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Physicochemical and mechanical characterization of *Brosimum lactescens* and *Parkia discolor* wood from Guaviare, Colombia

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Caracterización físicoquímica y mecánica de la madera *Brosimum lactescens* y *Parkia discolor* del Guaviare, Colombia

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ABSTRACT

Keywords:
Bending
Density
Holocellulose
Lignin
Parallel compression

Colombia has numerous wood species of great importance; however, information on many of these species is scarce. For this reason, the woods Guaimaro (*Brosimum lactescens*) and Dormidero negro (*Parkia discolor*) cultivated in Calamar (Guaviare) were studied, with the aim of determining their properties and enhancing their rational use. The evaluations were carried out following the Colombian Technical Standards NTC 290, 663, 701 and 784. Density was evaluated according to NTC 290; shrinkage and stability coefficient were determined following the NTC 701; the holocellulose content was according to the procedure of Wise, the lignin content and extractives were determined as described by TAPPI T 222 and T 204; the mechanical bending strength with NTC 663 and to calculate the parallel compression under the NTC 784. The Guaimaro is a very dense wood, dimensionally stable and of high resistance to bending and parallel compression being of optimal use for construction with extractives of 18.52%, holocellulose of 65.59% and lignin of 35.81%; it presents higher lignin contents than other species of the same genus. The Dormidero negro has a medium density, low dimensional stability, and low resistance to static bending and parallel compression. It is not suitable for construction, but it can be used for carpentry. The chemical composition was consistent with that of other species in the same genus, with extractives at 15.88%, holocellulose at 69.30%, and lignin at 31.77%. Expanding mechanicaltests, such as hardness and shear tests, is recommended, along with exploring treatments to enhance its properties.

RESUMEN

Palabras clave:
Flexión
Densidad
Holocelulosa
Lignina
Compresión paralela

Colombia cuenta con numerosas especies maderables de gran importancia; sin embargo, la información de muchas de estas especies es escasa. Por ello, se estudiaron las maderas Guaimaro (*Brosimum lactescens*) y Dormidero negro (*Parkia discolor*) manejadas en Calamar, Guaviare; con el objetivo de determinar sus propiedades y propender por su uso racional. Se evaluó la densidad siguiendo la Norma NTC 290; las contracciones y coeficiente de estabilidad se determinaron con la Norma NTC 701; los contenidos de holocelulosa mediante el procedimiento de Wise, el contenido de lignina y los extractivos se determinaron como se describe en TAPPI T 222 y T 204; la resistencia mecánica a flexión con la Norma NTC 663 y compresión paralela Norma NCT 784. El Guaimaro es una madera muy densa, muy estable dimensionalmente y de alta resistencia a la flexión y compresión paralela, siendo de óptimo uso para construcción; con extraíbles de 18,52%, holocelulosa de 65,59% y lignina de 35,81%; presenta mayores contenidos de lignina que otras especies del mismo género. El Dormidero negro presentó mediana densidad, poco estable dimensionalmente, de baja resistencia a la flexión estática y a la compresión paralela, no aptas para construcciones, si para la ebanistería; la composición de contenidos químicos fue igual a otras especies del mismo género, extraíbles 15,88% holocelulosa 69,30% y lignina 31,77%. La composición química fue coherente con la de otras especies del mismo género, con un 15,88% de extractivos, un 69,30% de holocelulosa y un 31,77% de lignina. Se recomienda ampliar las pruebas mecánicas, como las de dureza y cizallamiento, y estudiar tratamientos para mejorar sus propiedades.

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Brosimum lactescens is a native species to the region known as the “Atlantic Forest” which is located along the southeastern end of Brazil, it grows over 2,700 meters above sea level (masl) and, because to this long altitudinal gradient, both temperature and precipitation have very wide spectra throughout the territory, therefore, the mean annual temperature varies between 20 and 25.1 °C (Carneiro 2014), while the average annual rainfall is between 1,000 and 4,000 mm depending on the area. Given these factors, it is possible to identify areas of endemism in this region (Lazos et al. 2017). In addition to the above, it has been distributed throughout northern South America thanks to the Amazon, so it has been able to reach out to countries such as Bolivia, Colombia, Peru and Venezuela (dos Santos et al. 2020), even going to Central America where the species has been sampled, especially in Costa Rica (Quesada-Monge and Fernández-Vega 2012), therefore, it may occur in humid tropical forests and very humid tropical forests (dos Santos et al. 2020). When they pass to dominate the canopy, their height usually ranges from 18 to 35 m, being common to be close to 30 m. Leaves are simple, alternate, elliptic to oblong. Fruits are sub globose drupes about 1-2 cm in diameter, yellow or orange when ripe, simple, alternate (Spichiger et al. 1989), acuminate apex, it presents exudate both in leaves and stem, which is white and abundant (Flores 2014). It is known by the vulgar name of Chimicua or White Palisangre in Peru (Villacorta 2011; Flores 2014). Quecho in Bolivia (Poorter et al. 2001) and Ojoche in Costa Rica (Quesada-Monge and Fernández-Vega 2012). The seeds can be eaten boiled, roasted, or fried. It is also used milled to make tortillas.

