

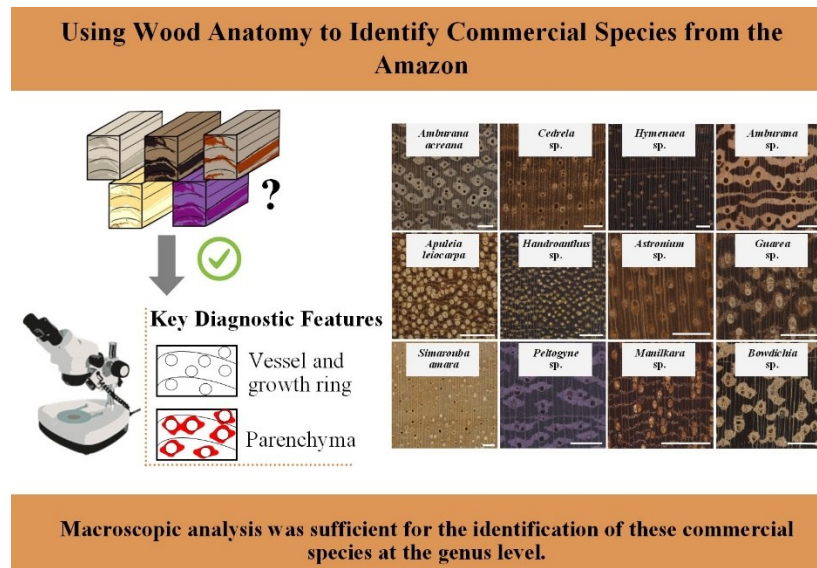
# Macroscopic Anatomy as a Strategy for Recognizing Commercial Wood from the Brazilian Amazon

Waldelaine R. Hoffmann <sup>a,\*</sup> Camila M. Campos <sup>a</sup>, Michelly C. Stragliotto <sup>b</sup>,  
Aylson C. Oliveira <sup>a</sup> and Bárbara L.C. Pereira <sup>a,\*</sup>

*\*Corresponding authors: waldelaine-hoffmann@hotmail.com (W.R. Hoffmann); barbara.pereira@ufmt.br (B.L.C. Pereira)*

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## GRAPHICAL ABSTRACT



# Macroscopic Anatomy as a Strategy for Recognizing Commercial Wood from the Brazilian Amazon

Waldelaine R. Hoffmann <sup>a,\*</sup> Camila M. Campos <sup>a</sup>, Michelly C. Stragliotto <sup>b</sup>,  
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Wood anatomical characterization is a key method for species identification and for combating illegal logging. This study aimed to provide a detailed macroscopic anatomical characterization of twelve wood species from the Brazilian Amazon, supporting species identification in forensic analysis and contributing to educational resources in wood anatomy. The samples were collected from a sawmill in Colniza, northern Mato Grosso, Brazil. Three woods were identified at the species level, and nine were identified at the genus level. *Cedrela* sp., *Hymenaea* sp., *Hymenolobium* sp., *Handroanthus* sp., and *Peltogyne* sp. presented well-demarcated growth rings. Diffuse porosity was common, except in *Cedrela* sp. In *Manilkara* sp., vessels occurred in radial chains, whereas *Handroanthus* sp. was notable for pore obstructions caused by a yellowish substance. The main parenchyma type was aliform and/or confluent, along with marginal bands. Six species displayed storied rays. Macroscopic analysis proved effective for wood identification, as parenchyma, vessel, and growth-ring features were sufficient to identify these commercial species at the genus level.

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Keywords: Wood identification; Growth rings; Axial parenchyma; Hardwood

Contact information: a: Graduate Program in Forestry and Environmental Sciences, Federal University of Mato Grosso, Mato Grosso 78060-900, Brazil; b: Laboratory of Wood Technology and Bioproducts, Federal University of Western Pará, Pará 68040-255, Brazil; \*Corresponding authors: waldelaine-hoffmann@hotmail.com (W.R. Hoffmann); barbara.pereira@ufmt.br (B.L.C. Pereira)

## INTRODUCTION

The Amazon Forest is the largest continuous tropical forest in the world (Hoang and Kanemoto 2021) and is considered a biodiversity *hotspot*, representing one of the main macroregions in Neotropical studies (Andrade-Silva *et al.* 2024). This forest accounts for more than 10% of the global terrestrial biodiversity (Flores *et al.* 2024) and performs essential ecosystem functions, such as ecological activities, nutrient cycling (Andrade-Silva *et al.* 2024) and climate regulation (Armstrong McKay *et al.* 2022). It also acts as an important carbon sink, storing an amount of carbon equivalent to 15 to 20 years of global CO<sub>2</sub> emissions (IPCC 2021; Meunier *et al.* 2024). Brazil contains the largest portion of the Amazon, covering 4.3 million km<sup>2</sup> (60% of the forested area), but it also faces the highest rates of deforestation and degradation, mainly due to land use change, agriculture, livestock, and illegal logging.

Illegal logging currently represents one of the main obstacles to the sustainable use of the Amazon forest (Duarte *et al.* 2021). This has been widely discussed in the context of the conservation of this tropical forest (Pereira *et al.* 2020; Flores *et al.* 2024). The misidentification of species impacts the commercialization and conservation of tropical

wood, highlighting the need for precise studies to protect biodiversity and strengthen legal trade (Souza *et al.* 2020). In view of this, the implementation of legislation related to the prohibition of illegal deforestation and the commercialization of Amazonian wood without traceability has led to the creation of tools to identify and verify the origin of the wood at inspection posts (Ferreira *et al.* 2023). Among these methods, wood anatomy stands out as a traditional method that has been widely used for the identification of tree species in the scientific community (Ferreira *et al.* 2023).

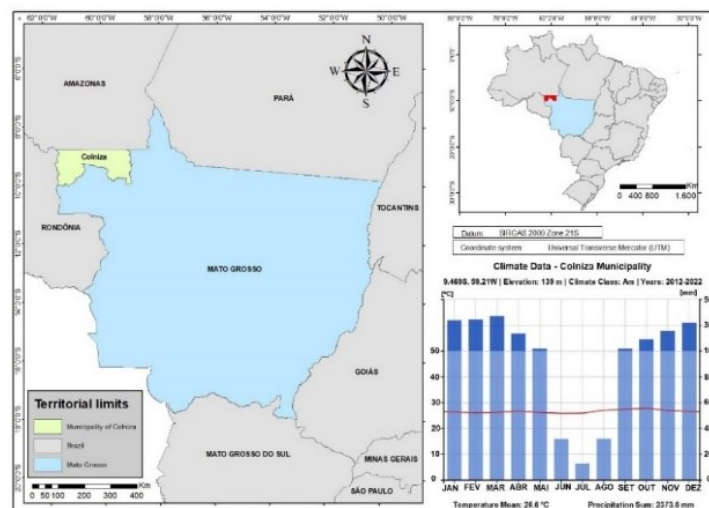
Macroscopic anatomical analysis is one of the most widely used techniques for species identification (Souza *et al.* 2020; Duarte *et al.* 2021). It allows the evaluation of structures, contributing to the identification of Amazonian tree species. Despite its efficiency, anatomical identification faces challenges in tropical regions because of the high diversity of species and wide anatomical variation. Its practical application can also be limited by the need for trained professionals and reliable databases of previously identified species (Lens *et al.* 2020; Ferreira *et al.* 2023). In addition, given the variety of anatomical features among the evaluated species, the dataset generated in this study can serve as valuable didactic material in wood anatomy courses, supporting the training of students and professionals. Nevertheless, macroscopic characterization remains faster and less complex than microscopic approaches (Alves *et al.* 2023).

Therefore, the aim of this study was to provide a detailed macroscopic anatomical characterization of twelve commercial wood species from the Brazilian Amazon, supporting species identification in forensic analysis and contributing to the development of educational resources in wood anatomy.

## EXPERIMENTAL

### Study Area and Sample Collection

Twelve Amazonian wood species were evaluated and collected from a sawmill located in Colniza, northern Mato Grosso, Brazil, within the Brazilian Legal Amazon region (Fig. 1).



**Fig. 1.** Location map of the collection region of the studied species, also showing temperature and precipitation

The region has an average annual rainfall of 2373.6 mm and an average temperature of 26.6 °C (Zepner *et al.* 2020), with an Am climate according to the Köppen-Geiger classification, with a short dry season and a monsoon influence (Aparecido *et al.* 2020). In the storage yard, three heartwood rafters (5.0 × 5.0 × 200.0 cm), free of defects, were randomly selected per species from a batch totaling 5 m<sup>3</sup>. For each rafter, a 2 × 3 × 5 cm sample was prepared for macroscopic wood characterization. The wood identification was initially based on local commercial names used by the sawmill (Table 1).

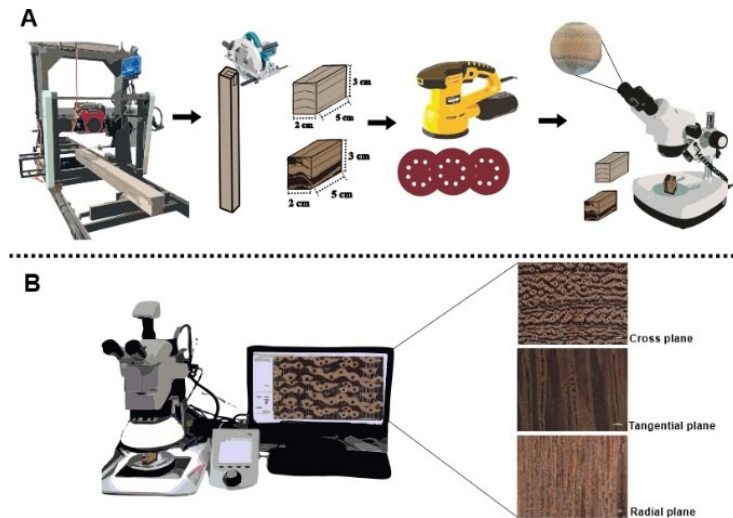
**Table 1.** Commercial and Scientific Names of the Brazilian Amazonian Timber Species Analyzed

| Portuguese Common Name | Commercial Trade Name*   | Associated Scientific Name (Genus) |
|------------------------|--------------------------|------------------------------------|
| Cerejeira              | Cerejeira                | <i>Amburana</i>                    |
| Cedro rosa             | Spanish Cedar            | <i>Cedrela</i>                     |
| Jatobá                 | Jatoba, Brazilian Cherry | <i>Hymenaea</i>                    |
| Angelim Pedra          | Angelim                  | <i>Hymenolobium</i>                |
| Garapeira              | Grapia                   | <i>Apuleia</i>                     |
| Ipê                    | Lapacho                  | <i>Handroanthus</i>                |
| Muiracatiara           | Tigerwood                | <i>Astronium</i>                   |
| Jitô                   | Light guarea             | <i>Guarea</i>                      |
| Marupá                 | Paradise Tree            | <i>Simarouba</i>                   |
| Roxinho                | Purpleheart              | <i>Peltogyne</i>                   |
| Maçaranduba            | Bulletwood               | <i>Manilkara</i>                   |
| Sucupira preta         | Black sucupira           | <i>Bowdichia</i>                   |

Note: \*The Wood Database (2024).

### Macroscopic Characterization

The samples were sequentially polished with sandpapers ranging from 80 to 2000 grit (Fig. 2). Then, they were brushed to unclog the vessels. A stereomicroscope was used for anatomical characterization to characterize the distinguishing features of the growth ring limits, vessels (visibility, porosity, grouping, arrangement and content), axial parenchyma (visibility and disposition), and rays (visibility in the transverse plane; contrast in the radial plane; and storied rays in the tangential plane) (Fig. 2), according to COPANT (1974), the IAWA Committee (1989), Ruffinatto *et al.* (2015) and Latorraca *et al.* (2018).



