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PHYSICAL PROPERTIES OF THE WOOD OF *Didymopanax morototoni* (Aubl.) Decne. & Planch., TAMBOPATA, MADRE DE DIOS, PERU

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Resumo

Parâmetros físicos da madeira de Didymopanax morototoni (Aubl.) Decne. & Planch., *Tambopata, Madre de Dios, Peru.* As propriedades físicas da madeira constituem um aspecto fundamental para avaliar o uso adequado de espécies florestais pouco conhecidas, bem como para identificar alternativas frente às espécies comerciais tradicionais, atualmente vulneráveis devido à sobreexploração. Nesse contexto, o objetivo do estudo foi determinar os parâmetros físicos da madeira de *Didymopanax morototoni* (Aubl.) Decne. & Planch. (sacha uvilla). A metodologia foi desenvolvida em quatro etapas: identificação e coleta da árvore, transformação mecânica das toras, seleção de vigotas e preparação de corpos de prova conforme a direção de corte, seguindo as Normas Técnicas Peruanas NTP 251.008, 251.010, 251.011 e 251.012, com um nível de confiabilidade de α=0,05. Os resultados mostraram um teor de umidade (CH) de 90,295 %, um teor de umidade máxima (CHM) de 181,858 %, um teor de umidade livre (CHL) de 149,192 %, um teor de umidade de equilíbrio (CHE) de 13,472 % e um ponto de saturação das fibras (PSF) de 30,357 %. A densidade saturada (D) foi de 0,806 g/cm³, a densidade seca em estufa (Do) de 0,492 g/cm³ e a densidade básica (DB) de 0,425 g/cm³. As retrações registradas foram: longitudinal (Cl) 0,356 %, radial (Cr) 4,85 %, tangencial (Ctg) 8,89 % e volumétrica (Cv) 13,554 %. A porosidade da madeira foi de 55,921 % e o índice de estabilidade (T/R) de 1,834, valor considerado estável. Com base nesses resultados, *D. morototoni* foi classificada no grupo III, sendo considerada adequada para móveis, formas, forros e compensados.
Palavras-chave: xilema, umidade, densidade, retração, porosidade, índice de estabilidade.

Abstract

The physical properties of wood are fundamental for evaluating the appropriate use of lesser-known forest species and for identifying alternatives to traditional commercial species, which are now vulnerable due to overexploitation. In this context, the objective of this study was to determine the physical parameters of *Didymopanax morototoni* (Aubl.) Decne. & Planch. (sacha uvilla) wood. The methodology was developed in four stages: tree identification and collection, mechanical transformation of logs, selection of beams, and preparation of specimens according to the cutting direction, following Peruvian Technical Standards NTP 251.008, 251.010, 251.011, and 251.012, with a confidence level of α=0.05. The results showed a moisture content (MC) of 90.295%, a maximum moisture content (MMC) of 181.858%, a free moisture content (FMC) of 149.192%, an equilibrium moisture content (EMC) of 13.472%, and a fiber saturation point (FSP) of 30.357%. The normal density (ND) was 0.806 g/cm³, the oven-dry basic density (OD) was 0.492 g/cm³, and the basic density (BD) was 0.425 g/cm³. The recorded shrinkages were: longitudinal (L) 0.356%, radial (R) 4.85%, tangential (T) 8.89%, and volumetric (V) 13.554%. The wood porosity was 55.921% and the stability index (T/R) was 1.834, a value considered stable. Based on these results, *D. morototoni* was classified within group III, making it suitable for furniture, formwork, ceilings, and plywood.
Keywords: Xylem, humidity, density, contraction, porosity, stability index.

INTRODUCTION

Didymopanax morototoni (Aubl.) Decne. & Planch., commonly known as "huarmi huarmi," "sacha uvilla," and "hueso" Vásquez Martínez; Rojas Gonzáles (2022), is a tree species that reaches heights of up to 30 m Gartland; Bohren (2008). It is a species of high ecological value, although it is rarely used in forest plantations Lores Torrero (2018).