Their fruits support the diet of the avifauna, and their leaves and sap are used in folk medicine. It also presents good potential to be used as an ornamental plant, as well as it is widely used in places where it lives by the production of latex, fodder resources, folk medicine and the production of its fruits, in addition, it has significant properties that give high value to its timber and non-timber products, so it is included as species of potential value of sustainable exploitation (Minorta-Cely et al. 2019).

Parkia discolor is a native species to South America, in Venezuela, Colombia, Peru and northern Brazil. Its habitat is the Amazon rainforest, in open areas on floodplains on poor, white and sandy soils of the Amazon rainforest (Pereira and Ferreira 2010; Guariguata and Kattan 2002). It has managed to make way in the Amazon Forest so it is possible to be found in lands adjacent to the Amazon basin, such as the Atlantic Forest and the Brazilian. This species is found in the Orinoco River basin in Venezuela and Colombia (Ramos and Varela 2003), extending along the gradient there present, thus offering a suitable model for the study of germination behavior in response to water availability. Pereira and Ferreira (2010) mention that it is one of the species of the genus *Parkia* with 15 m in height. Leaves are compound and alternate; inflorescence showy, of capilliform type, and its horizontal axis projects beyond the foliage; its fruits in the form of pods are oblong, coriaceous, and indehiscent and contain between 9 and 15 seeds. It is a species that largely tolerates flooding; therefore, it is capable of remaining underwater for long periods. That said, it requires sites with low disturbances to develop correct functioning and growth (Pereira and Ferreira 2010). This species does not have a common name because it is not commonly found; however, in Colombia, it is known as Dormidero (Galindez and García-R 2011), while in Venezuela it is called ´Casabe de murciélago´ (Vidondo 2014), on the other hand, in many texts, mainly of Portuguese language refer to this principally ´visgueiro-do-igapó´, like other variations such as araratucupi and faveira, although these are ways of calling other species of the genus *Parkia* (Hopkins 1986; Pereira and Ferreira 2010; Pereira and Ferreira 2017). It can be used in a range of ways, ranging from timber to non-timber products, stands out as gum, due to its fruits having similar properties to those found in gum Arabic, and also has medicinal characteristics that have been used by various communities (Ahmed 2018); finally, it has ornamental and ecological potential (Ramos and Varela 2003). At the industrial level, wood is considered a vital resource used in the building sector, pulp for paper, biomaterial production and clean energy generation. In this context, the importance of characterizing the chemical properties of wood is due to the direct impact that its basic composition has on its ability to retain water as well as their characteristics of flexibility, strength and rigidity. These aspects are fundamental for determining the behavior of wood in various industrial applications, enabling its optimal use and ensuring performance under diverse conditions. Natural forest wood is therefore a renewable natural resource of great ecological and economic importance for many regions around the world. In forest ecosystems, wood is the main structural component and performs various functions in the provision of ecosystem services such as soil and water conservation, carbon capture and storage, and biodiversity conservation (Fichtner and Härdtle 2021).

In recent years, interest in the study and marketing of new and lesser-used timber species from natural forests has increased to reduce over-exploitation and pressure of more traditional and demanded species; this makes poorly studied woods potential substitutes for high-value tropical species (Sseremba et al. 2011). In this sense, the communities of Puerto Cubarro in Calamar (Guaviare) manage the woods of *Brosimum lactescens* and *Parkia discolor* in a sustainable way by using extraction techniques that do not affect the health of the forest. With controlled harvesting and the implementation of appropriate management practices, which ensures the preservation of ecosystems, avoiding deforestation and promoting long-term sustainability.

