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Anatomical characterization of wood from three tree species from a floodplain forest, Central Amazon, Brazil

Caracterización anatómica de la madera de tres especies de árboles de un bosque de llanura inundable, Amazonía Central, Brasil

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SUMMARY

The anatomical structure of wood from tree species found in floodplain forests can undergo alterations due to seasonal fluctuations in water levels, potentially affecting the volume of wood available for sustainable forest management in inundated areas. Thus, this study aims to characterize the anatomical features of *Hura crepitans*, *Ocotea cymbarum* and *Eschweilera albiflora*, assessing whether these characteristics differ from descriptions reported in previous studies of the same species conducted in other environments. Samples were collected from six adult trees of each species in two sustainable development reserves (SDR), Mamirauá and Amanã, located in the middle Solimões region, state of Amazonas, using a non-destructive method with an increment borer. Two samples were collected from three different heights (0.30, 1.30, and 2.30 m). Microscopic descriptions of the species were determined (porosity, axial parenchyma, rays, fibers, and vessel elements). Two-way factorial ANOVA followed by Tukey's post hoc test was used to verify the differences in the anatomical elements of the wood samples collected at the three heights. The wood of *H. crepitans* has diffuse porosity, a predominance of solitary vessels, diffuse-in-aggregates, scarce axial parenchyma, non-storied rays, and libriform fibers. The wood of *O. cymbarum* has solitary vessels in radial multiples, vasicentric axial parenchyma, non-storied rays, and septate fibers. *E. albiflora* has a radial grouping of vessels, banded parenchyma, and non-storied rays. This study confirms previous descriptions of this species, revealing that its anatomical characteristics remain constant throughout the trunk.

Keywords: Wood anatomy, *Hura crepitans*, *Ocotea cymbarum*, *Eschweilera albiflora*, non-destructive methods.

RESUMEN

La estructura anatómica de la madera de las especies de árboles que se encuentran en los bosques de llanuras aluviales puede sufrir alteraciones debido a las fluctuaciones estacionales en los niveles de agua, afectando potencialmente el volumen de madera disponible para el manejo forestal sostenible de las áreas inundadas. Así, este estudio tiene como objetivo caracterizar las características anatómicas de *Hura crepitans*, *Ocotea cymbarum* y *Eschweilera albiflora*, evaluando si estas características difieren de las descripciones reportadas en estudios previos de las mismas especies realizados en otros ambientes. Se recolectaron muestras de seis árboles adultos de cada especie en dos reservas de desarrollo sustentable (RDS), Mamirauá y Amanã, ubicadas en la región media de Solimões, estado de Amazonas, utilizando un método no destructivo con barrenador incremental. Se tomaron dos muestras en cada una de tres alturas diferentes (0,30, 1,30 y 2,30 m). Se determinaron descripciones microscópicas de las especies (porosidad, parénquima axial, radios, fibras y elementos de los vasos). Se utilizó ANOVA factorial de dos vías seguido de la prueba post hoc de Tukey para verificar las diferencias en los elementos anatómicos de las muestras de madera recolectadas en las tres alturas. La madera de *H. crepitans* tiene porosidad difusa, predominio de vasos solitarios, difusos en agregados y escaso parénquima axial, radios no estratificados y fibras libriformes. La madera de *O. cymbarum* tiene vasos solitarios en múltiplos radiales, parénquima axial vasicéntrico, radios sin pisos y fibras septadas. La madera de *E. albiflora* tiene agrupaciones radiales de vasos, parénquima bandeado y radios sin pisos. Este estudio confirma descripciones previas de la especie, revelando que las características anatómicas permanecen sustancialmente constantes en todo el tronco.

Palabras clave: anatomía de la madera, *Hura crepitans*, *Ocotea cymbarum*, *Eschweilera albiflora*, método no destructivo.

INTRODUCTION

The floodplain areas of the Amazon Estuary follow the banks of rivers, lakes, streams, and ponds. These areas cover a territorial extension of 75,880.8 km², representing approximately 1.6 % of the Brazilian Amazon area and are exposed to flood cycles influenced by tides. Regular flooding constitutes a restrictive element for species to establish themselves, resulting in a notable difference in species composition between dryland and floodplain areas (Junk *et al*. 2014).

The species studied, *Hura crepitans* L. (Euphorbiaceae), *Ocotea cymbarum* Kunth (Lauraceae), and *Eschweilera albiflora* (DC.) Miers (Lecythidaceae) are native to the Amazon biome, with a confirmed occurrence in northern Brazil, rainforests, floodplains, and igapó areas. The wood of these species has several applications, including the production of plywood and other laminated products, construction of houses and other structures, boats, and furniture (LPF 2023), and providing income to regional communities through sustainable forest management.

According to data from the Ministry of the Environment (MMA 2024), in the 2020 – 2024 period, in the northern region of Brazil alone, 899,363 forest guides (FGs) and documents of forest origin (DOF) were issued or requested in the northern region of Brazil alone. These documents are necessary for the sale and transport of wood and its products throughout the country. Among these documents, 8,412 were intended for *Hura crepitans*, 6,889 for *Ocotea cymbarum*, and 192 for *Eschweilera albiflora*, covering 22, 21, and seven types of wood products, respectively.

In the Amazon, it is common for wood from different species to be identified by the same vernacular name, mainly because of their similar characteristics such as color, smell, texture, and hardness. The abundance of species and the similarity of wood sold in this region result in the frequent misidentification of species, both intentionally and unintentionally, causing discredit in the market (Reis 2015). In transport registration documents, *Hura crepitans* have been recorded with eight different vernacular names, *Ocotea cymbarum* with eight vernacular names, and *Eschweilera albiflora* with only one vernacular name, according to data from the Ministry of the Environment (MMA 2024).