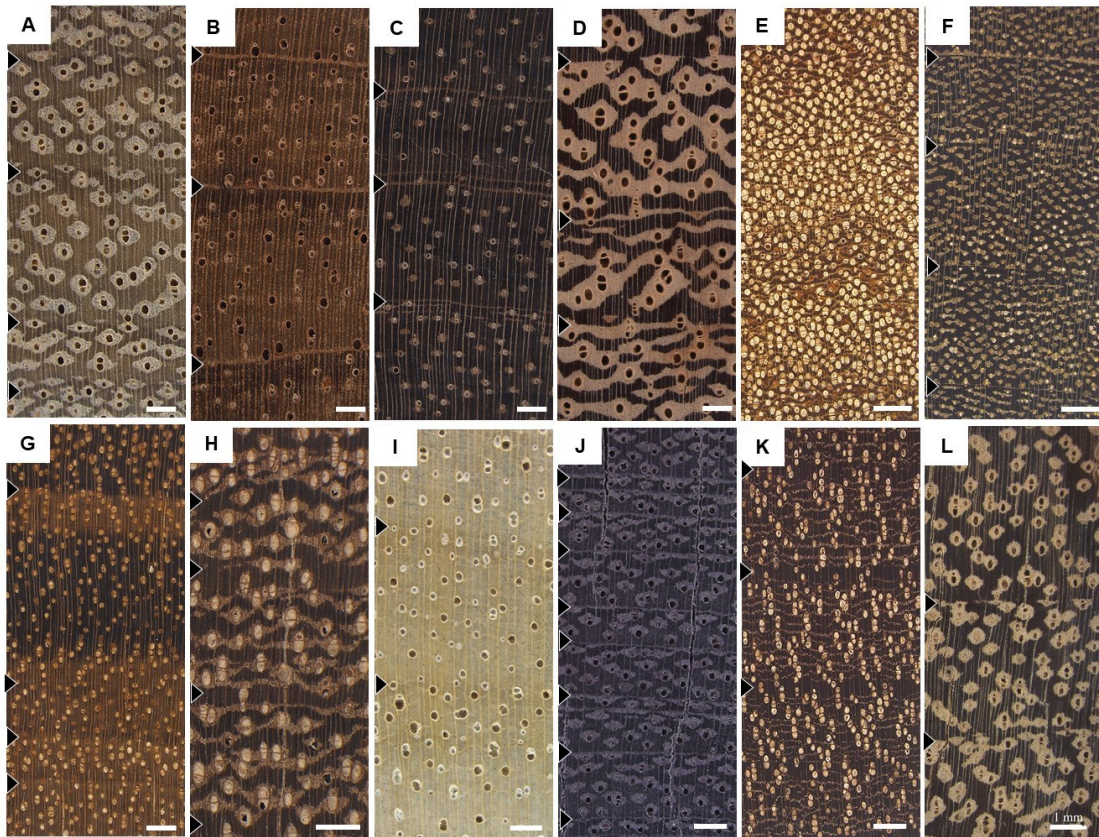
**Fig. 2.** Scheme of the procedures adopted for the macroscopic characterization of 12 commercial wood species from the Brazilian Amazon: (A) sample preparation; (B) image capture

The species characteristics were subsequently recorded through images captured in the transverse, tangential, and radial planes using a Leica M205C stereomicroscope equipped with a photomontage system (Fig. 2) and a 1 mm scale. The identification was confirmed by comparison with wood deposited in the Wood Collection of the Institute of Agricultural Defense of Mato Grosso (INDEA/MT), located in Cuiabá, Mato Grosso, Brazil.

Considering that the evaluated woods are traded in both domestic and international markets, lists of endangered species were consulted to assess the level of exploitation of the genera and their representatives. For this analysis, the following main reference sources were consulted: the List of Endangered Species in Brazil, the IUCN Red List of Threatened Species, and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (Brasil 2022; IUCN 2024; CITES 2024).

## RESULTS AND DISCUSSION

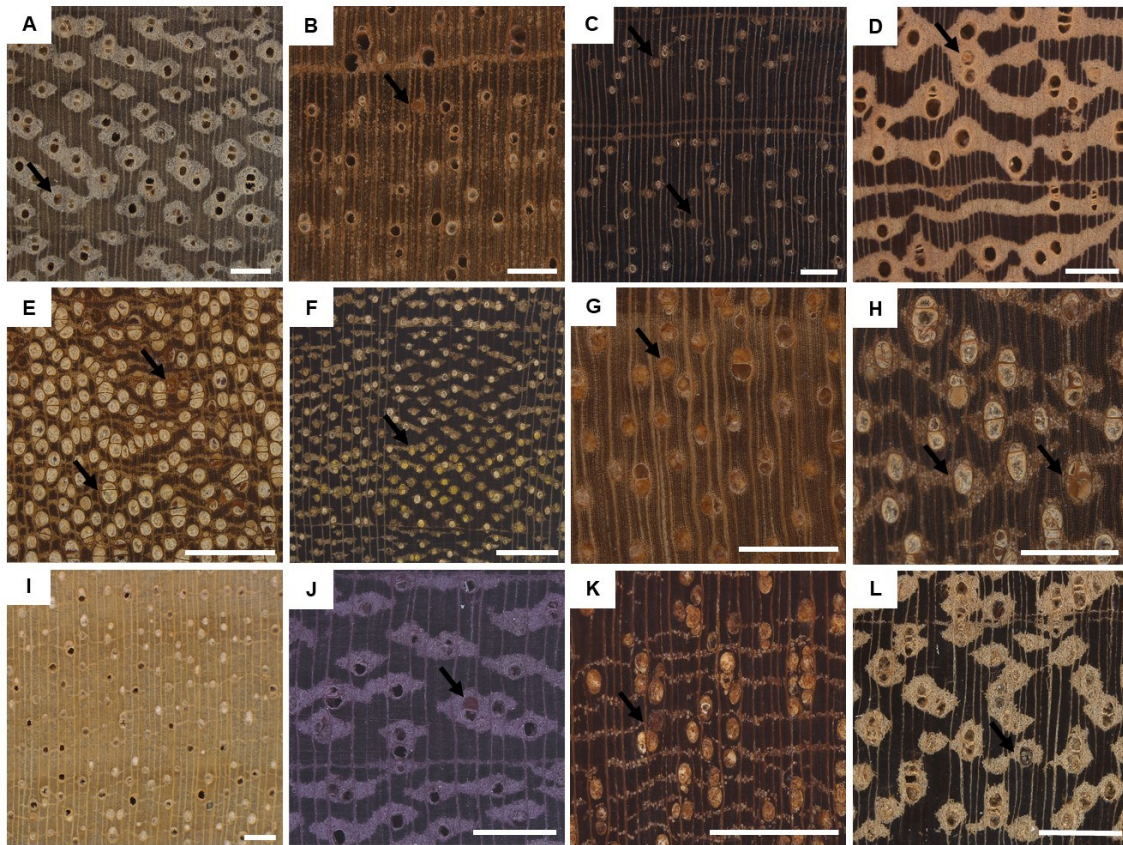
In this study, the genera corresponding to the trade names were confirmed through macroscopic identification (Fig. 3), with the observed genera matching the common names assigned to the species in the region, as noted by Schmitz *et al.* (2020).



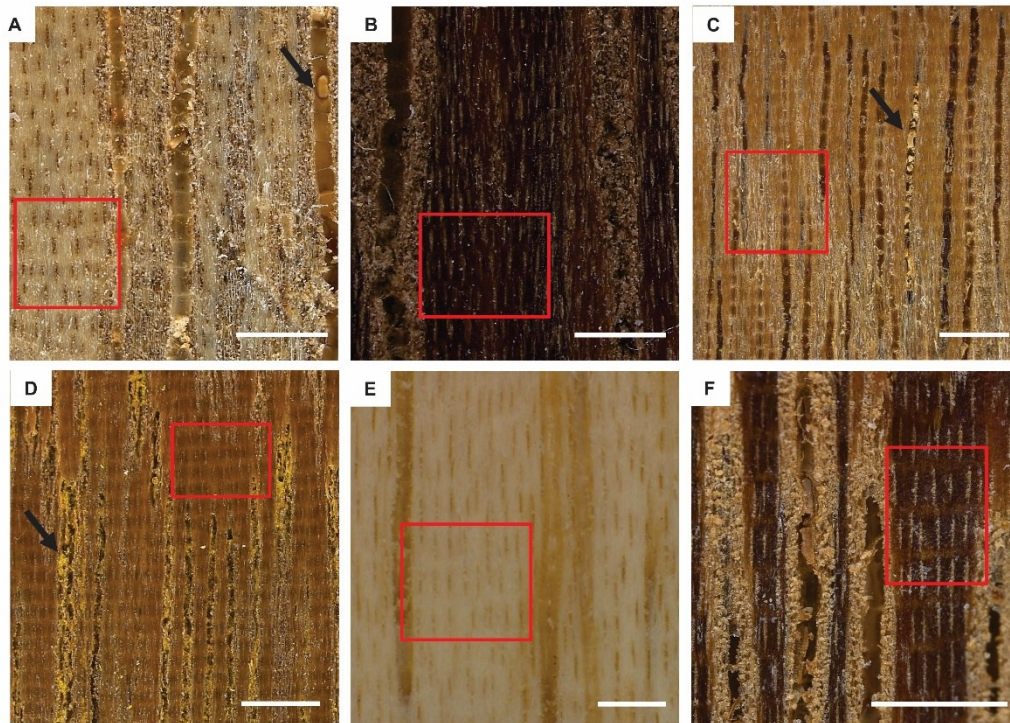
**Fig. 3.** Transverse plane of twelve commercial wood samples from the Brazilian Amazon at lower magnification, highlighting color, patterns, and growth rings: (A) *Amburana acreana*; (B) *Cedrela* sp.; (C) *Hymenaea* sp.; (D) *Hymenolobium* sp.; (E) *Apuleia leiocarpa*; (F) *Handroanthus* sp.; (G) *Astronium* sp.; (H) *Guarea* sp.; (I) *Simarouba amara*; (J) *Peltogyne* sp.; (K) *Manilkara* sp.; (L) *Bowdichia* sp. The black arrows on the left side of each image indicate the growth rings. A representative scale (white bar) equivalent to 1 mm is shown.

Macroscopic characterization provides important diagnostic features for wood identification; however, distinguishing species within the same genus can be particularly challenging when it is based solely on wood characteristics. Six botanical families were identified, with Fabaceae comprising 50% of the samples, followed by Meliaceae (16.7%), and the remaining families with one representative (8.3%). Twelve species were evaluated, three of which were identified at the species level, and the remaining nine were identified at the genus level. Macroscopic wood identification is usually supported by background information, such as the approximate harvest location (Schmitz *et al.* 2020). Such information considerably reduces the number of taxa to be assessed. In this study, this was the case for *Amburana acreana* and *Simarouba amara*.

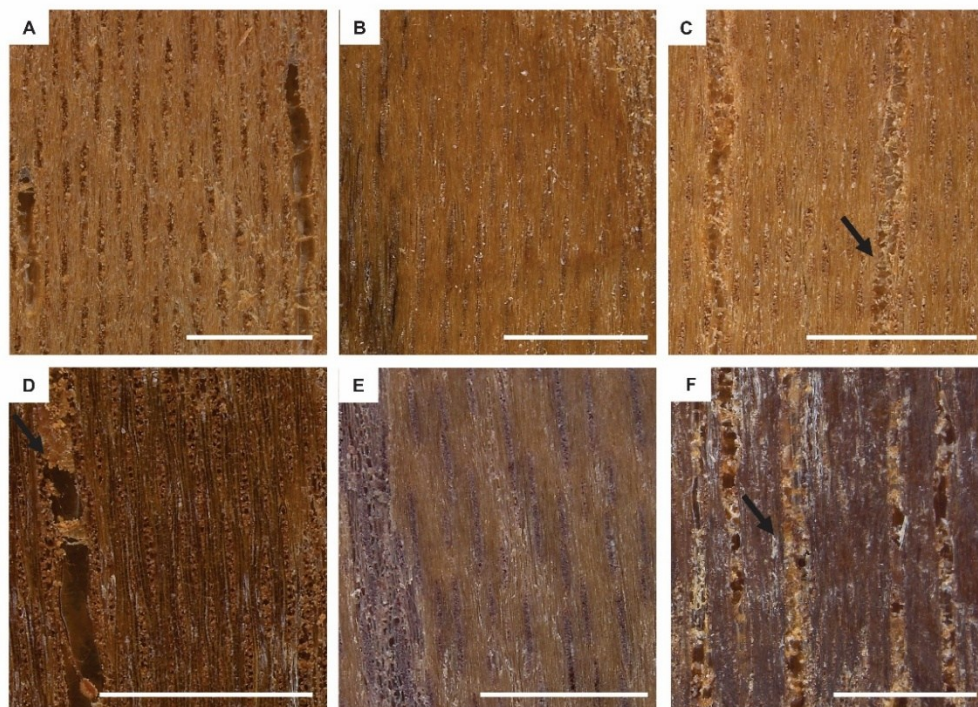
Figure 4 also presents the transverse plane at a higher magnification, allowing clearer visualization of the axial parenchyma and vessels. The tangential plane of woods with storied rays is shown in Fig. 5, whereas non-storied rays are illustrated in Fig. 6. The ray flecks and contrasts in the radial plane are presented in Fig. 7.