Among the most common physical parameters that can be measured in wood are density, moisture content, shrinkage, bending strength, hardness, and weight. Studying the physical and mechanical properties of wood is essential to expand knowledge about its potential uses, adapt its applications, and evaluate it as a viable alternative to other materials Braz *et al.* (2013). Density can be determined by different methods, such as water immersion or direct measurement of weight and volume. Moisture content is also an important property, as its variation significantly affects the strength and durability of wood. Shrinkage refers to the reduction in wood dimensions as a result of water loss Samuel V. Glass; Zelinka (2021). Density is the most commonly used physical property as a quality index for wood utilization, due to its correlation with most physical-mechanical properties. The utilization and interest in wood largely depend on these physical parameters (density, shrinkage, swelling, fiber saturation point, anisotropy, among others), each with specific requirements depending on the intended use Welling *et al.* (2023). Dimensional changes in wood, such as shrinkage and swelling, occur between different saturation states, taking the fiber saturation point as a limit, and are expressed in the tangential, radial, and longitudinal directions. The magnitude of these changes determines the behavior of wood under moisture variations, especially during drying.

According to anatomical and physical studies, this species presents barely visible pores, some solitary and others multiple, with diffuse porosity, and indistinct sapwood and heartwood, ranging in color from yellowish-white to grayish-white Ramalho Carvalho (2014). Its basic density varies between 0.36 and 0.40 g/cm^3 Escobar C; Rodriguez (1995), In Brazil, the apparent specific mass of the wood is moderately dense (0.53 to 0.60 g/cm^3), at a moisture content between 12% and 15%. Likewise, in Colombia, a green moisture content of 81.69% and 11.09% in air-dried condition were reported, associated with a basic density of 0.42 g/cm^3. The same authors recorded, for normal shrinkage (from green to air-dry), values of 5.42% tangential, 3.18% radial, 0.05% longitudinal, and 7.48% volumetric; and for total shrinkage (from green to oven-dry), 8.42% tangential, 4.46% radial, 0.19% longitudinal, and 13.26% volumetric, with a T/R ratio of 1.97 Vargas Avila; Giraldo Benavides (2019).

There are no studies on the physical properties of *D. morototoni* in the Madre de Dios region, Peru, which represents a relevant information gap considering that this species has high ecological value and still underexplored potential uses. Generating knowledge about its physical parameters not only expands alternatives to traditional commercial species but also provides baseline information for future ecological, taxonomic, and sustainable forest management studies. Therefore, the general objective of this research was to determine the physical parameters of *D. morototoni*, specifically saturated density, oven-dry basic density, basic density, porosity, shrinkage, expansion, stability index, and moisture content levels of the wood.

MATERIALS AND METHODS

Location

The study was carried out in the Wood Properties Laboratory of the Pilot Plant for Wood Technology at the Amazonian National University of Madre de Dios, located 16.5 km southeast of Puerto Maldonado, in the Madre de Dios region, Peru, with UTM coordinates 484,925 E and 8,622,337 S.

Wood material and sample

The wood ofv *D. morototoni* (sacha uvilla) was obtained from the property of the company Acuicultura Integral Roalca, located 10 km along the Interoceanic Highway Puerto Maldonado–Iñapari. The species was identified through botanical and dendrological samples from each of the three sampled trees. These samples were taken to the "Alwyn Gentry" Herbarium of the Amazonian National University of Madre de Dios, where species identification was confirmed (Figure 1). The population and sample were determined considering the reference of the National Institute for Quality and Standards INACAL. NTP 251.008 (2016).

Figure 1: Tree (A), logs (B) and test specimens (C) of *D. morototoni.*
Figura 1: Árvore (A), toras (B) e corpos de prova (C) de *D. morototoni*.