From this perspective, knowledge of wood in terms of its physical properties, such as shrinkage and density, is essential for a sustainable and efficient use of this resource (Dong et al. 2016). Shrinkage of wood, which is the change in wood dimensions according to moisture content is one of the most important parameters to consider in the design and manufacture of wood products in order to eliminate future defects and unstable dimensions (Sargent 2019). Wood density, on the other hand, is a key indicator of wood quality in terms of mechanical strength and load capacity, which determines its suitability to be used in different structural applications and moved in the global market (Ramage et al. 2017).

Proper knowledge of the contraction and density of these new species is crucial to developing sustainable forest management techniques, establishing criteria for the classification and selection of woods, and optimizing their industrial and commercial processing. Through a solid understanding and application of knowledge about these fundamental physical properties of wood, these vital ecosystems can be protected and conserved and at the same time, facilitate the development of related industries and the promotion of a circular and sustainable economy (Arriaga et al. 2023).

Thus, the aim of this study was to characterize the wood by determining density, shrinkage, resistance to bending and compression parallel to fibers; as well as holocellulose, lignin and wood contents of *Brosimum lactescens* and *Parkia discolor* species cultivated in Calamar (Guaviare) region.

MATERIALS AND METHODS

Materials

The woods were extracted from the Puerto Cubarro sidewalk (1°50 32” N, 72°42 40.2” W) in the municipality of Calamar located on the left bank of the Unilla River belonging to the Department of Guaviare, 80 km from San José del Guaviare the capital with a mean annual precipitation of 2,800 mm, mean temperature up to 26.5 °C, and relative humidity >80% (Figure 1).

Ten trees of each species of *Parkia discolor* and *Brosimum lactescens* were used; all the activities of directed logging and of preparation for their extraction from the forest were included. Felling operations involved cutting the standing tree, measurement to determine the ideal size of the logs, limbing and bucking. Its fall was directed in order to reduce damage to the remaining mass and thus ensure forest sustainability. Good fuel management was ensured in all harvesting operations to avoid spills that altered soil conditions or caused a fire.

The logs were sawn and dimensioned for the extraction of samples or wooden specimens that after an airdrying process were measured and tested to technologically characterize the species under study. The test pieces were elaborated following the methodology proposed by the American Society for Testing and Materials (ASTM 2003) and the Colombian technical standards (NTC), which establish the procedures both in specifications of the test pieces, test speed and number of samples to be tested.

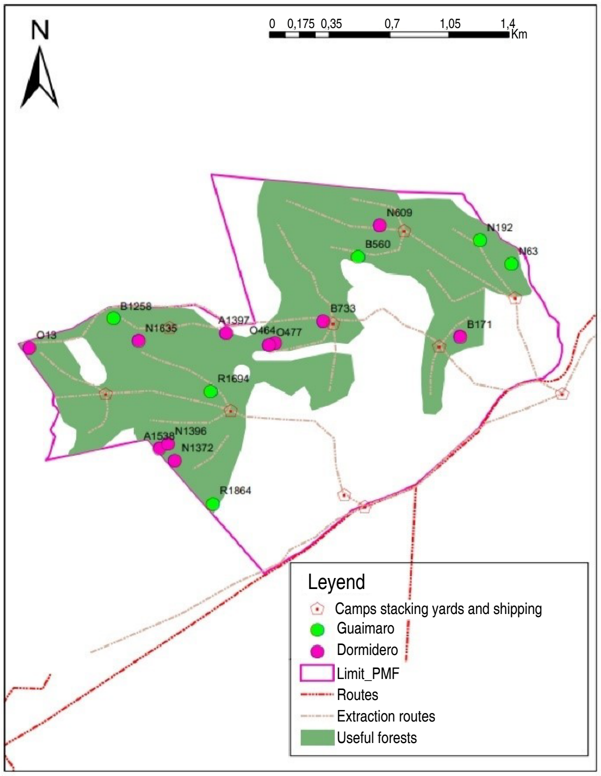

Figure 1. Location map of the trees under study, Puerto Cubarro, in the Calamar region (Guaviare).

From each log, a central plank 8 cm thick was taken for the length of the log, from which two lumbers were obtained, maintaining very well-differentiated radial and tangential orientations, from which the test pieces necessary for each of the tests were obtained (Figure 2).