The identification of forest species is mainly based on the characteristics of flowers, leaves, and fruits. However, for the marketing of logs, wood anatomy is essential for identification (Souza *et al*. 2015). Knowledge of a species' wood anatomical structure is of fundamental importance because the use of wood can vary depending on specific anatomical characteristics. This also helps avoid waste and inappropriate use (Motta *et al*. 2014).

The study of the wood anatomy of Amazonian species is important because this ecosystem harbors immeasurable and poorly understood biodiversity (Souza *et al*. 2015). This can be attributed to the difficulty of access and vast territorial extension of the region. Furthermore, anatomical characterization helps understand wood behavior in response to seasonal fluctuations in flood and dry periods, as observed in floodplain species. According to De Micco *et al*. (2016), these species undergo adaptation to overcome challenges posed by extreme conditions.

Anatomical characterization of wood species found in floodplain forest areas in the Amazon is still limited. Most of the descriptions available in the literature refer to wood from dryland-forested areas. Therefore, it is essential to characterize these species in this ecosystem, especially because they are exploited for forest management. This study contributes to a better understanding of the possible changes in the anatomical structure of species influenced by water conditions compared to those in dry land areas. Furthermore, these differences may affect the volume of wood available for sustainable forest management in flooded areas.

The objective of this study is to describe the microscopic characteristics of the wood of *H. crepitans*, *O. cymbarum*, and *E. albiflora*, which are native to a floodplain forest area in the middle Solimões region of Amazonas. Additionally, this study aimed to investigate whether variations in river fluctuation influence the anatomical features of these species compared to their equivalents in dryland environments, and to evaluate variations in anatomical structure relative to trunk height.

METHODS

Study area. Wood samples used for anatomical characterization were collected from the middle Solimões region, near the city of Tefé in the state of Amazonas, within two sustainable development reserves. The first collection area was situated in the Mamirauá Sustainable Development Reserve (MSDR), which is located in the central-west region of the state of Amazonas (03° 08' S and 64° 45' W to 02° 36' S and 67° 13' W). This reserve spans 1,240,000 hectares of floodplain forest area and is bounded by the Solimões, Japurá, and Auati Paraná Rivers.

The other study area was the Amanã Sustainable Development Reserve (ASDR), one of the largest protected tropical forest areas in South America, covering approximately 2,350,000 ha. The ASDR encompasses parts of two western Amazonian watersheds, the Solimões River and Negro River basins, within an area located between coordinates 01° 35' 43" " and 03° 16' 13" S and 62° 44' 10" and 65° 23' 36" W.

The climate of the region is classified as humid tropical, with an average annual precipitation of 2,373 mm. The flood season (high water) in the region is from May to July, with a peak flooding in June. At the end of July, the ebb season begins, during which drought primarily occurs in September, October, and November.

Sample collection. Wood samples for anatomical analysis of *Hura crepitans*, *Ocotea cymbarum*, and *Eschwei-*

lera albiflora were collected during the dry season using a nondestructive method employing an increment borer. Six adult individuals of each species were sampled at three different heights: H1, at the base of the tree (0.30 m above the ground); H2, at DBH (1.30 m above the ground); and H3, closer to the branches (2.30 m above the ground), in order to cover a representative variation of the trunk during flood periods. Two samples were collected at each height from opposite directions.

All the collected materials were identified in the field and stored separately in folders with dividers. Botanical material from each species was collected, and all samples were sterile. The vernacular name was determined "in loco" by an experienced parabotanist, and the material was sent to the INPA herbarium for further identification. All evaluated species were registered in the National System for Genetic Heritage Management (SisGen) under code A66D164.

Sample preparation. The wood specimens were immersed in distilled water for 72 h for softening. Transverse, radial, longitudinal, and tangential longitudinal sections were prepared using a sliding microtome with thicknesses ranging from 15 to 20 µm.

To prepare permanent slides, sections were clarified using household bleach (sodium hypochlorite), washed in distilled water, and stained with 1 % alcoholic safranin. Subsequently, the sections were dehydrated in an ascending alcohol series (30 %, 50 %, 70 %, 95 %, and 100 % absolute alcohol), immersed in butyl acetate, and mounted on glass slides using Canada balsam (IAWA Committee 1989).

To prepare macerated material for fiber analysis, small wood fragments were collected and transferred to test tubes containing a macerating solution composed of hydrogen peroxide and glacial acetic acid in a 1:1 ratio (Franklin 1945). The material was placed in a kiln at 60 °C for 48 h. After this period, the material was rinsed three times with running water, stained with 1 % alcoholic safranin dye, and mounted on temporary slides using glycerin (Franklin 1945).

Anatomical description of the wood. For wood characterization, both qualitative and quantitative observations of anatomical elements were performed using the IAWA Hardwood List (IAWA Committee 1989). All anatomical element analyses were viewed and photographed using a microscope equipped with a video camera and an image analysis system using Motic Images Plus 3.0. Analyses were performed at the Wood Anatomy and Technology Laboratory of the Federal Rural University of the Amazon, Capitão Poço Campus.

Statistical analysis. A two-way factorial ANOVA (species × height) was performed at a 5 % significance level to determine whether there were differences among the anatomical elements of the floodplain wood species. The Shapiro-Wilk normality test, implemented with the Nortest package, was applied at a 5 % significance level to assess the normality of the residuals. Heteroscedasticity was tested using the Lavene method with the Lawstat package. A post hoc Tukey's test was conducted at 5 % significance to verify the differences in the anatomical elements of wood among the studied heights. The variables exhibited homoscedasticity and a normal distribution of residuals. All analyses were performed using R software.

RESULTS

General descriptions

- *Hura crepitans*

The growth ring boundaries are indistinct. Diffuse-porous, with solitary vessels most common and some radial multiples of two and three (figure 1A), tangential diameter average 129 µm (SD = 22); range 87–184 µm, up to 3 vessels mm^{-2} (table 1). Vessel elements (VE) have simple perforation plates (figure 1E) and alternate polygonal intervessel pits.