Determination of the Physical Properties of Wood

To determine the physical properties, 120 specimens measuring 2.5× 2.5×10 cm were selected according to ASTM D143-94 (2018), distributed among the three sampled trees, with 40 specimens per tree. Each specimen was selected to ensure well-defined radial and tangential cutting planes. After coding, the dimensions and masses corresponding to the green condition of each specimen were recorded. Subsequently, the specimens were oven-

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dried using progressive temperature increments of 10 °C, with daily gravimetric monitoring until reaching the standard temperature of 105 °C.

The data obtained from the 120 experimental units were subjected to descriptive statistical analysis. The relationship between moisture content levels and basic density was evaluated using Pearson's correlation coefficient (r), complemented by simple linear regression models for each moisture variable analyzed, with a significance level of $\alpha = 0.05$. All statistical analyses and graphical representations were performed using the R software environment with the ggplot2, tidyverse, and readxl packages.

Moisture Content:

The moisture content of the specimens was determined from their green weight (Pi) and oven-dry weight (Po), corresponding to a final moisture content between 6% and 10%. This procedure was carried out according to INACAL Standard NTP 251.010 (2014).

$$\mathrm{MC} = \frac{\mathrm{P_i - P_o}}{\mathrm{P_o}} \times 100 \quad (1)$$

Where: MC = Moisture content of the specimen. Pi = Initial weight of the specimen. Po = Final weight of the specimen.

Volume

Two methods were used to determine specimen volume: the indirect water displacement method, used to obtain the saturated volume of the specimen, and the direct method, based on measuring specimen width, height, and length, which was used to calculate shrinkage. Both procedures followed INACAL Standard NTP 251.011 (2014).

$$\mathrm{Vh\ (directo)} = \mathrm{Ah} \times \mathrm{Hh} \times \mathrm{Lh}\ \mathrm{y}\ V_O = A_O \times H_O \times L_O \quad (2)$$

Where: MV = Volume of the wet specimen. Vo = Volume of the oven-dried specimen. Ah = Width of the wet specimen. Hh = Height of the wet specimen. Lh = Length of the wet specimen. Ao = Width of the dry specimen. Ho = Height of the dry specimen. Lo = Length of the dry specimen.

Normal Density, Basic Density, and Oven-Dry basic Density

Normal density, basic density, and oven-dry basic density were determined according to the procedure established in INACAL Standard NTP 251.011 (2014).

$$\mathrm{ND} = \frac{m}{\mathrm{Vh}} g/cm^3 \quad (3)$$

$$\mathrm{BD} = \frac{mo}{\mathrm{Vh}}\ g/cm^3 \quad (4)$$

$$\mathrm{OD} = \frac{mo}{\mathrm{Vo}} g/cm^3 \quad (5)$$

Where: ND = Normal (saturated) density of the specimen. BD = Basic density of the specimen. OD = Oven-dry basic density of the specimen. m = Wet (green) mass of the specimen. mo = Oven-dry mass of the specimen. Vh = Wet (green) volume of the specimen. Vo = Dry volume of the specimen.

Moisture Content Levels

Unlike moisture content (MC), which was calculated directly from the green and oven-dry weights of each specimen, the maximum moisture content (MMC), free moisture content (FMC), equilibrium moisture content (EMC), and fiber saturation point (FSP) could not be determined directly because the experimental procedure did not include complete saturation of the specimens or stabilization under equilibrium environmental conditions. Therefore, these parameters were estimated from the basic density of each specimen using the equations developed by Rosales-Solórzano (2020) for forest species from Madre de Dios, Peru, considering that these equations were calibrated using data from the same study region.

$$\mathrm{MC} = \frac{\mathrm{P_i - P_o}}{\mathrm{P_o}} \times 100 \quad (6)$$

$$\mathrm{MMC} = 597.96\mathrm{e}^{-2.843\mathrm{BD}} \quad (7)$$

$$\mathrm{FMC} = 583.96\mathrm{e}^{-3.263\mathrm{BD}} \quad (8)$$

$$\mathrm{FSP} = 14.678\mathrm{BD}^{-0.83} \quad (9)$$

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$$EMC = -4.141\mathrm{Ln}(BD) + 9.8939 \quad (10)$$

Where: MC = Moisture Content. MMC = Maximum Moisture Content. FMC = Free Moisture Content. FSP = Fiber Saturation Point. EMC = Equili-brium Moisture Content.