**Fig. 4.** Transverse plane of twelve commercial wood samples from the Brazilian Amazon, allowing visualization of axial parenchyma and vessels: (A) *Amburana acreana*; (B) *Cedrela* sp.; (C) *Hymenaea* sp.; (D) *Hymenolobium* sp.; (E) *Apuleia leiocarpa*; (F) *Handroanthus* sp.; (G) *Astronium* sp.; (H) *Guarea* sp.; (I) *Simarouba amara*; (J) *Peltogyne* sp.; (K) *Manilkara* sp.; (L) *Bowdichia* sp. Black arrows indicate vessel contents. A representative scale (white bar) equivalent to 1 mm is shown.



**Fig. 5.** Tangential plane of commercial wood from the Brazilian Amazon with storied rays: (A) *Amburana acreana*; (B) *Hymenolobium* sp.; (C) *Apuleia leiocarpa*; (D) *Handroanthus* sp.; (E) *Simarouba amara*; (F) *Bowdichia* sp. Red squares indicate storied rays, and black arrows indicate vessel contents. A representative scale (white bar) equivalent to 1 mm is shown.



**Fig. 6.** Tangential plane of commercial wood from the Brazilian Amazon with non-storied rays: (A) *Cedrela* sp.; (B) *Hymenaea* sp.; (C) *Astronium* sp.; (D) *Guarea* sp.; (E) *Peltogyne* sp.; (F) *Manilkara* sp. Black arrows indicate vessel contents. A representative scale (white bar) equivalent to 1 mm is shown.



**Fig. 7.** Radial plane of twelve commercial wood samples from the Brazilian Amazon: (A) *Amburana acreana*; (B) *Cedrela* sp.; (C) *Hymenaea* sp.; (D) *Hymenolobium* sp.; (E) *Apuleia leiocarpa*; (F) *Handroanthus* sp.; (G) *Astronium* sp.; (H) *Guarea* sp.; (I) *Simarouba amara*; (J) *Peltogyne* sp.; (K) *Manilkara* sp.; (L) *Bowdichia* sp. The black arrows on the left side of each image indicate the growth rings. A representative scale (white bar) equivalent to 1 mm is shown.

The macroscopic anatomical characteristics of each identified wood sample are described below.

#### ***Amburana acreana* (Ducke) A.C.Sm. (Fabaceae)**

**Growth ring boundaries:** distinct, varying from slightly to well demarcated, characterized by a fibrous zone associated with a marked reduction in vessel size and in the amount of axial parenchyma (Fig. 3A). **Vessels:** visible without a 10x lens, diffuse-porous, predominantly solitary vessels with the occurrence of twinning, predominantly diagonal patterns with vessels in tangential bands near the fibrous zone (Fig. 4A). The vessels were slightly obstructed by translucent and light-yellow substances (Figs. 4A, 5A). **Axial parenchyma:** paratracheal parenchyma, lozenge aliform and confluent aliform in short stretches, visible without a 10x lens (Fig. 4A). **Rays:** visible without a 10x lens, irregular storied rays (Fig. 5A), and well contrasted (Fig. 7A).

These results are in agreement with the observations of López and Villalba (2016). In this study, the macroscopic characteristics related to the axial parenchyma corroborated those observed by Latorraca *et al.* (2018) and Ferreira *et al.* (2023) when studying *Amburana cearensis*. Storied rays were also present in the studies by Ferreira *et al.* (2023). Furthermore, Borges *et al.* (2017) reported the presence of deposits of yellowish substances in vessels.

The genus *Amburana* Schwacke & Taub. comprises three species: *Amburana acreana* (Ducke) A.C.Sm. and *Amburana cearensis* (Allemão) A.C. Sm., which are distributed in Argentina, Brazil, Bolivia, Paraguay, and Peru; and *Amburana erythrosperma* E.P. Seleme, C.H. Stirton & V.F. Mansano, which is endemic to the Brazilian Caatinga (Seleme *et al.* 2015; Ferreira *et al.* 2025). In Brazil, the genus occurs mainly in the Amazon Forest but is also present in the Caatinga, Cerrado, Atlantic Forest, and Pantanal (Seleme *et al.* 2015). Considering the geographic distribution of the species and the harvest location in Colniza, Mato Grosso, Brazilian Amazon, the analyzed wood was identified as *A. acreana*.

The wood of *Amburana* sp. is widely used in the production of furniture, cosmetics and folk medicine (Seleme *et al.* 2015; Ferreira *et al.* 2025). However, the high demand in the timber sector puts the species *A. acreana* at risk, and it is currently classified as “vulnerable” on the list of endangered species in Brazil and on the IUCN Red List of threatened species (Brasil 2022; IUCN 2024). This condition highlights the need for measures that reconcile the economic use of its wood with the preservation of its natural stocks.

### ***Cedrela* sp. P. Browne (Meliaceae)**

**Growth ring boundaries:** distinct, characterized by a semiring porous pattern and the presence of marginal parenchyma, which is macroscopically visible as a fine line of lighter tissue. This line contrasts with an adjacent fibrous zone (Fig. 3B). **Vessels:** visible without a 10x lens, semiring-porous, solitary vessels with the occurrence of twinning (Fig. 4B). The vessels are slightly obstructed by light brown substances (Fig. 4B). **Axial parenchyma:** visible without a 10x lens, marginal parenchyma bands, with the occurrence of diffuse apotracheal parenchyma, and scant and vasicentric paratracheal parenchyma tending to form a confluence of lighter coloration (Fig. 4B). **Rays:** visible without lens, non-storied (Fig. 6A), and well contrasted (Fig. 7B).

The macroscopic characteristics are consistent with those reported in the literature, which describe highly distinct growth rings in a semiring-porous pattern and axial parenchyma arranged in marginal bands (Marcelo-Peña *et al.* 2020; Bauer *et al.* 2020). Furthermore, Duchesne *et al.* (2023) observed predominantly solitary vessels, which were occasionally arranged in radial chains, along with diffuse apotracheal and scant to vasicentric paratracheal axial parenchyma. Santos *et al.* (2020) observed rays visible without lenses and gum deposits in vessels, as observed in the present study. The results of the macroscopic characterization performed by Silva *et al.* (2022) and Ticahuanca *et al.* (2020) are also in agreement with those reported in the present study.

*Cedrela* is a genus that originates from seasonally dry forests and is widely distributed in Neotropical regions (Layme-Huaman *et al.* 2018). Its main species are *Cedrela fissilis* and *Cedrela odorata* (Layme-Huaman *et al.* 2018). These species are known to have well-demarcated growth rings, even in tropical and subtropical areas (Layme-Huaman *et al.* 2018; Marcelo-Peña *et al.* 2020). Since both species occur in the Brazilian Amazon, it was not possible to determine which one was analyzed. The differentiation of these species relies mainly on the morphological characteristics of the leaves and the size of the fruits (Flores 2020).

*Cedrela* wood is widely traded, which has led to significant exploitation. Consequently, *C. fissilis* and *C. odorata* are classified as “vulnerable” on the List of Endangered Species in Brazil and the IUCN Red List of Threatened Species (Brasil 2022; IUCN 2024). These species are also listed in CITES (Convention on International Trade in

Endangered Species of Wild Fauna and Flora) as species not currently threatened with extinction but that may become endangered without strict control of their commercialization (CITES 2024). This underscores the importance of accurate species identification in wood inspection (Santos *et al.* 2020).

### ***Hymenaea* sp. L. (Fabaceae)**

**Growth ring boundaries:** Distinct, with the presence of marginal parenchyma macroscopically visible as a fine line of lighter tissue (Fig. 3C). **Vessels:** visible without a 10x lens, diffuse-porous, solitary with the occurrence of twinning, without a defined arrangement with regions in a diagonal pattern (Fig. 4C). Vessels obstructed by a translucent brown substance were observed in the transverse plane (Fig. 4C). **Axial parenchyma:** lozenge-aliform paratracheal parenchyma and marginal bands visible without a 10x lens (Fig. 4C). **Rays:** visible without a 10x lens, non-storied (Fig. 6B) and well contrasted (Fig. 7C).

The macroscopic analysis performed in this study was in agreement with the literature, which also describes the presence of growth rings delimited by marginal bands. The presence of lozenge-aliform parenchyma was also observed as a marked macroscopic characteristic of *Hymenaea* sp. (Granato-Souza *et al.* 2019; Mamoňová and Reinprecht 2020; Rodriguez *et al.* 2022). The porosity characteristics observed in the present study were also reported by other authors, such as Albuquerque *et al.* (2016), who described diffuse, obstructed, and solitary vessels (Mamoňová and Reinprecht 2020).

The genus *Hymenaea* includes Neotropical tree species widely distributed from Mexico to Brazil (Chaves *et al.* 2018). The genus is known for producing high-density wood, which is widely used in applications such as furniture and flooring (Chaves *et al.* 2018; Costa *et al.* 2021). These properties make the wood of *Hymenaea* sp. a raw material highly valued by the timber market (Chaves *et al.* 2018), but it is also a frequent target of illegal exploitation (Chaves *et al.* 2018; Granato-Souza *et al.* 2019).

Nascimento *et al.* (2016) reported that inadequate identification, which is based only on organoleptic characteristics, contributes to the illegal marketing of *Hymenaea* sp. The authors also indicated that macroscopic identification is a tool to combat the trade of endangered species. The excessive exploitation of the genus led to the inclusion of *H. parvifolia* Huber as “vulnerable” on the National List of Endangered Species of Brazil (Brasil 2022).

### ***Hymenolobium* sp. Benth. (Fabaceae)**

**Growth ring boundaries:** distinct and poorly demarcated, with axial parenchyma in seemingly discontinuous and narrow marginal bands (Fig. 3D). **Vessels:** visible without a 10x lens, diffuse-porous, with solitary and groups of 2 to 3 vessels, arranged irregularly and featuring regions with a diagonal pattern (Fig. 4D). Vessels slightly obstructed by beige substances were observed in the transverse plane (Fig. 4D). **Axial parenchyma:** visible without a 10x lens, confluent aliform paratracheal type arranged in long and short stretches, sometimes diagonally. Eventually, thin irregular marginal lines formed (Fig. 4D). **Rays:** visible without a 10x lens, storied (Fig. 5B) and well contrasted (Fig. 7D).

In this study, the growth rings were finely demarcated but still distinguishable. In contrast, Lima *et al.* (2023), when studying *H. heterocarpum*, described indistinct growth rings. However, the authors observed similar characteristics to those found in the present study, such as diffuse porosity, predominantly solitary vessels and radial groupings (2 to 3 vessels). They also noted axial parenchyma, which were aliformly confluent in bands, as

well as storied rays. When *H. petraeum* was evaluated, Rodrigues *et al.* (2023) reported similar characteristics, such as indistinct growth rings, diffuse porosity and predominantly solitary vessels. They classified the axial parenchyma as visible without a 10x lens and the confluent paratracheal parenchyma type. Barbosa *et al.* (2021), when evaluating *H. petraeum*, reported the occurrence of obstructions in vessels in light tones, which are common in the heartwood of Fabaceae. The authors also observed confluent aliform axial parenchyma and fibrous zone formation, which agrees with those observed in the present study. The two species share wood anatomical characteristics, with macroscopic features matching those reported in the literature for *Hymenolobium* sp.