Fiber libriform, non-septate (figure 1D), average length of 1,119 µm (SD = 115 µm), ranging from 962 µm to 1,329 µm (table 1). These fibers fall within the category of short fibers (900-1,600 µm), which are common in angiosperms (IAWA Committee 1989).

The average fiber wall thickness (WT) and lumen diameter (LD) of the species were 3.31 µm (SD = 0.46) and 22.57 µm (SD = 2.75), respectively (table 1; figure 1E). The lumen of the species is approximately three times wider than the wall, classifying the fibers as having thin walls (IAWA Committee 1989).

The axial parenchyma showed diffuse-in-aggregates and scant paratracheal parenchyma (figure 1A).

Rays non-storied, primarily uniseriate with occurrence of multiseriate portions (figure 1B), all ray cells procumbent (figure 1C), heights of 8 to 13 cells, ranging 239 - 455 µm; the number of rays per linear millimeter varies from 4 to 8 (table 1).

Rhomboidal crystals in parenchyma cells, two per cell, were observed in macerated samples (figure 1E) and radial sections (figure 1C).

- *Ocotea cymbarum*

The growth ring boundaries are indistinct. Diffuse-porous, vessels solitary and in radial multiples, tangential diameter ranges from 74 - 179 µm with average of 117 µm (sd = 23) (table 1). Vessel frequency: 3-11 vessels mm^{-2}. Vessel elements had simple perforations and polygonal alternate intervessel pits (figure 4F).

Fibers (figure 2D) were septate and libriform, non-storied (figure 2C; IAWA Committee 1989), with an average length of 1,288 µm (SD = 209) and a range from 964 to 1,986 µm (table 1). The average WT and LD of

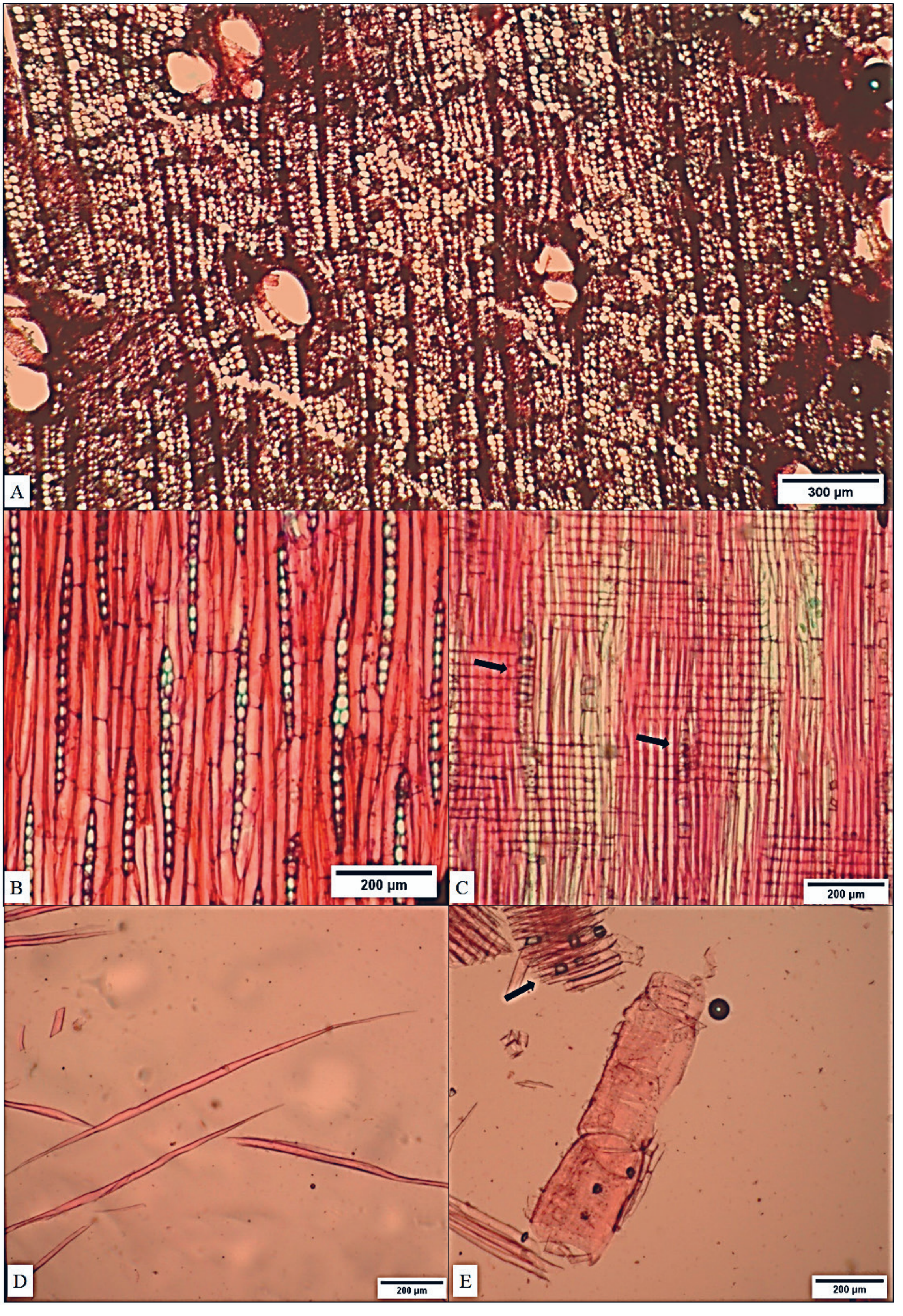

Figure 1. *Hura crepitans* - transverse section (A), longitudinal tangential (B), longitudinal radial (C), fibers (D), and vessel elements (E). Rows indicate crystals in axial parenchyma.