Porosity

La porosidad de las probetas se determinó a partir de la densidad básica en el punto de saturación de las fibras, mediante la fórmula propuesta por Siau (1984):

$$P\% = [1 - BDfsp\ (0.667 + 0.01Mfsp)]100 \quad (10)$$

Where: BD~fsp = Basic density at the fiber saturation point. M~fsp = Moisture content at the fiber saturation point.

Shrinkage

Volumetric, tangential, radial, and longitudinal shrinkage were determined according to INACAL Standard NTP 251.012 (2016).

$$\mathrm{Vc}\ (\%) = \frac{Vh - Vs}{\mathrm{Vs}} \times 100 \quad (11)$$

$$\mathrm{Tc}\ (\%) = \frac{dts - dto}{\mathrm{dts}} \times 100 \quad (12)$$

$$\mathrm{Rc}\ (\%) = \frac{drs - dro}{\mathrm{drs}} \times 100 \quad (13)$$

$$\mathrm{Lc}\ (\%) = \frac{ls - lo}{\mathrm{ls}} \times 100 \quad (14)$$

Where: Vc = Volumetric shrinkage. Tc = Tangential shrinkage of the wood. dts = Tangential dimension of the saturat-ed specimen, dto = Tangential dimension of the oven-dried specimen, Rc = Radial shrinkage of the wood, drs = Radial dimension of the saturated specimen, dro = Radial dimension of the oven-dried specimen, Lc = Longi-tudinal shrinkage. ls = Longitudinal dimension of the saturated specimen. lo = Longitudinal dimension of the oven-dry specimen.

Wood Classification Groups

The classification of wood groups according to moisture content levels and basic density is presented in Table 1.

Table 1. Wood classification ranges according to moisture levels related to basic density.
Tabela 1. Faixas de classificação das madeiras de acordo com os níveis de teor de umidade em relação à densidade básica.

Classification by humidity groups		HUMIDITY LEVELS (%)				BD
		EMC	FSP	FMC	MMC	($g.cm^{-3}$)
Group A	Very low (MB)	< 11.1	< 18.5	< 50	< 70	> 0.75
Group B	Low (BA)	11.1 - 12	18.51 - 22.2	50 - 80	70 - 107	0.61 – 0.75
Group C	Medium (ME)	12.01- 13.6	22.21 - 30.8	80.01 - 155	107.01 - 187	0.41 – 0.60
Group D	High (AL)	13.61 - 14.8	30.81 - 39	155.01 - 215	187.01 - 257	0.30 – 0.40
Group E	Very high (MA)	> 14.8	> 39	> 215	> 257	< 0.30

Fountain: Rosales Solórzano (2018).

Additionally, MVCS (2021) classifies hardwood species according to their basic density (g/cm³) into Group A (> 0.71 g/cm³), Group B (0.56–0.70 g/cm³), Group C (0.40–0.55 g/cm³), and Group D (0.36–0.39 g/cm³).

RESULTS

Moist to dry condition of the Wood

Figure 2 shows the variation between the green and oven dry conditions of the wood, evidencing a reduction in specimen dimensions after reaching the anhydrous state. The longitudinal dimension decreased by 0.04 cm, the radial dimension by 0.12 cm, and the tangential dimension by 0.23 cm. Likewise, a weight loss of 24.44 g and a volume reduction of 11.45 cm³ were recorded.