*Hymenolobium* is a genus that contains 12 species in Brazil, eight of which are endemic (Melchor-Castro 2020). With timber characteristics that are attractive to the market, especially for structural use, for doors, roofs and furniture (Teixeira *et al.* 2021), illegal logging threatens the genus. The species *H. excelsum* is already considered “vulnerable” on the National List of Endangered Species of Brazil (Brasil 2022). The identification of species using wood anatomy within the genus *Hymenolobium* is a challenge (Nascimento *et al.* 2016), but macroscopy can contribute to preliminary identification.

### ***Apuleia leiocarpa* (Vogel) J.F. Macbr. (Fabaceae)**

**Growth ring boundaries:** indistinct (Fig. 3E). **Vessels:** visible without a 10x lens, diffuse-porous, grouping of solitary vessels with the occurrence of multiples of 2 to 3 vessels (Fig. 4E). Vessels completely obstructed by translucent beige to brown substances were observed in the transverse plane (Fig. 4E). **Axial parenchyma:** aliform type visible at 10x magnification with linear extension with lines in long stretches (Fig. 4E). **Rays:** visible with a 10x lens, storied (Fig. 5C) and poorly contrasted (Fig. 7E).

The macroscopic description observed in this study showed partial similarities with the results of Acosta *et al.* (2024), who also identified diffuse porosity and storied rays. However, differences were observed in the axial parenchyma, which the authors classified as lozenge-aliform with the formation of confluences, whereas the present study described aliform with linear extension. A difference was also identified in the macroscopic description observed by Braga Júnior *et al.* (2020) regarding the distinction of growth rings. While in this study they were described as indistinct, the authors reported distinct growth rings. In addition, the axial parenchyma was distinct and was described as aliform-confluent with thin marginal lines. On the other hand, Braga Júnior *et al.* (2020) confirmed storied rays. These variations are attributed to differences in growth sites and environmental factors that influence the anatomical development of wood.

*Apuleia* is a Neotropical genus restricted to South America, occurring in Venezuela, Colombia, Ecuador, Peru, Bolivia, Paraguay, and Argentina and widely distributed in Brazil (Falcão and Mansano 2020). Its uses include woodworking, furniture and boats (Canetti *et al.* 2020; Braga Júnior *et al.* 2020). Currently, the genus has only one species, *Apuleia leiocarpa* (Falcão and Mansano 2020). Owing to intense commercialization, the species was included as “vulnerable” in the National List of endangered Species of Brazil (Brasil 2022).

### ***Handroanthus* sp. Mattos (Bignoniaceae)**

**Growth ring boundaries:** distinguished by discontinuous marginal bands macroscopically visible as a fine line of lighter tissue (Fig. 3F). **Vessels:** visible without a 10x lens, diffuse-porous, solitary vessels with the occurrence of twinning (Fig. 4F). Vessels

obstructed by bright yellow substances (Figs. 4D, 5D). **Axial parenchyma:** lozenge-aliform and unilateral paratracheal, aliform confluent in short stretches and discontinuous marginal bands, visible with a 10x lens (Fig. 4F). **Rays:** visible with a 10x lens, storied rays (Fig. 5D) and well contrasted (Fig. 7F).

The present study is similar to the macroscopic characteristics observed by Aragão *et al.* (2022), who evaluated three species of *Handroanthus* and reported the presence of marginal parenchyma delimiting the growth rings and aliform axial parenchyma forming confluences. Similarly, the results of Souza *et al.* (2024), who evaluated four species of *Handroanthus* and observed distinct growth rings, ranging from slight to well demarcated, were delimited by fibrous zones and marginal bands in three of the species. The porosity was diffuse, with vessels being predominantly solitary and obstructed by yellowish deposits. The authors also indicated visible rays at the 10x lens and storied rays. However, the rays observed by the authors were classified as noncontrast rays, which differs from the findings of this study.

The genus *Handroanthus* is common in the Neotropics and is widely distributed in seasonal tropical forests, with eight species recorded in the Amazon (Lohmann 2020; Souza *et al.* 2024). Individuals of the genus *Handroanthus* are among the most exploited timber species in the Brazilian Amazon due to the desired properties of their wood, such as mechanical strength, high natural durability, and high density (Melo and Camargos 2016; Souza *et al.* 2024, Silva *et al.* 2021).

Its main uses include furniture, flooring, and civil construction (Ferreira *et al.* 2020; Costa *et al.* 2021; Pimenta *et al.* 2024). However, owing to intensive and predatory commercial exploitation, five species of the genus are categorized as “Endangered” and one as “Critically Endangered” on the Brazilian National List of Threatened Species and on the IUCN Red List of Threatened Species (Brasil 2022; IUCN 2024). They are still listed in CITES as species that are not necessarily threatened with extinction but may become threatened if there is not strict control of their trade (CITES 2024), emphasizing the need for sustainable forest management, conservation and correct identification of these species.

### ***Astronium* sp. Jacq. (Anacardiaceae)**

**Growth ring boundaries:** distinct by seemingly marginal bands that macroscopically appear as thin lines that stand out from the fibrous zone region (Fig. 3G). **Vessels:** visible without a 10x lens, diffuse-porous, solitary vessels with radial multiples of 2–3 vessels, diagonal pattern and, in some regions, radial pattern (Fig. 4G). The vessels are obstructed by brown translucent substances (Fig. 4G). **Axial parenchyma:** visible under a 10x lens, forming marginal bands, and present as scant and vasicentric parenchyma (Fig. 4G). **Rays:** visible only at the 10x lens, non-storied rays (Fig. 6C) and well contrasted (Fig. 7G).

Similar findings were reported by Rodriguez *et al.* (2022), who described the anatomy of *A. lecointei* with well-defined and contrasted growth rings, diffuse porosity and scant paratracheal parenchyma. However, unlike the present study, in which the vessels were highly obstructed, Rodriguez *et al.* (2022) reported that few vessels were obstructed by tyloses. Additionally, Abreu *et al.* (2023) characterized *A. lecointei*, noting distinct growth rings with darker fibrous zones, vessels mostly solitary (2 to 4 multiples), diffuse porosity, occasional diagonal arrangement, and pores with obstructions (whitish substances or tyloses). The axial parenchyma was visible only under 10x magnification, whereas rays were visible macroscopically and not storied.

The genus *Astronium* is widely distributed in Brazil and occurs in all geographical regions. Currently, ten species are recognized in the genus, three of which occur in the Amazon phytogeographic domain: *A. fraxinifolium* Schott, *A. graveolens* Jacq., and *A. lecointei* Ducke (Silva-Luz *et al.* 2020). Most species are found in tropical dry forests or in tropical humid forests with a well-defined dry season (Mitchell and Daly 2017).

Species of the genus *Astronium* are known for the use of wood to make musical instruments. Baar *et al.* (2016), when evaluating the acoustic properties of *Astronium* sp., concluded that the species has the potential for making instruments because its anatomical characteristics are correlated with the acoustic properties (Baar *et al.* 2016). Owing to the commercial exploitation of the wood of species of the genus *Astronium*, some of them are currently at risk of extinction.

The IUCN Red List includes two species: *A. lecointei* (Least Concern) and *A. glaziovii* Mattick (Endangered) (IUCN 2024). Three other *Astronium* species, *A. balansae* Engl., *A. glaziovii* (classified as "Endangered") and *A. pumilum* J.D.Mitch. & Daly (classified as "Vulnerable") – are included in the Official List of Endangered Species of Brazilian Flora, published by the Ministry of the Environment (Brasil 2022).

### **Guarea sp. F. Allam. ex L. (Meliaceae)**

**Growth ring boundaries:** distinct, poorly demarcated by a fibrous zone and eventually delimited by irregular marginal bands of axial parenchyma (Fig. 3H). **Vessels:** visible without a 10x lens, diffuse-porous, solitary vessels, with the occurrence of radial multiples of 2–4 vessels (Fig. 4H). The vessels were completely obstructed by translucent beige to brown substances (Fig. 4H). **Axial parenchyma:** lozenge-aliform and aliform confluent in short to long stretches, forming marginal bands (Fig. 4H). **Rays:** visible only at the 10x lens, non-storied (Fig. 6D), and well contrasted (Fig. 7H).

For the genus *Guarea*, the predominant characteristic was the presence of lozenge-aliform and confluent aliform paratracheal parenchyma. Ferreira *et al.* (2023), in their study of the Peruvian Amazon forest, described the species *G. guidonia*, which can be mistaken for and traded as *Vochysia vismiifolia* (Vochysiaceae). Similarly, *Guarea* sp. displays distinct growth rings with dark and irregular regions. As noted by Gonzales (2011), this confusion arises from the presence of aliform axial parenchyma forming thin lines, which are occasionally slightly thicker. In the macroscopic characterization performed by Ferreira *et al.* (2023), the wood had a medium texture, with growth rings visible only with a 10x lens. The vessels were visible without a 10x lens, with diffuse porosity, confluent aliform axial parenchyma and non-storied rays. Although Ferreira *et al.* (2023) could only visualize growth rings with a magnifying glass, their description closely matches that used in the present study.

The genus *Guarea* has a wide distribution in Brazil. Flores *et al.* (2024) described the species of *Guarea* sp. formed by small saplings of the understory to large trees of the forest canopy, which occur exclusively in the Neotropics. According to Flores *et al.* (2024), the genus currently has 32 accepted species in Brazil, 8 of which are endemic (IPT 2024; The Wood Database 2024). *Guarea* sp. is known for its phytochemical compounds with pharmaceutical applications, and Safriansyah *et al.* (2022) identified several compounds from *Guarea* species, including sesquiterpenoids, diterpenoids, triterpenoids, limonoids, steroids and aromatic compounds. In a previous study, Conserva *et al.* (2017) reported that chemical compounds, according to the authors of *G. macrophylla*, demonstrated cytotoxic activity against cancer cell lines.

Despite its economic potential in the pharmaceutical industry, the exploitation of wood from species of the genus *Guarea* has limitations. Two representative species of the genus, *G. guidonia* and *G. gracilis*, are described as “Least Concern” and “Vulnerable”, respectively, by the IUCN (2024). One of the species, *G. gracilis*, is also included in the list of endangered species and is classified as vulnerable according to the most recent assessment (Brasil 2022).

### ***Simarouba amara* Aubl. (Simaroubaceae)**

**Growth ring boundaries:** Distinct, with regions poorly demarcated by a fibrous zone (Fig. 3I). **Vessels:** visible without a 10x lens, diffuse-porous, solitary vessels with the occurrence of twinning (Fig. 4I). There are no obstructions (Fig. 5E). **Axial parenchyma:** winged-aliform, visible without a 10x lens (Fig. 4I). **Rays:** visible without a 10x lens, irregular storied rays (Fig. 5E) and well contrasted (Fig. 7I).

Faria *et al.* (2020) described *Simarouba versicolor* as having indistinct or absent growth rings, winged-aliform axial parenchyma forming long confluent stretches, and diffuse porosity. Marcelo-Peña *et al.* (2020) considered the genus *Simarouba* to have indistinct or absent growth rings. In Peruvian forests, *Simarouba amara* Aubl. is often confused with and traded as *Brosimum alicastrum*. The two species can be distinguished by their lighter wood color, shorter linear extensions of axial parenchyma, and lower vessel density, whereas *B. alicastrum* is characterized by a yellow color and aliform axial parenchyma (Ferreira *et al.* 2021; Olivia and Zerpa 2018). This challenge in accurately identifying species, particularly when relying solely on the organoleptic characteristics of wood, underscores the critical role of macroscopic descriptions in sustainable forest management and wood commercialization.

The genus *Simarouba* Aubl., which is widely distributed in Central and South America, is composed of six species. In Brazil, there are *Simarouba amara* Aubl., which is widely distributed throughout the tropical region of South America, and *Simarouba versicolor* A. St.-Hil., restricted mainly to the Cerrado domain (Devecchi *et al.* 2024). Thus, given that the wood originates from the Amazon region, it can be identified as *S. amara*.