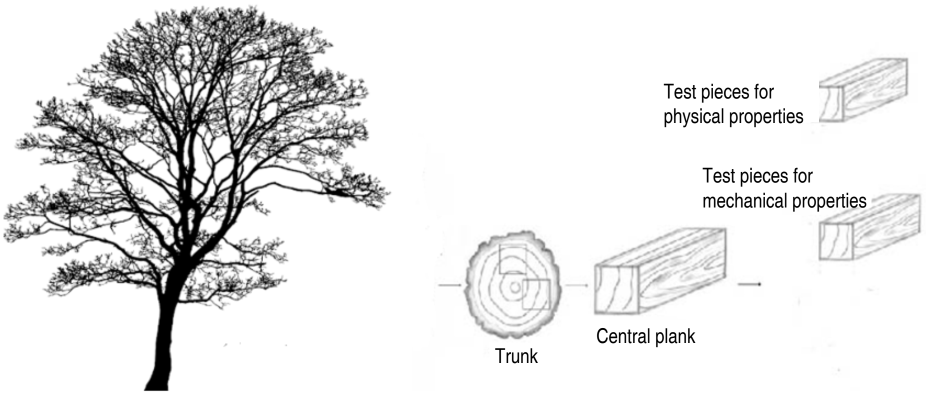

Figure 2. Scheme of wood extraction.

For the physical properties, 20 test pieces per species with a dimension of 3x3x10 cm length were used. To determine wood density under different moisture content conditions, the Colombian Technical Standard NTC 290 (ICONTEC 2006) was followed and to determine the radial, tangential, longitudinal and volumetric contractions of the wood following the NTC 701.

Mechanical properties characterization

For the mechanical properties, 20 test pieces were extracted with dimensions of 5x5x20 cm, as established by the Colombian Technical Standard NTC 663 (NTC 2006), and 2.5x2.5x41 cm according to NTC 784 (NTC 2006), to calculate the parallel compression and static bending tests of the two forest species, which were free of defects such as knots, piths, cracks, missing edges, etc.

To evaluate the mechanical properties, the wood was taken to a dry-air (moisture content close to 12%). The tests were carried out in a Tinius Olsen universal testing machine with a load capacity of 15,000 kilograms.

Determination of chemical composition

The holocellulose content was determined using sodium chlorite according to the procedure of Wise et al. (1946). In a beaker, 150 mL of 1.5% (w/w) sodium chlorite solution were poured into 2 g of wood, and 10 drops of glacial acetic acid and the sample was placed in a water bath at 75 °C for 1 h. After that hour, 10 drops of glacial acetic acid and 1.5 g of sodium chlorite were added, it was cyclically repeated every hour, for a total period of 4 h. After chlorination, the solution was filtered, washed with 200 mL of cold water, followed by 10 mL of acetone; the residue was taken to a conventional oven at 105 °C until constant weight.

The lignin content was determined as described by TAPPI T 222 om-02 (2002). 15 mL of 72% sulfuric acid (w/w) were added to 1 g of wood sample, stirring it for 10 min and letting it stand for 2 h. Subsequently, 575 mL of distilled water were added and it was boiled for 4 h maintaining a constant volume, if necessary distilled water was occasionally added. Finally, it was filtered in Büchner funnels and the samples were repeatedly washed until the acid residues were removed. Finally, samples were brought to constant weight in an oven at 105 °C. All measurements were made in 12 replicates for each chemical composition determination (one sample per tree). Data were presented as percentages on a dry basis.

The extractive content was determined as described by TAPPI T 204 CM-97 (1997). 100 mL of NaOH to 1% were added to 2 g of wood sample, stirring it with a glass rod for 10 seconds, and placed the sample in a water bath, letting the water in the boiling bath for 1 h (97 °C); after bath, it was stirred again for 25 minutes. The digestion material was filtered and neutralized by adding 25 mL acetic acid to 10% for 1 min, then it was washed with 100 mL of hot water. The previous step was repeated, with a second portion of 25 mL of acetic acid to 10% for 1 min, then washed again with hot water leaving the material free of acid. Finally, they were brought to constant weight in an oven at 105 °C.

Data analysis

The statistical analysis was performed using a completely randomized experimental design for each test, with the help of the Statgraphics software. The information was processed according to the methodology described by Hoshmand (2006).

RESULTS AND DISCUSSION

Physical properties

The results of density, dimensional stability coefficient (DSC) obtained for Guaimaro (*Brosimum lactescens* (S. Moore) C.C. Berg) *are presented in* Table 1 and for Dormidero negro (*Parkia discolor* Spruce ex Benth) in Table 2.

The results of the physical properties appear in each box and are represented as follows:

$\bar{y}$	$\pm$	q
	CVt	

Where, $\bar{y}$ is Mean, ± q is 95% Confidence Interval and CVt is the total coefficient of variation.