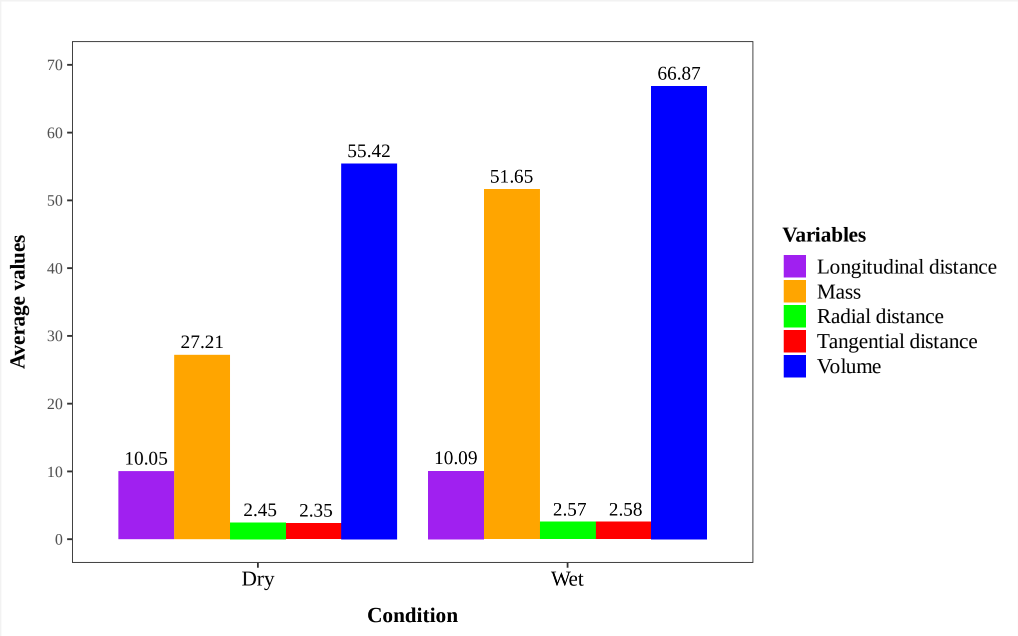

Figure 2. Mass, volume, tangential, radial and longitudinal distance of the specimens.
Figura 2. Massa, volume e dimensões tangencial, radial e longitudinal dos corpos de prova.

Variabilidade das propriedades físicas da madeira

Table 2. Physical parameters of *D. morototoni* wood.
Tabela 2. Parâmetros físicos da madeira de *D. morototoni.*

	Physical parameters	Mean	Coefficient of variation (%)	Maximum	Minimum
Humidity Levels (%)	Maximum moisture content (MMC)	181.858	14.494	244.667	133.167
	Free moisture content (FMC)	149.192	16.648	209.345	104.149
	Fiber saturation points (FSP)	30.357	10.285	38.357	24.928
	Equilibrium moisture content (EMC)	13.472	4.013	14.686	12.521
	Moisture content (MC)	90.295	8.636	104.866	68.402
Density (g/cm³)	Basic density (BD)	0.425	12.729	0.530	0.314
	Oven-dry basic density (DO)	0.492	13.177	0.653	0.364
	Normal density (ND)	0.806	10.966	1.025	0.568
Contraction (%)	Tangential shrinkage (Tc)	8.899	28.696	14.398	3.680
	Radial shrinkage (Rc)	4.850	28.417	8.462	2.056
	Longitudinal shrinkage (Lc)	0.159	19.510	0.209	0.100
	Volumetric shrinkage (Vc)	13.554	24.279	22.866	5.427
Space empty (%)	Porosity (P)	55.921	12.910	72.035	43.012
Stability	Stability Index	1.653	24.973	3.019	1.013

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Moisture content levels showed coefficients of variation ranging from 4.0% to 16.6%, with equilibrium moisture content (EMC) exhibiting the lowest variability and free moisture content (FMC) the highest. The evaluated densities (basic, oven-dry basic, and saturated) showed an increasing trend and similar coefficients of variation. In contrast, shrinkage values exhibited greater dispersion, particularly radial and tangential shrinkage, with coefficients of variation exceeding 28%, indicating a more heterogeneous response of the wood to moisture loss in these directions.

