et al.* (2022) and Costa *et al.* (2023).

*Determination of physical-mechanical properties of wood of Pinus caribaea Morelet var. caribaea
Barret and Golfari*

In the Wood Laboratory, belonging to the Materials Laboratory, located in Lisbon, Portugal, the specimens obtained were placed in an air-conditioned environment with a temperature of 20 °C and relative humidity of 65 % (ASTM-D13, 2009), until an equilibrium humidity of approximately 12 % was obtained, taking into consideration the methodology proposed by Vírgen *et al.* (2022) and Aramburu *et al.* (2023).

Table 2 shows aspects related to the dimensions of the specimens used for the determination of the physical-mechanical properties of wood, depending on the different standards used.

Table 2. - General information of the analyzed mechanical tests

Mechanical properties	Standard used	Specimen dimensions (mm)	Number of specimens used
Specific density (DENS) ₁₂	UNE 56 531 77	20X20X25	102
Compression parallel to the fibers (MORC)	ISO3787	20x20x60	102
Modulus of elasticity in static bending (MOE)	ISO3133	20x20x340	102

For the determination of the magnitudes of the mechanical properties studied, the following mathematical expressions are used according to the methodology developed by Garcia *et al.* (2013); ASTM D1037-12 (2020); Marini *et al.* (2021); Vírgen *et al.* (2022) and Costa *et al.* (2023) (Equation 1), (Equation 2) and (Equation 3)



Density at 12 % moisture content ($DENS_{12}$)

$$DENS_{12} = \frac{P_{12}}{V_{12}} \quad (1)$$

Where:

$DENS_{12}$ - Density at 12 % moisture, $cm^3 * g^{-1}$;

P_{12} - weight at 12 % moisture, g;

V_{12} - Volume at 12 %, m^3 .

Compression parallel to the fibers (MORC)

$$MORC = \frac{F_{max}}{a*b} \quad (2)$$

Where:

F_{max} - Force applied to specimens at the limit of proportionality,

kgf; a- width of specimens, cm;

b- thickness of specimens, cm.

Modulus of Elasticity in static bending (MOE)

$$MOE = \frac{PL^3}{4bdh^3} \quad (3)$$

Where:

MOE- Modulus of elasticity at bending,

Mpa; P- Force applied to the limit of proportionality,

kgf; L- distance between the support points of the specimens, cm; b- width of the specimens, cm; d- Magnitude of the deformation corresponding to the force applied to the limit of proportionality, cm;

h- thickness of the specimen, cm.

Statistical differences in wood properties between provenances and between trees are performed from analysis of variance (ANOVA), with a significance level $p < 0.05$; coinciding with the methodologies proposed by Sadiku and Abdulkareem (2019) and Modes *et al.* (2020).



RESULTS AND DISCUSSION

Influence of the origin and the transverse position of the samples in the logs on the biometric dimensions of the tracheids in Pinus caribaea Morelet var caribaea Barret and Golfari

Marqués *et al.* (2022), state that one of the most important elements for the correct utilization of wood is the knowledge of it. Its proper use requires transformation stages that allow to have a suitable material for the satisfaction of needs. The anatomical characteristics of wood have a great influence on its physical-mechanical properties.

Table 3 shows the average length of the tracheids and the thickness of the cell wall of *Pinus caribaea* Morelet var. *caribaea* Barret and Golfari wood from the three provenances analyzed (Marbajita, Cajalbana and Malas Aguas) (Table 3).

Table 3. - Average dimensions of the tracheids that make up the wood of *Pinus caribaea* Morelet var *caribaea* Barret and Golfari depending on the provenance. Mean comparison analysis (ANOVA)

	Marbajita	Cajalbana	Malas Aguas
Length (mm)	2.91±0.91b	2.82±1.12c	3.08±0.42a
Diameter (µm)	40.75±0.88b	42.37±0.25a	40.77±0.16b
Wall thickness (µm)	9.74±1.87b	8.35±0.37c	10.52±2.22a

Results with the same line letter do not show significant differences $p < 0.05$.

From the results obtained and taking into consideration the statistical analysis of comparison of means (Anova), it can be established that there are significant differences in the dimensions of the tracheids between origins. It is shown that the largest dimensions appear in the woods from Malas Aguas in the case of tracheid length and cell wall thickness. Characteristics that have a positive effect on wood quality; taking into consideration the results obtained by Trevisan *et al.* (2013) and Winck *et al.* (2015).



With respect to tracheid length, its variation has direct effect on some fields of utilization. For example, in the pulp and paper industry, a series of morphological indices are determined to determine the suitability of a species for that type of product and some of these indices take into consideration the length of tracheids (Marqués *et al.* 2022).