The wood of *Simarouba* is considered versatile because it has different applications. Souza *et al.* (2020) reported that *S. Amara* wood is suitable for furniture manufacturing because of its low density (0.40 g.m<sup>-3</sup>). In addition, the species shows potential as a reforestation option for the paper industry, with studies indicating its suitability for the production of chemical pulp and high-yield pulp (Corrêa and Ribeiro 1972).

The genus *Simarouba* is listed in the IUCN (2024) as “Least Concern.” This classification reflects a lower risk of extinction, which implies that logging faces fewer regulatory restrictions, making the commercial use of wood more viable in the timber sector.

### ***Peltogyne* sp. Vogel (Fabaceae)**

**Growth ring boundaries:** Distinctly, axial parenchyma in marginal bands macroscopically appear as a fine line of lighter tissue (Fig. 3J). **Vessels:** visible without a 10x lens, diffuse-porous, solitary vessels with the occurrence of twinning (Fig. 4J). Some vessels were obstructed by purple substances (Fig. 4J). **Axial parenchyma:** visible without the 10x lens, unilateral lozenge-aliform and unilateral confluent aliform in short stretches and in long stretches forming the marginal bands (Fig. 4J). **Rays:** visible without a 10x

lens, non-storied (Fig. 6E) and contrasted well (Fig. 7J).

When the present study is compared with the literature, it is possible to observe a similarity in the anatomical aspects observed. Rodriguez *et al.* (2022) described *P. paniculata* Benth. as having diffuse porosity, with vessels visible without a lens, in a radial pattern, and often filled with gums and other deposits. The wood exhibits marginal bands associated with unilateral and confluent paratracheal parenchyma. The authors reported that *P. paniculata* produces well-defined and contrasting growth rings.

Amais *et al.* (2021), in a study of species with dendrochronological potential, highlighted the presence of marginal parenchyma and confluent aliform vasicentric axial parenchyma in *P. paniculata*. Similarly, Jácome *et al.* (2021), when evaluating the wood of *Peltogyne* sp., reported distinct growth rings, aliform paratracheal parenchyma with linear extension and eventual confluences, in addition to marginal parenchyma. The vessels were solitary and occasionally twinned, with diffuse porosity and a diagonal pattern, and they were obstructed by tylosis. The rays were also visible, well contrasted, non-storied, and the tangential fibrous zones were rectilinear and darker.

Despite the characteristic purple coloration of the genus *Peltogyne*, distinguishing between species is difficult. This difficulty requires the evaluation of the distinctions between the growth rings, the type and amount of axial parenchyma, and the width and composition of the rays. Jácome *et al.* (2021) emphasized that microscopic analysis is necessary for the differentiation of species of the genus.

The genus *Peltogyne* is present in the northern, northeastern, central-western and southeastern regions. Currently, there are 24 cataloged species, 16 of which are endemic to Brazil (Lima and Cordula 2015). This genus is known for its purple heartwood, which produces highly valued wood with unique characteristics. Wood color significantly differs between sapwood and heartwood (Valverde *et al.* 2020). *Peltogyne* species show excellent resistance to termites, which is attributed to the high density and hardness of their wood (Cosme *et al.* 2018).

Owing to its extensive commercial use, which results in intense logging, the genus *Peltogyne* has several species included in lists of extinction risk. The IUCN (2024) cataloged four species: *P. chrysopis* and *P. gracilipes* as “Endangered”; *P. excelsa* as “Vulnerable”; and *P. discolor* as “Least Concern.” In the official list of the Brazilian Ministry of the Environment, the genus has eight listed species. Among them, *P. altissima*, *P. chrysopis*, *P. gracilipes* and *P. mattsiana* are classified as “Endangered.” The other four species, *P. discolor*, *P. excelsa*, *P. maranhensis* and *P. paradoxa*, are considered “vulnerable” (Brasil 2022).

### ***Manilkara* sp. Adans. (Sapotaceae)**

**Growth ring boundaries:** range from absent to demarcated, and when demarcated, they are poorly defined, with demarcation by fibrous zones (Fig. 3K). **Vessels:** visible without a 10x lens, diffuse-porous, multiple vessels grouping in radial multiple of 2–3 vessels, and the occurrence of solitary vessels. Radial pattern with diagonal zones (Fig. 4K). The vessels were completely obstructed by translucent brown substances (Fig. 4K). **Axial parenchyma:** visible without the 10x lens, in narrow bands or lines up to three cells wide (Fig. 4K). **Rays:** visible only at the 10x lens, non-storied rays (Fig. 6F) and poorly contrasted (Fig. 7K).

When the results of this study are compared with findings from other anatomical studies, several similarities can be observed. Mamoňová and Reinprecht (2020) characterized the species *M. bidentata* A. Notably, its vessels were diffuse, arranged in

short radial chains, and predominantly found in pairs. Sclerotic tyloses were frequently present in the vessel lumens. Additionally, the axial parenchyma was described as diffuse-in-aggregates with tangential bands.

Furthermore, Jácome *et al.* (2021) performed macroscopic anatomical characterization of *Manilkara* sp. and observed growth rings visible without a lens and axial paratracheal parenchyma arranged in linear bands. The vessels, which were also visible via the 10x lens, presented diffuse porosity, a radial pattern and a predominance of chains, with the occasional occurrence of solitary vessels. As in the present study, the authors observed visible rays with a 10x lens, which were poorly contrasted and clearly demarcated tangential fibrous zones. Furthermore, the rays did not present a storied structure and were indistinct even under a 10x lens in the tangential plane.

*Manilkara* is native to Brazil and has 17 cataloged species, 14 of which are considered endemic (Alves-Araújo and Almeida 2020). Compared with the literature, the most striking characteristics that identify the genus *Manilkara* include the presence of axial parenchyma in narrow bands and diffuse-porous wood in a radial pattern, as described in the present study.

The genus is known for its high-density wood and for providing nontimber forest products, such as edible fruits, latex production and phytochemical use, making its use economically profitable and attractive (Hegde and Lakshman 2023). *Manilkara* wood is known for its durability and resistance to insects and fungi, making it suitable for construction, furniture, and musical instruments (Kukachka 1981). In addition, plants contain several phytochemicals responsible for their biological effects, including anti-inflammatory, antibacterial, antifungal and antidiabetic activities (Bano and Ahmed 2017; Gam *et al.* 2024).

Because the genus is attractive on the market, four species are currently on the IUNC list of threatened species: *M. elata* and *M. decrescens*, classified as “Endangered”; and *M. dardanoi* (Critically Endangered) and *M. maxima* (vulnerable) (IUNC 2024). In turn, the MMA list includes three species: *M. dardanoi* (critically endangered), *M. decrescens* (vulnerable) and *M. maxima* (endangered) (Brasil 2022).

### ***Bowdichia* sp. Kunth (Fabaceae)**

**Growth ring boundaries:** distinct but poorly demarcated regions, macroscopically appearing as fine, discontinuous lines of lighter tissue, often accompanied by a fibrous zone (Fig. 3L). **Vessels:** visible without a 10x lens, diffuse-porous, solitary vessels with multiple radial chains of 2–3 vessels, diagonal pattern occurrence (Fig. 4L). The vessels are obstructed by translucent beige substances (Fig. 4L). **Axial parenchyma:** paratracheal, lozenge-aliform and confluent aliform, visible without the 10x lens, with vasicentric occurrence, with fine noncontinuous lines at the limits of the growth rings (Fig. 4L). **Rays:** visible with a 10x lens, storied (Fig. 5F) and well contrasted (Fig. 7L).

Faria *et al.* (2020) described the wood anatomy of the species *Bowdichia virgilioides* Kunth and noted that its growth rings are poorly defined and demarcated by changes in the fiber wall thickness or radial fiber size and by a continuous marginal parenchyma. When performing macroscopic descriptions of commercial species, Jácome *et al.* (2021) characterized the species *Bowdichia* sp. with indistinct growth rings even under a 10x lens. The visible axial parenchyma without a lens was described as having lozenge aliform forming confluences in short stretches. The vessels, visible only with a 10x lens, were characterized as predominantly solitary, grouped in pairs or trios, small, sparse and with diffuse porosity and a tangential pattern, often obstructed by tyloses. The

rays, visible under a 10x lens, were described as fine, numerous, and well contrasted. In addition, the author reported rectilinear vascular lines, well-demarcated tangential fibrous zones and storied rays.

As observed in this study and in the literature, one of the characteristics that differentiates the genus *Bowdichia* from other genera is the storied rays. An example of this is the genus *Diploptropis* sp., which also belongs to the family Fabaceae and can be easily confused with *Bowdichia* sp. Jácome (2019) reported that both are practically indistinguishable at first glance, whether in color, parenchyma, or diameter of the vessels. However, the primary difference lies in the presence of storied rays in the genus *Bowdichia*, which are absent in *Diploptropis* sp. (Santini Junior 2013).

*Bowdichia* is a genus composed of only two species, *B. virgilioides* Kunth and *B. nitida* Spruce ex Benth, both of which are widely distributed in Brazil. These species occur in different phytogeographic domains of the Amazon, Caatinga, Cerrado, Atlantic Forest and Pantanal (Cardoso *et al.* 2024).

The genus *Bowdichia* is recognized for its medicinal and ecological importance in ethnobotanical studies. *Bowdichia virgilioides* was identified as a species that warrants further research because of its versatility and high consensus of informants in traditional medicine (Souza *et al.* 2014).

Despite the commercial use of wood, the evaluation of the lists of species at risk of extinction revealed that the two species representing the genera *B. nitida* and *B. virgilioides* are classified by the IUCN (2024) as being of “Least Concern,” which indicates that, currently, they do not face extinction threats, although continued exploitation and deforestation may be a future concern.

## Comparative Wood Anatomy of 12 Wood Species from the Brazilian Amazon

Comparative analysis of Amazonian wood species highlights distinctive anatomical features that are useful for education in hardwood anatomy and forensic applications. For example, *Handroanthus* sp. presented pore obstructions with yellow deposits, whereas *Peltogyne* sp. presented characteristic purple wood, both of which serve as practical markers for identification. Table 2 summarizes the main macroscopic wood features of twelve commercial species from the Brazilian Amazon, organized with adaptations from the table presented by Ferreira *et al.* (2021).

Among the evaluated woods, only *A. leiocarpa* presented indistinct growth rings, whereas *Manilkara* sp. presented distinct but difficult-to-visualize rings. Among the remaining 10 species (83%), the rings were distinct, with *Cedrela* sp., *Hymenaea* sp., *Hymenolobium* sp., *Handroanthus* sp., and *Peltogyne* sp. (42%) displaying particularly well-demarcated growth rings, primarily due to the presence of marginal axial parenchyma. Distinct and well-demarcated growth rings were also observed in 50% of the tree species when 20 species from the Peruvian Amazon were analyzed (Ferreira *et al.* 2023). The formation of growth rings results from the alternation between favorable and unfavorable growth conditions, which directly influences vascular cambium activity. In tropical regions, water availability is the main factor regulating cambial activity (Silva *et al.* 2019). However, this alternation is irregular and depends on variable environmental thresholds. Moreover, evolutionary adaptations have led to a greater diversity of anatomical markers, differences in the tangential arrangement and distinctness of rings, and multiple periodicities (Silva *et al.* 2019).

Diffuse porosity is a characteristic shared by the evaluated woods, except for *Cedrela* sp., and is common in species from tropical climates, such as those recorded in the Amazon. Another observed feature is a nonspecific vessel pattern in 67% of the species; regions with radial and tangential vessel arrangements are present, which is more pronounced in *Manilkara* sp., where radial chains are formed.