Relationship Between Moisture Content Levels and Basic Wood Density

Figure 3 shows the relationship between moisture content levels and basic density, indicating that some moisture parameters exhibit stronger correlations than others. The observed negative correlation is explained by the inverse relationship between moisture content levels and basic density. Specifically, correlation coefficients of 0.997, 0.996, 0.993, 0.998, and 0.579 were obtained for maximum moisture content (MMC), free moisture content (FMC), fiber saturation point (FSP), equilibrium moisture content (EMC), and moisture content (MC), respectively, indicating good to very strong correlations among the evaluated variables.

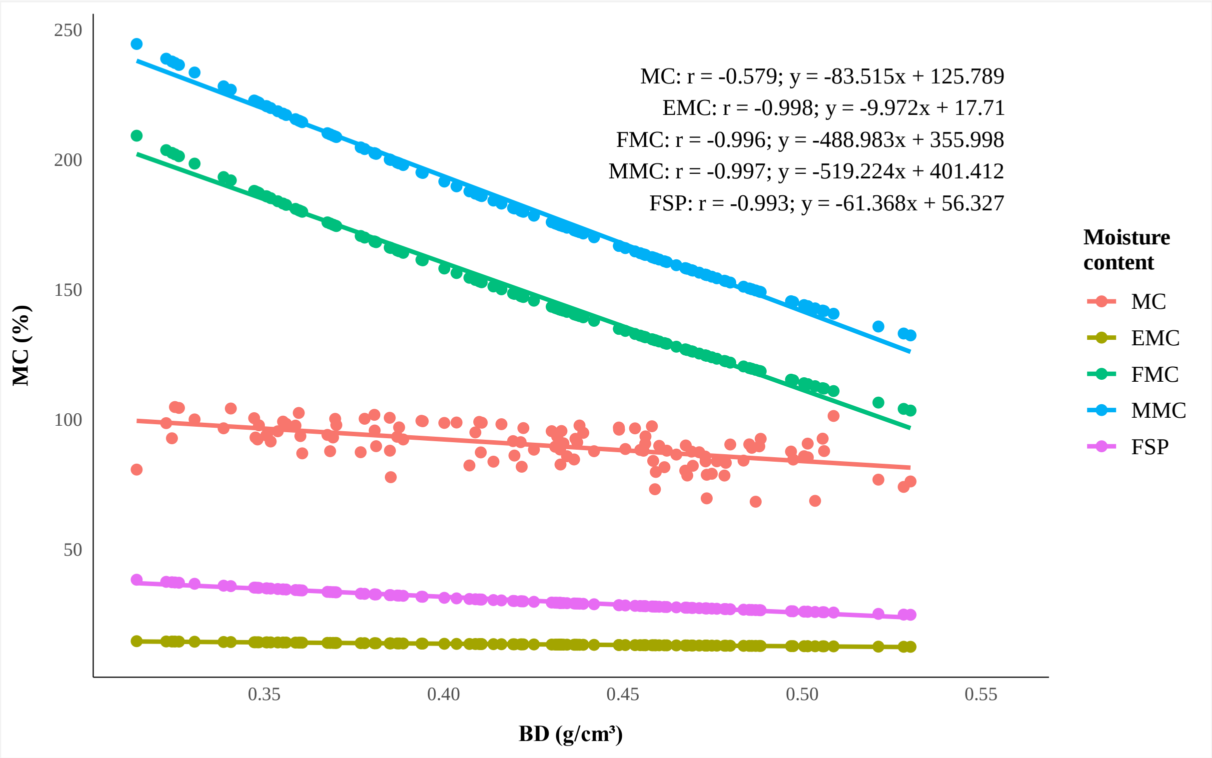

Figure 3. Relationship between moisture content (MC) and basic density (BD).
Figura 3. Relação entre o teor de umidade (CH) e a densidade básica (DB).