Table 1. Physical properties of the wood *Brosimum lactescens* (S. Moore) C.C. Berg species.

	Green (MC:45%)	Air-dry (MC:14%)	Anhydrous	Basic
Density (kg m^{-3})	1,048.28±21.27 4.33%	938.22±20.03 4.56%	898.85±20.33 4.83%	760.96±19.52 5.48%
	Tangential	**Radial**	**Volumetric**	**Dimensional Stability Coefficient (DSC)**
Shrinkage				
Total (%)	9.64±42.96	7.55±0.14	17.91±0.27	1.28±0.029
From green to oven-dry	9.09%	4.02%	3.27%	4.81%

Table 2. Physical properties of the wood *Parkia discolor* Spruce ex Benth species.

	Green (MC:45%)	Air-dry (MC:14%)	Anhydrous	Basic
Density (kg m^{-3})	750.11±53.28 15.17%	640.00±63.67 22.71%	605.22±66.46 23.46%	540.61±55.55 21.56%
	Tangential	**Radial**	**Volumetric**	**Dimensional Stability Coefficient (DSC)**
Shrinkage				
Total (%)	6.06±0.41	2.62±0.16	8.86±0.4	2.36±0.21
From green to oven-dry	14.61%	13.29%	11.32%	19.42%

The Guaimaro is considered a high-density wood due to the value obtained in dry air density of 938.22 kg m^{-3} and is classified as a heavy wood thanks to the anhydrous density value obtained of 898.85 kg m^{-3}; values that are within the range suggested by the ASTM (760-1,000 kg m^{-3}). According to the basic density classification of the NTC 2500 (*Civil Engineering and Architecture*. Using *Wood* for *Construction*), the wood of *Brosimun lactescens* species belongs to Group A, making it useful for construction with 760.96 kg m^{-3} (greater than 710 kg m^{-3}). These results are equal to those obtained by Rosales-Solórzano et al. (2018) in studies made for the same wood. Still, they are higher than those found for the wood of *Brosimun alicastrum* species, which has medium density and belongs to the Group B category used for construction purposes (Escobar and Rodríguez 1993).

The wood of Guaimaro (*B. lactescens*) has a high total volumetric shrinkage of 17.91%, placing it in the range suggested by the ASTM (15-20%). The wood has a very stable dimensional stability coefficient (DSC) of 1.28% (less than 1.5%), which determines its suitability for construction.

The Dormidero Negro is a wood of medium density and moderately heavy, with a dry air density of 640.00 kg m^{-3} and an anhydrous density of 605.22 kg m^{-3} range suggested by the ASTM (510-750 kg m^{-3}). The wood of *Parkia discolor* belongs to Group C, it is considered not suitable for heavy constructions and high resistance with 540.61 kg m^{-3} (400-550 kg m^{-3}). These results were similar to those reported by de Miranda et al. (2012) and were higher than those obtained in *Parkia biglobosa* wood (Ataguba et al. 2015).

The wood of Dormidero negro (*P. discolor*) presents a low total volumetric shrinkage of 8.86%, placing it in the range suggested by the ASTM (less than 10%). The wood is dimensionally unstable with a Dimensional Stability Coefficient (DSC) of 2.36% (greater than 1.8%); which makes it unsuitable to be used as a raw material for construction. These results are equal to those obtained for the wood of *Parkia biglobosa* (Ataguba et al. 2015).

Mechanical properties

The results of the mechanical characterization of the wood Guaimaro (*Brosimum lactescens*) species are presented in Table 3 and Table 4 for the wood of Dormidero negro (*Parkia discolor*).

The response of Guaimaro wood to static bending is considered to be of a slightly high resistance according to ASTM standards with a modulus of rupture of 1,293.16 kg cm^{-2} (1,260-1,519 kg cm^{-2}) and slightly high elasticity with MOE of 168.41x10^3 kg cm^{-2} (156-185 kg cm^{-2}), superior to that reported by Escobar and Rodríguez (1993) of 142x10^3 kg cm^{-2} for the wood of the species *Brosimun alicastrum*.

Table 3. Mechanical properties of the wood Brosimum lactescens species.

Condition	Static bending			Compression parallel
	ELP	MOR	MOEx10^3	MOR
	(kg cm^{-2})			
Air-dry 12%	890.02±12.92 13.10%	1293.16±62.09 10.26%	168.41±19.48 24.72%	786.82±25.13 16.82%

Table 4. Mechanical properties of the wood *Parkia discolor* Spruce ex Benth species.