**Table 2.** Main Wood Macroscopic Features of 12 Commercial Wood Species from the Brazilian Amazon

| Structure        |                      | Features            | Species                 |                    |                     |                         |                          |                         |                      |                   |                        |                      |                      |                      |
|------------------|----------------------|---------------------|-------------------------|--------------------|---------------------|-------------------------|--------------------------|-------------------------|----------------------|-------------------|------------------------|----------------------|----------------------|----------------------|
|                  |                      |                     | <i>Amburana acreana</i> | <i>Cedrela</i> sp. | <i>Hymenaea</i> sp. | <i>Hymenolobium</i> sp. | <i>Apuleia leiocarpa</i> | <i>Handroanthus</i> sp. | <i>Astronium</i> sp. | <i>Guarea</i> sp. | <i>Simarouba amara</i> | <i>Peltogyne</i> sp. | <i>Manilkara</i> sp. | <i>Bowdichia</i> sp. |
| Growth rings     |                      | Indistinct          |                         |                    |                     |                         |                          |                         |                      |                   |                        |                      |                      |                      |
|                  |                      | Distinct            |                         |                    |                     |                         |                          |                         |                      |                   |                        |                      |                      |                      |
| Vessels          | Vessel arrangement   | No specific pattern |                         |                    |                     |                         |                          |                         |                      |                   |                        |                      |                      |                      |
|                  |                      | Diagonal            |                         |                    |                     |                         |                          |                         |                      |                   |                        |                      |                      |                      |
|                  |                      | Radial              |                         |                    |                     |                         |                          |                         |                      |                   |                        |                      |                      |                      |
|                  |                      | Tangential          |                         |                    |                     |                         |                          |                         |                      |                   |                        |                      |                      |                      |
|                  | Porosity             | Diffuse             |                         |                    |                     |                         |                          |                         |                      |                   |                        |                      |                      |                      |
|                  |                      | Semi ring           |                         |                    |                     |                         |                          |                         |                      |                   |                        |                      |                      |                      |
|                  |                      | Ring porous         |                         |                    |                     |                         |                          |                         |                      |                   |                        |                      |                      |                      |
|                  | Tyloses/ Deposits    |                     |                         |                    |                     |                         |                          |                         |                      |                   |                        |                      |                      |                      |
| Parenchyma axial | Apotracheal          | Difuse              |                         |                    |                     |                         |                          |                         |                      |                   |                        |                      |                      |                      |
|                  |                      | Difuse Agregate     |                         |                    |                     |                         |                          |                         |                      |                   |                        |                      |                      |                      |
|                  | Paratracheal         | Scarse              |                         |                    |                     |                         |                          |                         |                      |                   |                        |                      |                      |                      |
|                  |                      | Vasicentric         |                         |                    |                     |                         |                          |                         |                      |                   |                        |                      |                      |                      |
|                  |                      | Unilateral          |                         |                    |                     |                         |                          |                         |                      |                   |                        |                      |                      |                      |
|                  |                      | Aliform             |                         |                    |                     |                         |                          |                         |                      |                   |                        |                      |                      |                      |
|                  |                      | Confluent           |                         |                    |                     |                         |                          |                         |                      |                   |                        |                      |                      |                      |
|                  | Bands                | Marginal            |                         |                    |                     |                         |                          |                         |                      |                   |                        |                      |                      |                      |
|                  |                      | Narrow              |                         |                    |                     |                         |                          |                         |                      |                   |                        |                      |                      |                      |
|                  |                      | Wide                |                         |                    |                     |                         |                          |                         |                      |                   |                        |                      |                      |                      |
|                  |                      | Reticulate          |                         |                    |                     |                         |                          |                         |                      |                   |                        |                      |                      |                      |
| Rays             | Visibility           | Conspicuous         |                         |                    |                     |                         |                          |                         |                      |                   |                        |                      |                      |                      |
|                  |                      | Poorly Distinct     |                         |                    |                     |                         |                          |                         |                      |                   |                        |                      |                      |                      |
|                  |                      | Indistinct          |                         |                    |                     |                         |                          |                         |                      |                   |                        |                      |                      |                      |
|                  | Storied rays         |                     |                         |                    |                     |                         |                          |                         |                      |                   |                        |                      |                      |                      |
|                  | Well Contrasted rays |                     |                         |                    |                     |                         |                          |                         |                      |                   |                        |                      |                      |                      |

The vessels contained deposits of substances such as tyloses and gums, both in the transverse and tangential planes, with *Handroanthus* sp. being particularly notable for the

presence of a yellowish substance. These deposits within vessels occur during heartwood formation, a process in which gums and tyloses are deposited in certain species. Tyloses are cellular structures that occlude vessels, whereas gums consist of various chemical compounds (Ruffinatto *et al.* 2023; Esteban *et al.* 2024). In *Handroanthus* sp., such deposits are frequently composed of lapachol, a member of the naphthoquinone class (Pace *et al.* 2015; Harwood *et al.* 2021). The only wood that did not show any vessel deposits was *Simarouba amara*, which has a low content of extractives (Nascimento *et al.* 2025). Consequently, it is common for vessels to remain unobstructed by significant concentrations of extractives.

The most evident macroscopic anatomical feature is the type of axial parenchyma, which allows differentiation among the studied woods. Apotracheal parenchyma was the least common parenchyma, occurring only in *Cedrela* sp., whereas paratracheal parenchyma, which was mainly aliform and/or confluent, was observed in nine species (75%) and six species (50%), respectively, and in bands, marginal or seemingly marginal bands, in seven species (58%). The presence of paratracheal parenchyma is more common in species from warmer climates, whereas apotracheal parenchyma predominates in species from cooler climates (Alves and Angyalossy-Alfonso 2002). This pattern reflects the influence of temperature, together with precipitation and soil conditions, as a primary factor regulating vascular functions. Among specific observations, unilateral parenchyma was observed in *Handroanthus* sp. and *Peltogyne* sp.; *Hymenolobium* presented wide parenchyma bands contrasting with the fibers; and *Simarouba amara* presented light-colored wood, although winged-aliform parenchyma was present.

The rays are storied in *Amburana acreana*, *Hymenolobium* sp., *Apuleia leiocarpa*, *Handroanthus* sp., *Simarouba amara*, and *Bowdichia* sp. (50%). The storied structure of rays is predominantly restricted to tropical hardwoods, with few exceptions (Ruffinatto *et al.* 2023). Although the origin of this structure has not been clearly characterized in the literature, theories suggest that its formation is associated with cambial activity. There is evidence that its occurrence is related to the uniformity in the height of the axial elements of trees, which exhibit a low level of intrusion by fusiform cells. From an evolutionary perspective, woods with a storied ray structure exhibit a greater degree of specialization than non-storied woods do (Larson 1994; Esteban *et al.* 2024).

### Main Limitations of the Macroscopic Description

In this study, through macroscopic characterization of wood, 12 genera of Amazonian wood species were described. However, the macroscopic characterization presented limitations in reaching identification at the species level. This was mainly due to the similarity between the macroscopic anatomical characteristics of species within the same genus, making precise identification difficult (Souza *et al.* 2020; Bessa *et al.* 2022). In addition, intraspecific variation and environmental influences limit the distinction and comparison between similar species (Aragão *et al.* 2019; Bessa *et al.* 2022). Therefore, integrative studies that combine wood anatomy with complementary botanical evidence are necessary, as demonstrated by Souza *et al.* (2024) for *Handroanthus*.

Despite the limitations observed for the species-level identification of these 12 analyzed genera, identification *via* macroscopic wood characterization is important because it is a fast, inexpensive, and accessible technique because it does not require extensive knowledge of wood anatomy compared with microscopy (Ruffinatto *et al.* 2023). Furthermore, it is one of the main tools used by environmental inspection agencies in the sorting, control and inspection of illegal and prohibited timber to be harvested (Ruffinatto

*et al.* 2023). Microscopic analysis can provide additional diagnostic characteristics, such as quantitative parameters of fibers, vessels, and parenchyma, as well as details related to pits, which can contribute to a more precise species description.

In addition, it is still recommended that this method be complemented with additional techniques for more precise identification (Schmitz *et al.* 2020). Faster and more effective methodologies that allow the precise identification of Amazonian species and minimize the interference of human errors, especially during environmental inspections and seizures of timber cargoes, are important. Several advanced techniques, such as NIR (Novaes *et al.* 2023; Silva *et al.* 2024), artificial neural networks (He *et al.* 2019; Moulin *et al.* 2022), DNA extraction (But *et al.* 2023; Kim and Kim 2024), and the establishment of a forensic tree database *via* DART-TOFMS technology (Price *et al.* 2022), have been developed. Although these approaches differ significantly from macroscopic wood identification and are not directly comparable, they can serve as complementary or alternative tools in situations requiring rapid and reliable species verification. While these methods often require specialized equipment and trained personnel, they provide solutions that can enhance or support traditional identification techniques in environmental inspections and timber commercialization.

## CONCLUSIONS

1. The genera described in this study corresponded to the local commercial names provided by the sawmill from which the samples were obtained. Nine samples were identified at the genus level, whereas three were identified at the species level. Owing to the anatomical similarities among species within the same genus, it was not possible to identify commercial Amazonian wood at the species level.
2. Among the twelve commercial species analyzed, detailed descriptions have been provided in this work that reinforce the reliability of macroscopic anatomy as a practical tool for species recognition, especially in inspection and educational contexts. These findings contribute to improving species traceability in the timber trade and provide a didactic resource for training professionals in wood anatomy. The most important implication is that macroscopic analysis, although less detailed than microscopic or molecular approaches, remains a fast, accessible, and effective method to support both conservation strategies and the legal timber market.

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## REFERENCES CITED

- Abreu, J. L. L., Silva, M. G., Ferreira, G. C., Franca, T. S. F. A., Reis, A. R. C., and Pamplona, V. M. S. (2023). "Wood properties of four tropical species from mining areas in the Amazon, Brazil Part 1: Anatomical characterization," *Wood and Fiber Science* 55(3), 242-266. DOI: 10.22382/wfs-2023-21
- Acosta, T. L. N., Vieira, H. C., Santos, J. X. d., Silva, W. D. S. d., Stange, R., Souza, D. V., Cademartori, P. H. G. d., Muñiz, G. I. B. d., and Nisgoski, S. (2024). "'Marfim pattern' of wood species in the Southern Brazilian timber market: Colorimetry and visible spectra," *Wood Material Science & Engineering* 20(1), 107-116. DOI: 10.1080/17480272.2024.2328767
- Albuquerque, A. R., Castro, V. R. d., Lobão, M. S., Sarto, C., Filho, M. T., and Guedes, F. T. P. (2016). "Comparative analysis of anatomy and micro-densitometry of the growth rings of hardwoods and conifers, with emphasis on dendrochronology," *Scientia Forestalis* 44(111), 1-13.
- Alves, A. F., Guimarães Carvalho, A., Pereira Lopes, O., Vinha Zanuncio, A. J., and de Cássia Oliveira Carneiro, A. (2023). "Secondary xylem of tree species from Cerrado biome," *BioResources* 18(4), 7428-7442. DOI: 10.15376/biores.18.4.7428-7442
- Alves-Araújo, A., and Almeida Júnior, E. B. (2020). "*Manilkara* in Flora and Funga of Brazil," *Jardim Botânico do Rio de Janeiro*, (<https://floradobrasil.jbrj.gov.br/FB14473>), Accessed 6 August 2025.
- Alves, E. S., and Angyalossy-Alfonso, V. (2002). "Ecological trend in the wood anatomy of some Brazilian species. 2. Axial parenchyma, rays and fibres," *IAWA Journal* 23(4), 391-418. DOI: 10.1163/22941932-90000311
- Amais, R. S., Moreau, P. S., Francischini, D. S., Magnusson, R., Locosselli, G. M., Godoy-Veiga, M., Ceccantini, G., Rodriguez, D. R. O., Tomazello-Filho, M., and Arruda, M. A. Z. (2021). "Trace elements distribution in tropical tree rings through high-resolution imaging using LA-ICP-MS analysis," *Journal of Trace Elements in Medicine and Biology* 68, article 126872. DOI: 10.1016/j.jtemb.2021.126872
- Andrade-Silva, J., Baccaro, F. B., Prado, L. P., Guénard, B., Kass, J. M., Warren, D. L., Economo, E. P., and Silva, R. R. (2024). "Common ant species dominate morphospace: Unraveling the morphological diversity in the Brazilian Amazon Basin," *Ecography* 2024(11), article 07121. DOI: 10.1111/ecog.07121
- Aparecido, L. E. d. O., Moraes, J. R. d. S. C. d., Meneses, K. C. d., Torsoni, G. B., Lima, R. F. d., and Costa, C. T. S. (2020). "Köppen-Geiger and Camargo climate classifications for the Midwest of Brasil," *Theoretical and Applied Climatology* 142(3-4), 1133-1145. DOI: 10.1007/s00704-020-03358-2
- Aragão, J. R. V., Zuidema, P. A., and Groenendijk, P. (2022). "Climate-growth relations of congeneric tree species vary across a tropical vegetation gradient in Brazil," *Dendrochronologia* 71, article 125913. DOI: 10.1016/j.dendro.2021.125913
- Armstrong McKay, D. I., Staal, A., Abrams, J. F., Winkelmann, R., Sakschewski, B., Loriani, S., Fetzer, I., Cornell, S. E., Rockstrom, J., and Lenton, T. M. (2022). "Exceeding 1.5 degrees C global warming could trigger multiple climate tipping points," *Science* 377(6611), article eabn7950. DOI: 10.1126/science.abn7950
- Baar, J., Tippner, J., and Gryc, V. (2016). "Wood anatomy and acoustic properties of selected tropical hardwoods," *IAWA Journal* 37(1), 69-83. DOI: 10.1163/22941932-20160121