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Densidad

Figure 4 shows that the mean basic density was 0.425 g/cm³, classifying the wood as lightweight, since its basic density is below 0.50 g/cm³, according to MVCS (2021). According to Rosales Solórzano (2018) *Didymopanax morototoni* (0.425 g/cm³) is classified within wood group C, which is characterized by medium basic density.

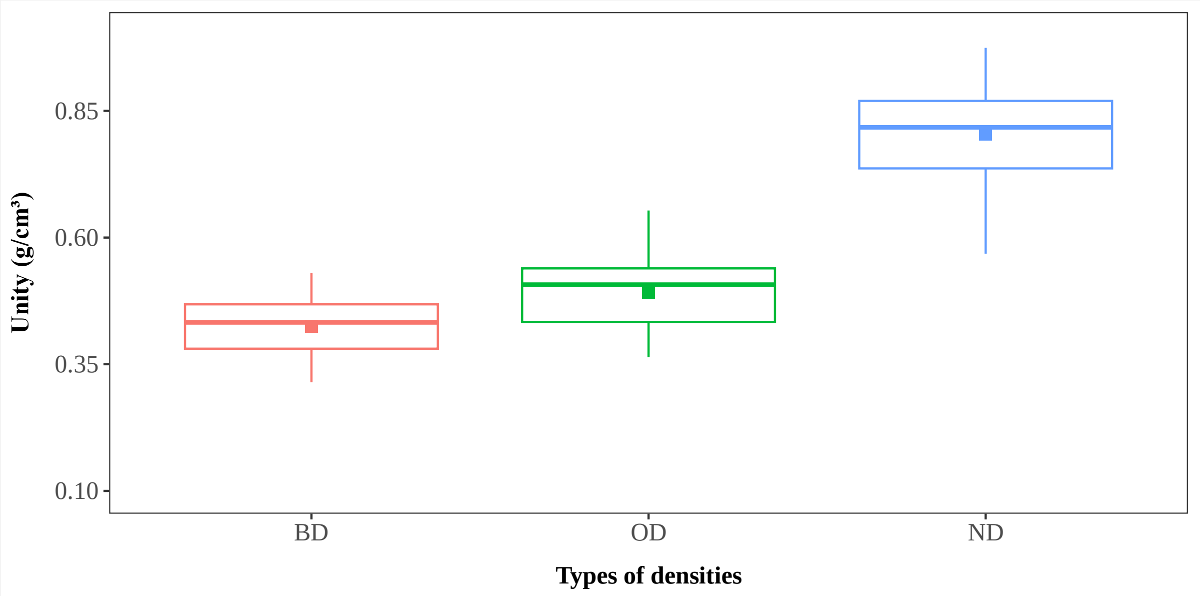

Figure 4. Box plot showing variability and mean of data across density types.
Figura 4. Diagrama de caixas mostrando a variabilidade e os valores médios dos diferentes tipos de densidade.

DISCUSSION

The reduction observed in the dimensions, weight, and volume of the specimens from the green to the oven-dry basic condition reflects the direct effect of water loss on the cellular structure of wood, a phenomenon widely documented by Samuel V. Glass; Zelinka (2021). This dimensional change occurs mainly as bound water is removed from the cell walls after the fiber saturation point has been exceeded.

Compared with the results reported by Vargas Avila; Giraldo Benavides (2019), who recorded a moisture content of 81.69% and an equilibrium moisture content of 11.09% for the same species in Colombia, the values obtained in the present study (90.295% and 13.472%, respectively) were considerably higher. However, Bohren *et al.* (2013) reported an equilibrium moisture content of 15%, which is higher than the value found in this study. These differences may be attributed to environmental conditions specific to each site of origin, such as precipitation, relative humidity, and average temperature, which directly influence the amount of water that wood can retain under natural conditions. Likewise, intrinsic factors such as tree age, the stem position from which the specimens were obtained, and genetic variability among populations may also explain part of these differences. Among the variables analyzed, equilibrium moisture content (EMC) showed the strongest correlation with basic density ($r = -0.998$), suggesting that, unlike maximum moisture content (MMC), free moisture content (FMC), or fiber saturation point (FSP), EMC is less sensitive to individual variability among specimens and is a more consistent predictor based on basic density.