Hura crepitans - sección transversal (A), longitudinal tangencial (B), longitudinal radial (C), fibras (D) y elementos vasculares (E). Las flechas indican cristales en el parénquima axial.

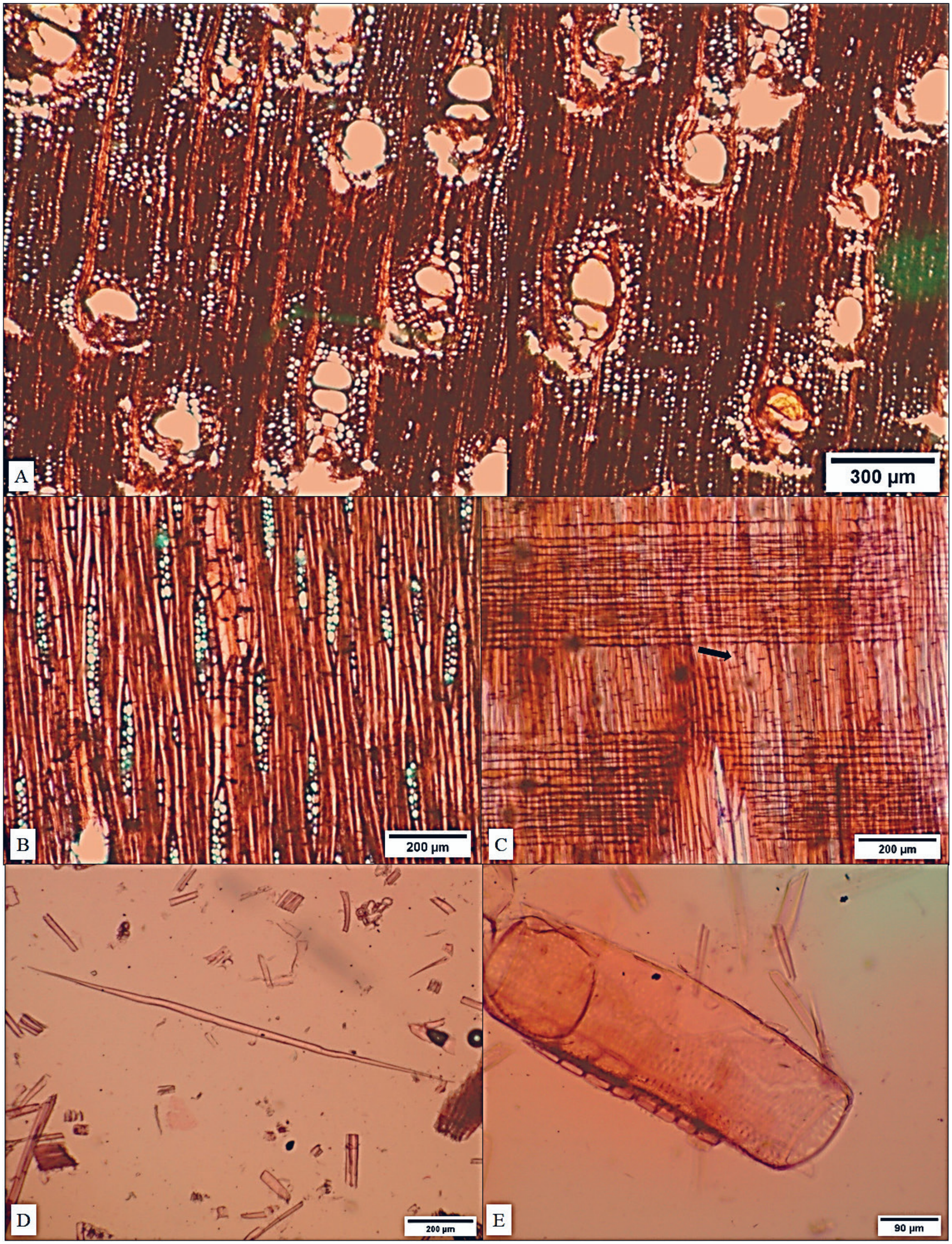

Figure 2. *Ocotea cymbarum* - transverse section (A), longitudinal tangential (B), longitudinal radial (C), fibers (D), and vessel elements (E). The arrow indicates the presence of an oil cell.

Ocotea cymbarum imágenes - sección transversal (A), longitudinal tangencial (B), longitudinal radial (C), fibras (D) y elementos vasculares (E). La flecha indica la presencia de celda de aceite.

O. cymbarum were 4.51 µm (sd = 0.88) and 15.35 µm (sd = 1.36), respectively (table 1; figure 2E).
Axial parenchyma paratracheal vasicentric, with a tendency toward confluent (figure 2A).
The rays were non-storied (figure 2B), and ray cells were predominantly procumbent (figure 2C). Occasionally, a single marginal row of square/upright cells is observed. Rays mostly biseriate, ray heights of 15-28 cells and 231-460 µm. Rays per linear millimeter 3 to 6 (table 1).
Oil cells (figure 2C) occasional, dispersed among the fibers.

- *Eschweilera albiflora*

The growth ring boundaries are indistinct. Wood diffuse-porous, with vessels solitary and in radial multiples and clusters (figure 3A), tangential diameter ranges from 62 to 221 µm, average of 112.00 µm (sd = 28.98). Approximately five vessels mm^{-2} (table 1). The vessels had simple perforation plates and alternate intervessel pits (figure 3E).
Fibers were libriform, non-storied, and non-septate (figure 3D; IAWA Committee 1989). The average fiber length was 1,388 µm (SD = 98.00), ranging from 1,223 to 1,548 µm (table 1). The average WT and LD values were 4.79 µm (SD = 0.46) and 6.43 µm (SD = 0.76), respectively (table 1).
Axial parenchyma in narrow bands up to three cells wide (figure 3A).
Rays were non-storied, mostly two cells wide (figure 3B), and homocellular, composed of procumbent cells (figure 3C). The ray heights of the 9-42 cells were 231-460 µm, with 3-12 per mm (table 1).