- Bano, M., and Ahmed, B. (2017). “*Manilkara zapota* (L.) P.Royen (Sapodilla): A Review,” *International Journal of Advance Research, Ideas and Innovations in Technology* 3(6), 1364-1371.
- Barbosa, A. C. F., Gerolamo, C. S., Lima, A. C., Angyalossy, V., and Pace, M. R. (2021). “Polishing entire stems and roots using sandpaper under water: An alternative method for macroscopic analyses,” *Applications in Plant Sciences* 9(5). DOI: 10.1002/aps3.11421
- Bauer, D., Schmitt, J. L., and Oliveira, J. M. (2020). “Xylem growth rings and leaf phenological patterns in tree species of a subtropical seasonal forest,” *Acta Botanica Brasílica* 34(4), 680-693. DOI: 10.1590/0102-33062019abb0395
- Bessa, F., Sousa, V., Quilhó, T., and Pereira, H. (2022). “An integrated similarity analysis of anatomical and physical wood properties of tropical species from India, Mozambique, and East Timor,” *Forests* 13(10), article 1675. DOI:10.3390/f13101675
- Borges, K. C. A. S., Dias, S. M., Mendonça, E. G., Lelis, R. C. C., Santos, L. A., and Souza, S. R. d. (2017). “DNA extraction and anatomic characterization in dried heartwood from Fabaceae species,” *Wood Research* 62(1), 13-26.
- Braga Júnior, M. M., Matos, T. S., Andrade, G. M. d., Ferreira, P. d. S., Silva, M. C. F., Souza, F. I. B. d., and Melo, L. E. d. L. (2020). “Technological properties of woods used in boat’s production in the Southeast of Pará, Brazil,” *Rodriguésia* 71, article 83. DOI: 10.1590/2175-7860202071083
- Brasil. Ministério do Meio Ambiente. (2022). “*Portaria MMA nº 148, de 7 de junho de 2022: Lista Nacional Oficial de Espécies da Flora Ameaçadas de Extinção*,” Diário Oficial da União: seção 1, Brasília, DF, nº 107, pp. 108–118, 8 jun. 2022. Disponível em <https://www.in.gov.br>. Acesso em 11 dez. 2024.
- But, G. W., Wu, H. Y., Siu, T. Y., Chan, K. T., Wong, K. H., Lau, D. T., and Shaw, P. C. (2023). “Comparison of DNA extraction methods on CITES-listed timber species and application in species authentication of commercial products using DNA barcoding,” *Scientific Reports* 13(1), article 151. DOI: 10.1038/s41598-022-27195-7
- Canetti, A., Braz, E. M., Mattos, P. P., Filho, A. F., and Basso, R. O. (2020). “Estrutura diamétrica e padrão de crescimento de garapeira na microrregião de Sinop, MT,” Comunicado Técnico nº 453, *Embrapa*, 1-10.
- Cardoso, D. B. O. S., Maia, T. A., and Lima, H. C. (2024). “*Bowdichia* in Flora and Funga of Brazil,” *Jardim Botânico do Rio de Janeiro*, (<https://floradobrasil.jbrj.gov.br/FB22834>), Accessed 6 August 2024.
- Chaves, C. L., Degen, B., Pakull, B., Mader, M., Honorio, E., Ruas, P., Tysklind, N., and Sebbenn, A. M. (2018). “Assessing the ability of chloroplast and nuclear DNA gene markers to verify the geographic origin of Jatoba (*Hymenaea courbaril* L.) timber,” *Journal of Heredity* 109(5), 543-552. DOI: 10.1093/jhered/esy017
- CITES. (2024). “Convention on International Trade in Endangered Species of Wild Fauna and Flora: Appendices I, II and III,” (<https://cites.org/eng/app/appendices.php>). Accessed 11 December 2024.
- Costa, A. C. S., Oliveira, A. C., Pereira, B. L. C., Silva, J. R. M. D., Oliveira, M. B. D., and Xavier, C. N. (2021). “Quality of tropical hardwood floors,” *Revista Árvore* 45, article e4503. DOI: 10.1590/1806-908820210000003

- Conserva, G. A. A., Girola, N., Figueiredo, C. R., Azevedo, R. A., Mousdell, S., Sartorelli, P., Soares, M. G., Antar, G. M., and Lago, J. H. G. (2017). "Terpenoids from leaves of *Guarea macrophylla* display *in vitro* cytotoxic activity and induce apoptosis in melanoma cells," *Planta Med* 83(16), 1289-1296. DOI: 10.1055/s-0043-107241
- COPANT. (1974). "*Descripción de características generales, macroscópicas y microscópicas de las maderas de Angiospermas Dicotiledóneas*" (No. 30, pp. 1–19). COPANT.
- Corrêa, A. D. A., and Ribero, E. B. P. (1972). "O Marupá como essência papeleira de reflorestamento," *Instituto Nacional de Pesquisas da Amazônia*, 83-91. DOI: 10.1590/1809-43921972023083
- Cosme, L., Jr., Haro, M. M., Guedes, N. M. P., Della Lucia, T. M. C., and Guedes, R. N. C. (2018). "Tropical wood resistance to the West Indian drywood termite *Cryptotermes brevis*: If termites can't chew," *Pest Management Science* 74(4), 914-924. DOI: 10.1002/ps.4785
- Devecchi, M. F., Pirani, J. R., and Thomas, W. W. (2024). "*Simarouba* in flora and funga of Brazil," *Jardim Botânico do Rio de Janeiro*, (<https://floradobrasil.jbrj.gov.br/FB1380>), Accessed 6 August 2024.
- Duarte, P. J., Borges, C. C., Ferreira, C. A., Cruz, T. M., de Souza, W. R. Q., and Mori, F. A. (2021). "Anatomical identification of tropical woods traded in Lavras, Brazil," *Journal of Tropical Forest Science* 33(1), 95-103. DOI: 10.26525/jtfs2020.32.4.95
- Duchesne, I., Lamichhane, D. D., Dias, R. P., de la Mata, P., Williams, M., Lamothe, M., Harynuk, J. J., Isabel, N., and Cloutier, A. (2023). "Comparing Gc×Gc-Tofms-based Metabolomic profiling and wood anatomy for forensic identification of five Meliaceae (mahogany) species," *Wood and Fiber Science* 55(1), 53-82. DOI: 10.22382/wfs-2023-07
- Esteban, L. G., Palacios, P., Gasson, P., García-Iruela, A., García-Fernández, F., and García-Esteban, L. (2024). "Hardwoods: Anatomy and functionality of their elements — A short review," *Forests* 15(7), article 1162. DOI:10.3390/f15071162
- Falcão, M. J. A., and Mansano, V. F. (2020). "*Apuleia* in Flora e Funga do Brasil," *Jardim Botânico do Rio de Janeiro*, (<https://floradobrasil.jbrj.gov.br/FB22795>), Accessed 5 August 2024.
- Faria, M. C. G. d., Silva Neto, C. d. M. e., Lima, P. A. F., Chagas, M. P., Tomazello Filho, M., and Sette Junior, C. R. (2020). "Brazilian cerrado species: Wood characteristics," *Bioscience Journal* 36(4), 1335-1352. DOI: 10.14393/BJ-v36n4a2020-48044
- Ferreira, A., Aguiar, R., Brandão, H., Santos, R., de Freitas, H., Teles, C., Reis, J., de Souza, J., and Alves, C. (2025). "Chemical constituents of *Amburana acreana* Ducke A. C. Sm. leaves," *Química Nova* 48(1). DOI: 10.21577/0100-4042.20250010
- Ferreira, C. A., Guillen, J. G. I., Buendia, R. H., Alanya, O. D. V., Aliaga, D. C. R., Centeno, W. G., Miranda, B. S. A., Mateo, S. M. M., Utos, T. C., Echeverry, A. V., and Tomazello Filho, M. (2023). "Identification of 20 species from the Peruvian Amazon tropical forest by the wood macroscopic features," *CERNE* 29, article 013134. DOI: 10.1590/01047760202329013134
- Ferreira, C. A., Inga, J. G., Vidal, O. D., Goytendia, W. E., Moya, S. M., Centeno, T. B., Vélez, A., Gamarra, D., and Tomazello-Filho, M. (2021). "Identification of tree species from the Peruvian tropical Amazon 'Selva Central' forests according to wood anatomy," *BioResources* 16(4), 7161-7179. DOI: 10.15376/biores.16.4.7161-7179

- Ferreira, D. d. R. G., Gonçalves, E. P., Viana, J. S., Ralph, L. N., Silva, J. C. d. A., and Silva, E. M. d. (2020). "Temperature and light under the physiological potential of seeds of *Handroanthus impetiginosus*," *Bioscience Journal* 36(1), 68-77. DOI: 10.14393/BJ-v36n1a2020-42454
- Flores, B. M., Montoya, E., Sakschewski, B., Nascimento, N., Staal, A., Betts, R. A., Levis, C., Lapola, D. M., Esquivel-Muelbert, A., Jakovac, C., Nobre, C. A., Oliveira, R. S., Borma, L. S., Nian, D., Boers, N., Hecht, S. B., Ter Steege, H., Arieira, J., Lucas, I. L., Berenguer, E., Marengo, J. A., Gatti, L. V., Mattos, C. R. C., and Hirota, M. (2024). "Critical transitions in the Amazon forest system," *Nature* 626(7999), 555-564. DOI: 10.1038/s41586-023-06970-0
- Flores, T. B. (2020). "Meliaceae in Flora e Funga do Brasil" (continuously updated), Jardim Botânico do Rio de Janeiro, (<https://floradobrasil.jbrj.gov.br/FB9992>), Access 15 September 2025.
- Gam, S., Ahmed, R., Kashyap, B., Sarma, H., Sahariah, B. J., Bora, N. S., Deka, K., Gogoi, B., and Dutta, K. N. (2024). "A systematic review on traditional use, phytochemistry and pharmacological activities of *Manilkara zapota*," *Pharmacological Research - Natural Products* 4, Article no. 100062. DOI: 10.1016/j.prenap.2024.100062
- Gonzales, I. (2011). "*Atlas de Maderas Selva Central*," National University of the Center of Peru, Huancayo, Peru.
- Granato-Souza, D., Barbosa, A. C. M. C., and Ferreira Chaves, H. (2019). "Drivers of growth variability of *Hymenaea stigonocarpa*, a widely distributed tree species in the Brazilian Cerrado," *Dendrochronologia* 53, 73-81. DOI: 10.1016/j
- Harwood, J., Tribaldos, W., Lobo, S., and Weislo, W. (2021). "Wood identification of the altarpiece and a sculpture of the Cathedral Basilica Santa María la Antigua," *European Journal of Science and Theology* 17(2), 137-149.
- He, T., Marco, J., Soares, R., Yin, Y., and Wiedenhoeft, A. (2019). "Machine learning models with quantitative wood anatomy data can discriminate between *Swietenia macrophylla* and *Swietenia mahagoni*," *Forests* 11(1), article 36. DOI: 10.3390/f11010036
- Hegde, M. M., and Lakshman, K. (2023). "Phyto-pharmacological review of genus *Manilkara*," *International Journal of Herbal Medicine* 11(5), 01-13. DOI: 10.22271/flora.2023.v11.i5a.882
- Hoang, N. T., and Kanemoto, K. (2021). "Mapping the deforestation footprint of nations reveals growing threat to tropical forests," *Nature Ecology & Evolution* 5(6), 845-853.
- IAWA Committee (1989). *IAWA List of Microscopic Features for Hardwood Identification*, E. A. Wheeler, P. Baas, and P. E. Gasson (eds.), Leiden, Netherlands.
- Instituto de Pesquisas Tecnológicas (IPT). "Informações sobre madeiras," (<https://madeiras.ipt.br>), Accessed 13 December 2024.
- IPCC. (2021). *Climate Change 2021: The Physical Science Basis. Working Group I Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Retrieved from Cambridge, United Kingdom and New York, United States of America.
- IUCN. (2024). "The IUCN Red List of Threatened Species (Version 2024-1)," (<https://www.iucnredlist.org>), Accessed 11 December 2024.
- Jácome, C. C., Duarte, P. J., Pires, M. R., Mori, F. A., Lafetá, B. O., and Sartori, C. J. (2021). "Anatomia macroscópica de madeiras comercializadas no município de São