The basic density of *D. morototoni* (0,425 g/cm (0.425 g/cm³) obtained in this study is close to the values reported by BOLFOR. (1998) (0.40 g/cm³ at 12% moisture content) and Vargas Avila; Giraldo Benavides (2019) (0.42 g/cm³), although it is slightly lower than the value of 0.45 g/cm³ reported by Bohren *et al.* (2013). This moderate variability is consistent with what is expected for a species with a broad geographic distribution, since wood density is influenced by the edaphic and climatic conditions of the growing site, as well as by tree growth rate. The internal variability of the data, evidenced by the height of the box plots in Figure 4, also supports this interpretation. Saturated density exhibited the widest range of variation (0.568–1.025 g/cm³), followed by oven-dry basic density (0.364–0.653 g/cm³) and basic density (0.314–0.530 g/cm³), suggesting a greater occurrence of extreme values under conditions of higher moisture content. According to the classification proposed by Arostegui (1975) and Rosales Solórzano (2018), in which very light woods have basic densities below 0.30 g/cm³ and very heavy woods exceed 0.75 g/cm³, *D. morototoni* is classified as a medium-density wood species.

Regarding volumetric shrinkage, the results place *D. morototoni* in Group 4 according to INACAL Standard NTP 251.012 (2016), which is characterized by high volumetric shrinkage, indicating considerable dimensional changes in response to variations in moisture content. However, the obtained T/R ratio (1.653) classifies the wood as dimensionally stable because tangential shrinkage does not reach twice the radial shrinkage, a condition that would indicate dimensional instability according to the same criterion. This combination of high volumetric shrinkage and a stable T/R ratio suggests that although the wood undergoes considerable dimensional changes during drying, these changes occur proportionally in the different anatomical directions, thereby reducing the risk of defects such as checking and warping. Compared with the results reported by Vargas Avila; Giraldo Benavides (2019), who found tangential, radial, longitudinal, and volumetric shrinkage values of 8.42%, 4.46%, 0.19%, and 13.26%, respectively, the values obtained in the present study were slightly higher in all directions. These differences may again be explained by differences in growing conditions among provenances as well as possible variations in the drying methodology. Likewise, Bohren *et al.* (2013) reported a T/R stability index of 1.97, which is higher than the value obtained in the present study (1.653), indicating relatively greater dimensional stability in the wood analyzed in this research.

The porosity determined for *D. morototoni* (55.921%) largely explains its classification as a wood with medium to low basic density, since a higher proportion of void spaces reduces the amount of woody material per unit volume Rodríguez; Vergara (2008). This inverse relationship between porosity and density also explains the species' high water-holding capacity, reflected in its high maximum and free moisture content values, as the pore spaces act as reservoirs for free water within the woody tissue. This pattern is consistent with the observations of Kollmann (1959), who indicated that lighter woods tend to be more porous and, consequently, retain larger amounts of water than denser woods.

CONCLUSION

- Based on the results obtained, it is concluded that *Didymopanax morototoni* exhibits physical properties characteristic of a medium-density wood, with a basic density of 0.425 g/cm³, high water-holding capacity, and considerable volumetric shrinkage, while maintaining good dimensional stability as indicated by its T/R ratio (1.653). According to these properties, the species is classified within wood group C, making it suitable for applications such as furniture, formwork, ceiling panels, and plywood.
- These findings represent the first physical characterization of *D. morototoni* in the Madre de Dios region of Peru and provide valuable baseline information to support its sustainable utilization as an alternative to traditional commercial timber species currently subjected to greater harvesting pressure. Furthermore, the results contribute to future research on sustainable forest management and conservation in the Peruvian Amazon.

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