Table 1. Variation in the mean values of the anatomical characteristics assessed in the wood of *Hura crepitans*, *Ocotea cymbarum*, and *Eschweilera albiflora* as a function of tree height.

Variación de los valores medios de los caracteres anatómicos evaluados en la madera de *Hura crepitans*, *Ocotea cymbarum* y *Eschweilera albiflora*, en función de la altura de la arból.

Species x Height	Vessels		Rays				Fibers		
	Diameter (µm)	Number mm^{-1}	Height (µm)	Height (cell)	Width (cell)	Rays mm^{-1}	Length (µm)	Lumen Diameter (µm)	Wall Thickness (µm)
Hura crepitans									
H1	123 Aa	2 Aa	358 Aa	10 Ac	1 Aa	5 Aa	1,123 Aa	24 Aa	3 Aa
H2	123 Aa	2 Aa	362 Aa	11 Ab	1 Aa	5 Aa	1,123 Aa	23 ABa	3 Aa
H3	140 Aa	2 Aa	358 Aa	11 Ab	1 Aa	5 Aa	1,113 Aa	20 Ba	3 Aa
Mean and Standard Deviation	129 a ± 22	2 c ± 1	359 b ± 49	11 b ± 2	1 c ± 0	5 b ± 1	1,119 b ± 115	23 a ± 3	3 b ± 0
Ocotea cymbarum									
H1	115 Aa	5 Aa	334 Aa	19 Ab	2 Aa	4 Aa	1,232 Aa	15 Ab	4 Aa
H2	114 Aa	5 Aa	328 Aa	20 Aa	2 Aa	4 Aa	1,335 Aa	16 Ab	4 Aa
H3	123 Aa	5 Aa	363 Aa	21 Aa	2 Aa	4 Aa	1,296 Aa	15 Ab	5 Aa
Mean and Standard Deviation	117 ab ± 23	5 a ± 2	342 b ± 51	20 a ± 4	2 a ± 0	4 c ± 1	1,288 a ± 209	15 b ± 1	5 a ± 1
Eschweilera albiflora									
H1	117 Aa	4 Aa	509 Aa	24 Aa	2 Aa	7 Aa	1,448 Aa	6 Ac	5 Aa
H2	108 Aa	4 Aa	428 Aa	17 Aa	1 Aa	7 Aa	1,380 Aa	7 Ac	5 Aa
H3	110 Aa	5 Aa	427 Aa	15 Ab	1 Aa	7 Aa	1,325 Aa	6 Ac	5 Aa
Mean and Standard Deviation	112 b ± 29	5 b ± 1	455 a ± 97	19 a ± 6	1 b ± 0	7 a ± 2	1,388 a ± 98	6 c ± 1	5 a ± 0

Index (Ij) alongside the mean, where I = comparison by Tukey's test between heights (H) specifically within the species; j = comparison by Tukey's test between the species paired at the same heights. Tukey's test was considered only if the interaction between height and species was significant at the 5 % level in the F-test. Different letters in the same column are significant at the 5 % level according to Tukey's test. Different letters in the same column indicate the overall means of the three species at a 5 % significance level using the F-test.

Índice (Ij) al lado de la media, i = comparación en la prueba de Tukey entre alturas (H) específicamente dentro de especies; j = comparación en la prueba de Tukey entre especies emparejando la misma altura, se consideró la prueba de Tukey solo si la interacción entre altura y especie fue significativa al 5 % en la prueba F. Letras diferentes en una misma columna fueron significativas al 5 % en la prueba de tukey. Letras diferentes en una misma columna considerando las medias globales de las tres especies al 5 % de significancia en la prueba F.