It is defined that longer cells give strength to the paper; although sometimes the tensile strength, which is usually the property most associated with the greatest strength of paper, depends more on the bond between fibers than on their length, but in turn, the degree of crosslinking of the cells is directly related to their length. Additionally, transverse tracheid length variations are the most reliable element to delimit juvenile and adult wood zones; an element of great importance due to the great differences in technological behavior between both zones.

On the other hand, in the radial direction of the logs, it can be seen that the biometric dimensions of the tracheids vary with an increasing behavior from the pith to the bark for the three provenances under study; coinciding with Kiaei (2012).

Figure 3 shows the biometric behavior of the tracheids according to the radial position of the wood samples of *Pinus caribaea* Morelet var *caribaea* Barret and Golfari for the Cajalbana provenance, which shows a similar behavior to the Marbajita and Malas Aguas provenances (Figure 3).



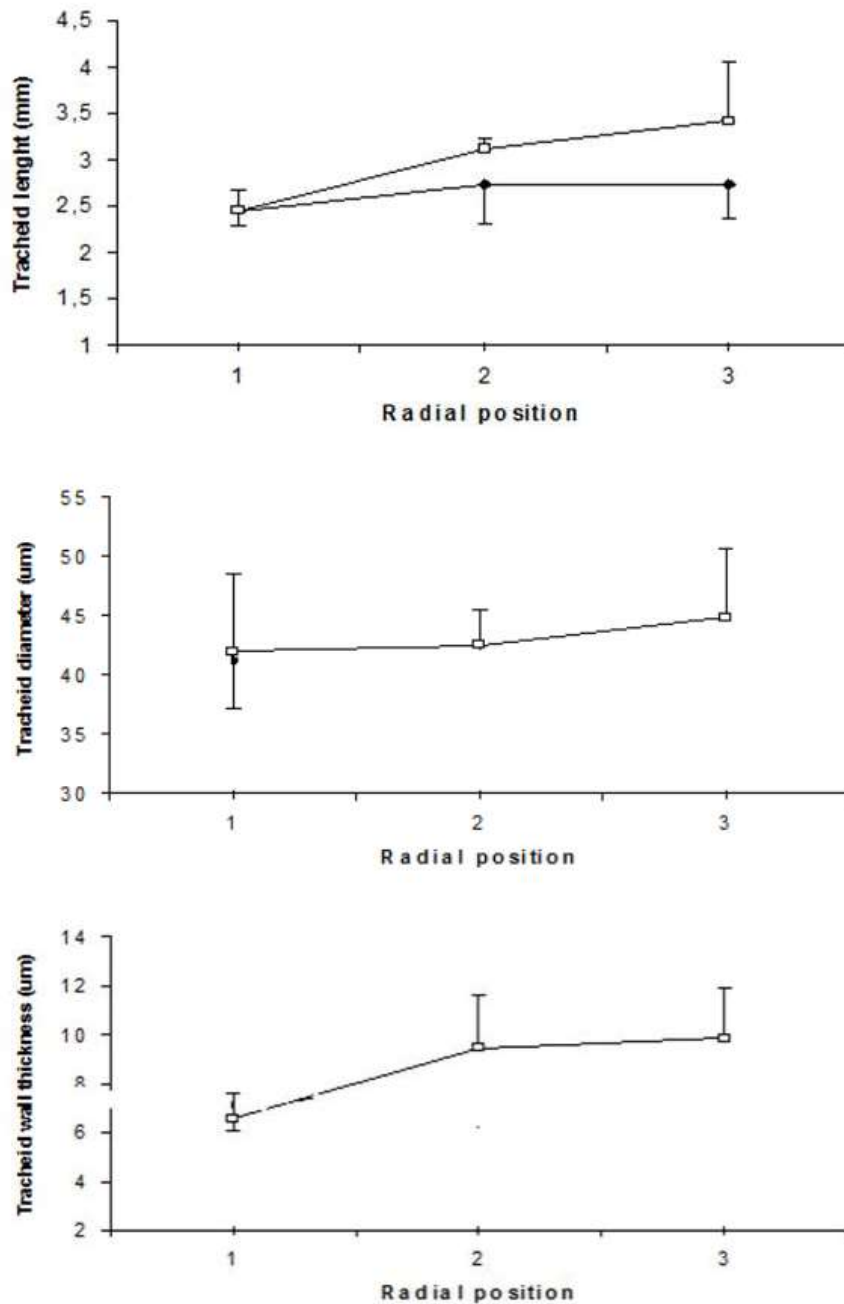


Figure 3. - Radial variation of tracheid biometric dimensions



Influence of provenance and radial position on the physical-mechanical properties of wood of Pinus caribaea Morelet var caribaea Barret and Golfari

The results of the physical-mechanical properties of the wood analyzed in this study are shown in Table 4, where it can be seen from an analysis of comparison of means (Duncan), that there are significant differences between provenances for $p < 0.05$ (Table 4).