Condition	Static bending			Compression parallel
	EPL	MOR	MOE x10^3	MOR
	(kg cm^{-2})			
Air-dry 12%	197.58±12.79 13.82%	713.50±67.47 20.21%	51.02±4.75 19.83%	92.24±6.73 15.58%

The response of the wood of Guaimaro (*B. lactescens*) to stress resistance in compressions parallel considers the wood to have high resistance to such compressions according to ASTM standards with compression parallel of 786.82 kg cm^{-2} (750-1,049 kg cm^{-2}), superior to that reported for the same wood of the species *B. alicastrum* of 725 kg cm^{-2} (Escobar and Rodríguez 1993). It can be used as wooden roofs, columns and pillars, wooden beams, wood for structures, etc.

The wood of Dormidero negro (*Parkia discolor*) presents low resistance to static bending with a modulus of rupture of 713.50 kg cm^{-2} (754-510 kg cm^{-2}) and very low elasticity with MOE of 51.02x10^3 kg cm^{-2} (43-71 kg cm^{-2}) according to ASTM standards, lower than those reported for *Parkia gigantocarpa* and *Parkia biglobosa* wood (de Miranda et al. 2012; Ataguba et al. 2015).

The response of Dormidero negro (*P. discolor*) wood is of very low resistance to compression parallel to the grain of 92.24 kg cm^{-2} (less than 479 kg cm^{-2}) according to ASTM standards, equal to those reported for *P. gigantocarpa* wood (de Miranda et al. 2012) and less than those obtained for *Parkia biglobosa* wood (Ataguba et al. 2015. It could be used to manufacture boxes or packaging that are not exposed to high pressures. It can also be employed in modular construction systems with low structural load and in decorative elements, such as picture frames, mirrors, or ornaments, where aesthetics and ease of handling are prioritized over strength.

Chemical composition
The composition of the polysaccharides obtained for the Guaimaro (*Brosimum lactescens*) wood and Dormidero negro (*Parkia discolor*) are listed in Table 5.

Table 5. Results for the chemical composition of the woods of *Brosimun lactescens* and *Parkia discolor* species.

	Holocellulose (%)	Lignin (%)	Extractives (%)
Brosimun lactescens	65.59±3.19	35.81±5.27	18.52±4.35
	8.96%	5.91%	9.45%
Parkia discolor	69.30±2.51	31.77±3.55	15.88±3.55
	7.45%	4.50%	9.07%

The holocellulose contents for Dormidero negro wood were similar to those reported for *P. pendula* and *P. timoriana* woods (Wahyuni 2018; Batista et al. 2021). The amount of lignin was similar to those reported for *P. pendula* and *P. timoriana* woods (Wahyuni 2018; Batista et al. 2021).

The wood of Guaimaro presented low contents in the polysaccharides formed by holocellulose of 65.60%, which were lower than those reported for the wood *B. alicastrum* of 81.05% (Castañeda 1986). Regarding lignin contents, they were 35.81% higher than those reported for *B. alicastrum* wood of 20.44% (Castañeda 1986).

The percentage of extractives for Guaimaro (*Brosimun lactescens*) wood was on average 18.52%, similar to that obtained for *Brosimum alicastrum* (17.51%), in studies conducted by Castañeda (1986) following the same procedure.

The percentage of extractives for Dormidero negro (*Parkia discolor*) wood is comparable to that presented by Batista et al. (2021); but greater than those obtained for *Parkia timoriana* wood (Wahyuni 2018).

CONCLUSION

The Guaimaro (*Brosimum lactescens*) is a wood of very good dimensional stability. It is a high-density wood classified as hardwood; it belongs to Group A, meaning that it can be used for construction purposes. It has high resistance to different bending strengths and compression parallel. This wood contains higher lignin content than other species in the same genus.

On the other hand, the wood of Dormidero Negro (*Parkia discolor*) presents very low dimensional stability. The wood of medium density; belongs to Group C undesirable for heavy constructions, but it can be used for carpentry. It presents low responses to mechanical properties. In terms of chemical composition, they are equal to other species in the same genus.

To expand the knowledge base, further investigations are recommended on their response to conventional drying treatment and alternative methods, such as thermal modification for the woods of Guaimaro (*Brosimum lactescens*) and Dormidero negro (*Parkia discolor*), which can modify their internal structure and thus improve a greater dimensional stability and hydrophobicity of these woods.

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