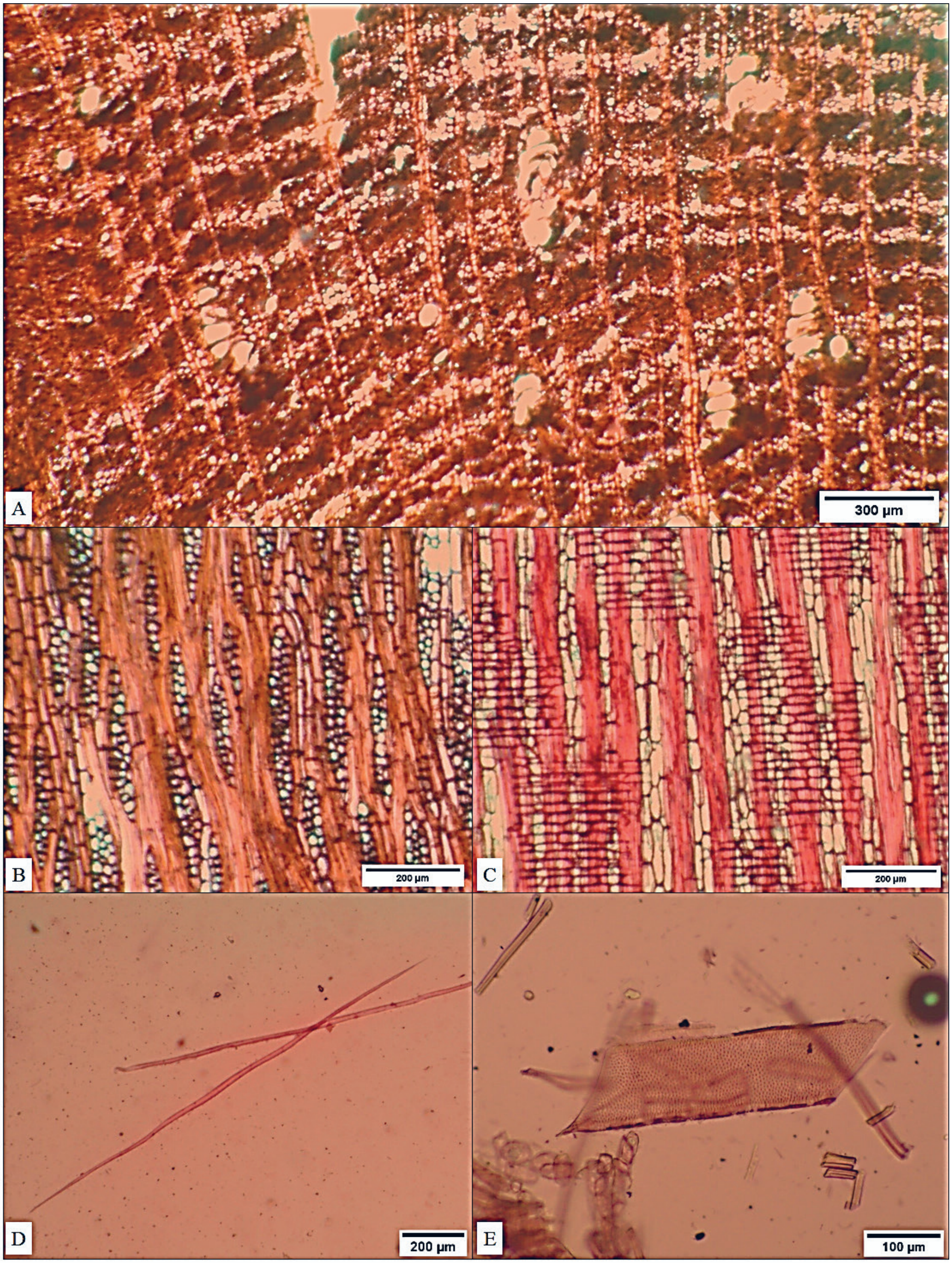

Figure 3. *Eschweilera albiflora* - transverse section (A), longitudinal tangential (B), longitudinal radial (C), fibers (D) and vessel elements (E).

Eschweilera albiflora - sección transversal (A), longitudinal tangencial (B), longitudinal radial (C), fibras (D) y elementos vasculares (E).

Quantitative anatomical variation as a function of height in the evaluated species. Only *H. crepitans* showed a difference in the lumen diameter between H1 and H3. Comparing the three species at the same height, significant differences were observed in the Tukey test ($P > 0.05$) for most of the variables related to vessels, rays, and fibers (table 1).

DISCUSSION

- *Hura crepitans*

Our observations were similar to those reported by Chavarri (2006), who described wood from a tropical Venezuelan forest. Similarities include diffuse porosity without a defined pattern, solitary vessels, radial multiples (2-3), and tangential diameters of vessels and vessels mm^{-2} (table 1), falling within the range reported by the same authors (115-214 µm), along with a low vessel frequency per mm² (1-2). Roque *et al.* (2007) described the axial parenchyma as moderately abundant, appearing as apotracheal diffuse-in-aggregates. The species may also have scanty paratracheal axial parenchyma (León y Chavarri 2006), visible only microscopically (figure 1A).
The description of the rays was similar to that of León and Chavarri (2006) and Roque *et al.* (2007), with non-storied uniseriate rays composed of procumbent cells. The height of the rays varies from 323 to 392 µm, with 5-10 rays per linear millimeter (León y Chavarri 2006). A wider range of ray heights and lower linear frequencies was observed (table 1). However, the average ray height is within the range reported by other authors. León and Chavarri (2006) observed different values for *H. crepitans* fibers with lengths ranging from 621 to 1,161 µm. They also classified the wall thickness of *H. crepitans* as either very thin or very thin. These fiber dimension details are significant because they can provide insights into potential wood uses and predict product properties.
It is noteworthy that for fibers, WT and LD exhibited the most significant variation (table 1). This phenomenon might be related to the difference in cell wall thickness in the formation of earlywood and latewood, where the former has thinner walls and the latter has thicker walls, typically occurring toward the end of the growing season. This allows for the distinction of growth rings in many species (Callado *et al*. 2013). A similar description was observed for the vessel elements of *H. crepitans*, particularly highlighting intervessel pitting (León y Chavarri 2006).
Similar to this study, the presence of two rhomboidal crystals in parenchyma cells was observed by León and Chavarri (2006). Crystals are of value from technological and diagnostic perspectives for wood anatomy and identification (IAWA Committee 1989).

- *Ocotea cymbarum*

The features observed were similar to those reported by León (2000), including solitary vessels and radial multiples of 2-4, with 6-11 vessels mm^{-2}, and tangential diameters ranging from 88 to 153 µm. Mainieri and Chimelo (1989) reported similar vessel frequencies. According to León (2000), the axial parenchyma in the wood of *O. cymbarum* is predominantly narrow paratracheal vasicentric, with the presence of confluent parenchyma.
According to León (2000), the rays of *O. cymbarum* are both heterocellular with procumbent and erect cells and homocellular with only procumbent cells. Rays are mostly biseriate, occasionally 3-seriate and 4-8 per linear mm.
The fibers of *O. cymbarum* were classified as libriform with septate fibers (figure 2D). According to the IAWA Committee (1989), fibers are classified as short (900-1,600 µm) or long (greater than or equal to 1,600 µm). According to León (2000), the fiber length range for this species is 1,187-1,516 µm. The fiber length can influence the properties of paper.
The fiber walls of *O. cymbarum* are thin-to thick-walled (IAWA Committee 1989). León (2000) classified the fiber walls of this species as medium to thick. The dimensions of WT hardwood fibers can vary from 3 µm to 5 µm (IAWA Committee 1989). According to Silva *et al*. (2007), LD has a direct relationship with fiber width and WT. In other words, the larger the LD value, the larger are the empty areas in the wood, resulting in a lower specific mass.