Table 4. - Wood properties of *Pinus caribaea* Morelet var *caribaea* Barret and Golfari by provenance. Duncan mean comparison analysis

Wood properties	CAJALBANA	MARBAJITA	MALAS AGUAS
DENS, Kg/m ³	656.07a	664.92a	722.47 ^a
MORC, MPa	41.14a	41.40a	46.83a
MOE, MPa	13 669.96b	14 212.61ab	18 133.86a

Results with the same line letter do not show significant differences $p < 0.05$.

Therefore, based on the magnitude of the results presented, it is shown that the provenance has a significant influence on the physical-mechanical behavior of the wood, considering that the Malas Aguas provenance is the one that presents the best indicators related to its physical-mechanical properties. This underlines the need to consider the role of provenances in explaining the contradictory results on wood properties. Aspects that are related to the results obtained in Table 3; which makes it possible to expose that as the dimensions of the tracheids increase, the physical and mechanical properties studied increase; coinciding with Trevisan *et al.* (2013) and Winck *et al.* (2015).

From the above elements, it can be defined that they are the theoretical basis for the selection of provenances as a way to improve the properties of wood; agreeing with Sandak *et al.* (2019) and Kask *et al.* (2021).

Table 5 shows that there is a positive relationship between density and the mechanical properties of wood, which shows that as density increases, compressive strength and modulus of elasticity increase, coinciding with the results obtained by Missanjo and Matsumura (2016), Herrera *et al.* (2017), as well as Miyoshi *et al.* (2018), who define that, by



controlling wood density in improvement programs, a positive impact on its mechanical properties can be obtained (Table 5).

Table 5. - Correlation between the physical-mechanical properties of *Pinus caribaea* Morelet var *caribaea* Barret and Golfari

	DENS	MORC	MOE
DENS	1.00	0.37*	0.39*
MORC	0.37*	1.00	0.53*
MOE	0.39*	0.53*	1.00

* Significance for a probability level of 95 %.

Density is defined as one of the most important properties of wood, since it is an excellent indicator of performance and quality of solid and reconstructed wood-based products (Antony *et al.*, 2012).

Table 6 shows the results that relate the properties of wood depending on its radial position, an aspect that is very important during the definition of sawing schemes and secondary processing methods to be used to obtain timber products with the highest possible quality (Table 6).

Table 6. - Wood properties of *Pinus caribaea* Morelet var *caribaea* Barret and Golfari as a function of radial direction. Duncan's test

	Pos 1	Pos 2	POS 3	POS 4
DENS, Kg/m ³	607.19 a	637.84 a	680.16 a	682.52 a
MORC, MPa	29.99 c	38.07 b	43.44 a	43.21 a
MOE, MPa	6986.56 c	11581.94 b	15600.35 a	13704.82 ab

Results with the same line letter do not show significant differences $p < 0.0$.

When performing an analysis of variance, from Duncan's test, it can be seen that there is a significant difference in the results obtained, demonstrating that the wood properties of *Pinus caribaea* Morelet var *caribaea* Barret and Golfari, increase from the pith to the bark, coinciding with the results obtained by Riki *et al.* (2019); Zawadzka and Kozakiewicz, (2019), as well as Belleville *et al.* (2020).



From the measurements obtained from the 30 trees, it can be concluded that the physical-mechanical properties depend not only on density but also on the position in the stem, since around the pith a higher percentage of juvenile wood was found in the tested wood specimens. The strong influence of juvenile on wood properties was demonstrated by Garbachevski *et al.* (2022).

CONCLUSIONS

The results obtained allow us to conclude that the biometric dimensions of the tracheids and the physico-mechanical properties of the wood of *Pinus caribaea* Morelet var *caribaea* Barret and Golfari vary between provenances, with Malas Aguas showing the best indicators.

The results show a strong effect of the pith to bark distance parameter on all the wood characteristics studied.

As tracheid dimensions increase, physical and mechanical properties also increase.

There is a significant positive relationship between wood strength properties and wood density.

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Conflict of interests:

The authors declare not to have any interest conflicts.

Authors' contribution:

The authors have participated in the writing of the work and analysis of the documents



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