- *Eschweilera albiflora*

The features of *E. albiflora* we observed were similar to the characteristics of four *Eschweilera* species described by Reis y Reis (2016). They macroscopically observed the occurrence of confluent axial parenchyma in the bands of all the species. Vessel frequency falls within the range described for *Eschweilera* species collected in the Amazon, like "mata-matá," where approximately 3 to 8 vessels mm^{-2} were observed. The perforated plates were simple (Moutinho *et al*. 2012).
Rays are non-storied and heterocellular with procumbent cells in the body and some upright/square marginal cells. Rays are mostly 1-3 cells wide, and occasionally 4 cells wide. Other features include non-septate libriform fibers, with wall thicknesses ranging from thin to thick (Moutinho *et al*. 2012).

- *Variation*

The differences in wood anatomical elements can vary within the species because the environment inhabited by trees, as local characteristics directly influence formation and adaptation (De Micco *et al*. 2016). However, the similarity in abiotic factors (hydrological variation, precipitation, and soil fertility) at the locations where the studied species were found can partly explain the limited variation in anatomical elements.

According to Gonçalves *et al*. (2009), wood heterogeneity is undesirable, because it negatively affects the quality of the final product. According to Quirino *et al*. (2004), different anatomical and chemical properties of wood alter its basic density.

Wood fibers have a positive relationship with wood density; thicker walled fibers are correlated with a higher wood density, and thinner walls are correlated with a lower density. Research involving estimations using artificial neural networks (ANN) applied to the technological properties of Amazonian woods found that physical and mechanical properties were positively correlated with basic density (Reis *et al*. 2018). The three species studied have a relationship between the fiber wall thickness and density. *Hura crepitans* (0.33 to 0.39 g cm^{-3}), *O. cymbarum* (0.55 to 0.65 g cm^{-3}), and *E. albiflora* (0.86 g cm^{-3}) also have different wood densities, classified as light, medium and heavy, respectively (Loureiro y Silva 1968, Jankowsky 1990, IBAMA 1997, LPF 2023).

Floodplain areas have a pronounced influence on the anatomical structure of trees growing within them. This influence arises from the unique environmental conditions found in the floodplains, including seasonal variations in water levels and periods of inundation. These conditions affect wood structure through evolutionary adaptations that enable these trees to thrive in the distinctive and challenging conditions of flooded areas (Jokanović *et al*. 2022).

Trees in floodplains can develop distinct growth rings for many species because of the variations in water availability throughout the year. This results in a wide and well-defined ring. Furthermore, to adapt to flooding and soil instability conditions, these trees tend to develop a higher proportion of support tissues, making the wood denser and more resistant (De Micco *et al*. 2016). Wood porosity can also be greater, thereby aiding in water absorption during floods. Vessel elements are most influential in flooded environments. Species adapted to these environments can have lower wood densities and variations in chemical composition owing to prolonged exposure to water and the anaerobic decomposition of organic materials (Wittmann *et al*. 2006).

The technological properties of the wood of a species in an environment subjected to a period of inundation can differ from those of trees of the same species growing in upland areas. This is because wood formation adapts to local habitat conditions, resulting in changes in the anatomical structure and consequently, other wood properties (Firmino *et al*. 2019).

CONCLUSIONS

This study describes the anatomical features of three timber species in the Amazon floodplain region, and confirms the observations of previous studies on these species. Statistical analysis showed that the anatomical features did not substantially vary with tree height within each species, indicating that wood properties were relatively constant along the trunk.

AUTHOR CONTRIBUTIONS

WDSS: Conceptualization, Formal analysis, Methodology, Visualization, Writing – original draft, writing – review, and editing. ASS: Conceptualization, Formal analysis, Methodology, Writing – original draft, writing – review, and editing. ACSF: Conceptualization, Methodology, Writing – review and editing. PCMRR: Conceptualization, Data curation, Supervision, Writing – review and editing. LPR: Conceptualization, Data curation, Supervision, Writing – review and editing. APSF: Writing – original draft, Methodology, Visualization. TLNA: Methodology, Writing – original draft, Visualization. JXS: Methodology, Writing – original draft, Visualization. MLF: Writing – original draft, Methodology, Visualization. DG: Conceptualization, Methodology, Visualization. RNS: Conceptualization, Methodology, Visualization. PRSJ: Methodology, Writing – original draft, Visualization. MGS: Methodology, Writing – original draft, Visualization. GIBM: Supervision, Writing – review and editing. SN: Conceptualization, Data curation, Supervision, Writing – review and editing.

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REFERENCES

Callado CH, FA Roig, M Tomazello-Filho, CF Barros. 2013. Cambial growth periodicity studies of South American woody species–a review. *IAWA journal* 34(3): 213-230. DOI: https://doi.org/10.1163/22941932-00000019

De Micco V, G Battipaglia, A Balzano, P Cherubini, G Aronne. 2016. Are wood fibres as sensitive to environmental conditions as vessels in tree rings with intra-annual density fluctuations (IADFs) in Mediterranean species? *Trees* 30: 971-983. DOI: https://doi.org/10.1007/s00468-015-1338-5

Firmino AV, GB Vidaurre, JTD Oliveira, M Guedes, MNF Almeida, JG Silva, JVF Latorraca, JC Zanuncio. 2019. Wood properties of *Carapa guianensis* from floodplain and upland forests in Eastern Amazonia, Brazil. *Scientific Reports* 9: 1-10. DOI: https://doi.org/10.1038/s41598-019-46943-w

Franklin GL. 1945. Preparation of thin sections of synthetic resin and wood: resin composites, and a new macerating method for wood. *Nature* 155(3924): 5. DOI: https://doi.org/10.1038/155051a0

Gonçalves FG, JTDS Oliveira, RMD Lucia, RC Sartório. 2009. Study of some mechanical properties of wood in a clonal hybrid of *Eucalyptus urophylla* x *Eucalyptus grandis*. *Revista Árvore* 33: 501-509. DOI: https://doi.org/10.1590/S0100-67622009000300012

IAWA Committee. 1989. IAWA: list of microscopic features for hardwood identification. *IAWA Bulletin* 10(3): 219-332.

IBAMA (Instituto Brasileiro do Meio Ambiente e dos Recursos Renováveis). 1997. Madeiras da Amazônia: características e utilização. Brasília, Brazil. IBAMA. 141 p.

Jankowsky IP. Madeiras brasileiras. 1990. Caxias do Sul, Brazil. Spectrum. 172 p.

Jokanović D, T Ćirković-Mitrović, VN Jokanović, R Lozjanin. 2022. Variability of wood fibres of mature pedunculate oak in flooded and non-flooded area. *Wood Research* 67(4): 533-544. DOI: https://doi.org/10.37763/wr.1336-4561/67.4.533544

Junk WJ, MTF Piedade, R Lourival, F Wittmann, P Kandus, LD Lacerda, RL Bozelli, FA Esteves, C Nunes da Cunha, L Maltchik, J Schöngart, Y Schaeffer-Novelli, AA Agostinho. 2014. Brazilian wetlands: their definition, delineation, and classification for research, sustainable management, and protection. *Aquatic Conservation: Marine and Freshwater Ecosystems* 24(1): 5-22. DOI: https://doi.org/10.1002/aqc.2386

León HWJ. 2000. Anatomía del leño de 17 especies del género *Ocotea* Aublet. *Pittieria* 1(29-30): 53-65. DOI: https://www.jstor.org/stable/41740729

León HWJ, RBN Chavarri. 2006. Anatomía xilemática del tallo de 8 especies de la subfamília Euphorbioideae (Euphorbiaceae) en Venezuela. *Revista de la Facultad de Agronomía* 106(1): 1-12.

Loureiro AA, MF Silva. 1968. Catálogo das madeiras da Amazônia. Belém, Brazil. INPA. p 1-2.

LPF (Laboratório de Produtos Florestais. Madeiras Brasileiras). Accessed 26 mar. 2023. Available in http://sistemas.florestal.gov.br/madeirasdobrasil/caracteristicas.php?ID=80&caracteristica=271.

Mainieri C, Chimelo JP. 1989. Fichas das características de madeiras Brasileiras. São Paulo, Brazil. IPT, 418 p.

MMA (Ministério do Meio Ambiente). Industrialização Comércio e Transporte de Produtos Florestais. Accessed 29 APR 2024. Available in https://info.serpro.gov.br/t/IBAMA-Publico/views/IBAMA-PAINELPUBLICOIndustrializacaoComercioeTransportedeProdutosFlorestais-NovoLayout/1_2-P-ProdutoseEspcies?%3Adisplay_count=n&%3Aembed=y&%3AisGuestRedirectFromVizportal=y&%3Aorigin=viz_share_link&%3AshowAppBanner=false&%3AshowVizHome=n

Motta JP, JTS Oliveira, RL Braz, APC Duarte, RC Alves. 2014. Caracterização da madeira de quatro espécie florestais. *Revista Ciências rural* 44(12): 2186-2192. DOI: https://doi.org/10.1590/0103-8478cr20130479

Moutinho VHP, JT Lima, OJR Aguiar, MOG Nogueira. 2012. Scientific determination and wood anatomical features of species know in Brazilian Amazonia as matá-matá (*Eschweilera* spp.). *Revista de Ciências Agrárias* 55: 134-141. DOI: http://dx.doi.org/10.4322/rca.2012.044

Quirino WF, AT Vale, APA Andrade, VLS Abreu, ACS Azevedo. 2004. Poder calorífico da madeira e de resíduos ligno-celulósicos. *Biomassa & Energia* 1(2): 173-182.

Reis ARS. 2015. Anatomia da madeira de quatro espécies de *Aspidosperma* Mart. & Zucc. comercializadas no estado do Pará, Brasil. *Ciência da Madeira* 6(1): 47-62. DOI: https://doi.org/10.12953/2177-6830/rcm.v6n1p47-62

Reis PCMR, LP Reis. 2016. Caracterização anatômica macroscópica da madeira de quatro espécies de Lecythidaceae. *Enciclopédia Biosfera* 13(24).

Reis PCMR, AL Souza, LP Reis, AMML Carvalho, L Mazzei, LJS Rego, HG Leite. 2018. Artificial neural networks to estimate the physical-mechanical properties of Amazon second cutting cycle wood. *Maderas. Ciencia y tecnología* 20(3): 343-352, 2018. DOI: http://dx.doi.org/10.4067/S0718-221X2018005003501

Roque RM, MG Cortés, JR Moreno. 2007. Clave de identificación macroscópica para 22 especies maderables de Bolivia. *Revista Forestal Venezolana* 51(2): 179-193.

Silva JC, M Tomazello Filho, JTS Oliveira, VR Castro. 2007. Influência da idade e da posição radial nas dimensões das fibras e dos vasos da madeira de *Eucalyptus grandis* Mill *ex*. Maiden. *Revista Árvore* 31(6): 1081-1090. DOI: https://doi.org/10.1590/S0100-67622007000600013

Souza MJC, KS Silva, CRV Perdigão, GR Silva, LEL Melo. 2015. Anatomia do lenho carbonizado de espécies madeireiras comercializadas na Amazônia. Brazil. Fundação Casa da Cultura de Marabá (Boletim Técnico n° 8).

Wittmann F, J Schöngart, P Parolin, M Worbes, MTF Piedade, WJ Junk. 2006. Wood specific gravity of trees in Amazonian white-water forests in relation to flooding. *IAWA Journal* 27(3): 255-268. DOI: https://doi.org/10.1163/22941932-90000153

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