- João Evangelista, estado de Minas Gerais, Brasil,” in: *Madeiras Nativas e Plantadas do Brasil: Qualidade, Pesquisas e Atualidades* (Vol. 1), W. V. Vangelista (ed.), Editora Científica, pp. 230-243.
- Kim, M., I. S., and Kim, T. J. (2024). “DNA barcodes for wood identification of anatomically similar species of genus *Chamaecyparis*,” *Forests* 15(7), article 1106. DOI: 10.3390/f15071106
- Kukachka, B. F. (1981). “*Wood Anatomy of the Neotropical Sapotaceae XX. Manilkara*,” Forest Products Laboratory, Forest Service, U.S. Department of Agriculture. Research Paper FPL 371, 1-16. Madison, WI.
- Larson, P. R. (1994). “Rays,” in: *The Vascular Cambium*, Springer, Berlin, Heidelberg. DOI:10.1007/978-3-642-78466-8\_8
- Latorraca, J. V. de F., Castro, J. P., and dos Santos, G. C. V. (2018). *Guia para a Identificação Macroscópica de Madeira* (1ª Ed.), Seropédica, Editora do autor.
- Layme-Huaman, E. T., Ferrero, M. E., Palacios-Lazaro, K. S., and Requena-Rojas, E. J. (2018). “*Cedrela nebulosa*: A novel species for dendroclimatological studies in the montane tropics of South America,” *Dendrochronologia* 50, 105-112. DOI: 10.1016/j.dendro.2018.06.004
- Lens, F., Liang, C., Guo, Y., Tang, X., Jahanbanifard, M., da Silva, F. S. C., Ceccantini, G., and Verbeek, F. J. (2020). “Computer-assisted timber identification based on features extracted from microscopic wood sections,” *IWA Journal* 41(4), 660-680. DOI: 10.1163/22941932-bja10029
- Lima, H. C. d., and Cordula, E. (2015). “*Peltogyne* in Lista de Espécies da Flora do Brasil,” (<http://floradobrasil2015.jbrj.gov.br/jabot/floradobrasil/FB78741>), Accessed 6 August 2024.
- Lima, M. F. M. d., Mascarenhas, A. R. P., Pereira, B. L. C., Susin, F., Silva, G. A. D. O., and Stangerlin, D. M. (2023). “Experimental characterization of density, defects and drying kinetic of three Amazonian wood species: *Astronium lecointei*, *Dinizia excelsa*, and *Hymenolobium heterocarpum*,” *Wood Material Science & Engineering* 18(4), 1264-1274. DOI: 10.1080/17480272.2022.2125339
- Lohmann, L. G. (2020). “*Handroanthus* in Flora and Funga of Brazil,” (<https://floradobrasil.jbrj.gov.br/FB114068>), Accessed 6 August 2024.
- López, L., and Villalba, R. (2016). “Reliable estimates of radial growth for eight tropical species based on wood anatomical patterns,” *Journal of Tropical Forest Science* 28(2), 139-152.
- López, L., Villalba, R., and Stahle, D. (2022). “High-fidelity representation of climate variations by *Amburana cearensis* tree-ring chronologies across a tropical forest transition in South America,” *Dendrochronologia* 72, article 125932. DOI: 10.1016/j.dendro.2022.125932
- Mamoňová, M., and Reinprecht, L. (2020). “The impact of natural and artificial weathering on the anatomy of selected tropical hardwoods,” *IWA Journal* 41(3), 333-355. DOI: 10.1163/22941932-bja10028
- Marcelo-Peña, J. L., Roig, F. A., Goodwin, Z. A., and Tomazello-Filho, M. (2020). “Characterizing growth rings in the trees of Perú: A wood anatomical overview for potential applications in dendroecological-related fields,” *Dendrochronologia* 62, article 125728. DOI: 10.1016/j.dendro.2020.125728
- Melchor-Castro, B., Lima, H. C., and Cardoso, D. B. O. S. (n.d.). “*Hymenolobium* in Flora e Funga do Brasil,” (<https://floradobrasil.jbrj.gov.br/FB22977>), Accessed 5 August 2024.

- Melo, J. D., and Camargos, J. A. A. (2016). “A madeira e seus usos,” SFB/LPF/MMA, Brasília, Brazil.
- Meunier, F., Boeckx, P., Botía, S., Bauters, M., Cherlet, W., Ciais, P., De Hertog, S., Dietze, M., Peaucelle, M., Sibret, T., Sitch, S., Li, W., and Vereeck, H. (2024). “Intact Amazon forests hit a record low gross primary productivity level in 2023-2024,” *Research Square* 1-19. DOI: 10.21203/rs.3.rs-4161696/v2
- Mitchell, J. D., and Daly, D. C. (2017). “Notes on *Astronium* Jacq. (Anacardiaceae), including a dwarf new species from the Brazilian Shield,” *Brittonia* 69(4), 457-464. DOI: 10.1007/s12228-017-9506-0
- Moulin, J. C., Lopes, D. J. V., Mulin, L. B., Bobadilha, G. d. S., and Oliveira, R. F. (2022). “Microscopic identification of Brazilian commercial wood species via machine-learning,” *CERNE* 28, article 12978. DOI: 10.1590/01047760202228012978
- Nascimento, C. S., Cruz, I. A., Soares, J. C. R., Silva, C. E., Lima, A. J. N., Santos, J., and Higuchi, N. (2025). “Functional chemical, physical, and mechanical traits of Amazonian forest species from different ecological groups using NIR spectroscopy,” *Canadian Journal of Forest Research* 55, 1-10. DOI: 10.1139/cjfr-2024-0260
- Nascimento, L. B., das Neves Brandes, A. F., Valente, F. D. W., and Tamaio, N. (2016). “Anatomical identification of commercialized wood in the state of Rio de Janeiro, Brazil,” *Brazilian Journal of Botany* 40(1), 291-329. DOI: 10.1007/s40415-016-0324-5
- Novaes, T. V., Ramalho, F. M. G., da Silva Araujo, E., Lima, M. D. R., da Silva, M. G., Ferreira, G. C., and Hein, P. R. G. (2022). “Discrimination of Amazonian forest species by NIR spectroscopy: Wood surface effects,” *European Journal of Wood and Wood Products* 81(1), 159-172. DOI: 10.1007/s00107-022-01862-y
- Oliva, J. U., and Zerpa, I. M. (2018). “Guía para la identificación de la madera de 50 especies forestales del Perú,” Lima, Perú: Centro de Innovación Productiva y Transferencia Tecnológica de la Madera - CITEmadera.
- Pereira, E. J. d. A. L., Ribeiro, L. C. d. S., Freitas, L. F. d. S., and Pereira, H. B. d. B. (2020). “Brazilian policy and agribusiness damage the Amazon rainforest,” *Land Use Policy* 92, article 104491. DOI: 10.1016/j.landusepol.2020.104491
- Pimenta, J. M. A., Souza, W. M. A. T. d., Egito, R. H. T. d., Ferrari, C. d. S., and Pacheco, M. V. (2024). “Divergência fenotípica de *Handroanthus impetiginosus* por meio de imagens digitais,” *Pesquisa Florestal Brasileira* 44, article e202202257. DOI: 10.4336/2024.pfb.44e202202257
- Price, E. R., McClure, P. J., Huffman, A. N., Voin, D., and Espinoza, E. O. (2022). “Reliability of wood identification using DART-TOFMS and the ForeST© database: A validation study,” *Forensic Science International: Animals and Environments* 2, article 100045. DOI: 10.1016/j.fsiae.2022.100045
- Quintilhan, M. T., Santini, L., Rodriguez, D. R. O., Guillemot, J., Cesilio, G. H. M., Chambi-Legoas, R., Nouvellon, Y., and Tomazello-Filho, M. (2021). “Growth-ring boundaries of tropical tree species: Aiding delimitation by long histological sections and wood density profiles,” *Dendrochronologia* 69, article 125878. DOI: 10.1016/j.dendro.2021.125878
- Rodrigues, E. F. C., De Araujo, V. A., Cavalheiro, R. S., Marini, L. J., Almeida, J. P. B., Azevedo, A. R. G., Oliveira, L. B., Lahr, F. A. R., dos Santos, H. F., and Christoforo, A. L. (2023). “Influence of growth rings position of wood on the determination of its shear strength parallel to grain,” *Journal of Materials Research and Technology* 24, 9765-9779. DOI: 10.1016/j.jmrt.2023.05.195

- Rodriguez, D. R. O., Hevia, A., Sánchez-Salguero, R., Santini, L., Carvalho, H. W. P. d., Roig, F. A., and Tomazello-Filho, M. (2022). "Exploring wood anatomy, density and chemistry profiles to understand the tree-ring formation in Amazonian tree species," *Dendrochronologia* 71, article 125915. DOI: 10.1016/j.dendro.2021.125915
- Ruffinatto, F., Crivellaro, A., and Wiedenhoeft, A. C. (2015). "Review of macroscopic features for hardwood and softwood identification and a proposal for a new character list," *IAWA Journal* 36(2), 208-241. DOI: 10.1163/22941932-00000096
- Ruffinatto, F., Negro, F., and Crivellaro, A. (2023). "The macroscopic structure of wood," *Forests* 14(3), article 644. DOI: 10.3390/f14030644
- Safriansyah, W., Sinaga, S. E., Supratman, U., and Harneti, D. (2022). "Phytochemistry and biological activities of *Guarea* genus (Meliaceae)," *Molecules* 27(24), article 8758. DOI: 10.3390/molecules27248758
- Santini Junior, L. (2013). "Descrição macroscópica e microscópica da madeira aplicada na identificação das principais espécies comercializadas no Estado de São Paulo – Programas 'São Paulo Amigo da Amazônia' e 'Cadmadeira'" (Dissertação de Mestrado). Escola Superior de Agricultura Luiz de Queiroz (ESALQ), Piracicaba-SP., 272 pp.
- Santos, J. X. d., Vieira, H. C., Silva, E. L. d., Muñiz, G. I. B. d., Reis, A. R. S., and Nisgoski, S. (2020). "Anatomical characterization of wood marketed as "tauari" (Lecythidaceae) in Pará state, Brazil," *Floresta* 50(3), 1421-1429. DOI: 10.5380/rf.v50
- Schmitz, N. (ed.), Beeckman, H., Blanc-Jolivet, C., Boeschoten, L., Braga, J. W. B., Cabezas, J. A., Chaix, G., Crameri, S., Degen, B., Deklerck, V., *et al.* (2020). *Overview of Current Practices in Data Analysis for Wood Identification: A Guide for the Different Timber Tracking Methods*, Global Timber Tracking Network, GTTN secretariat, European Forest Institute and Thünen Institute.
- Seleme, E. P., Lewis, G. P., Stirton, C. H., Sartori, A. L. B., and Mansano, V. F. (2015). "A taxonomic review and a new species of the South American woody genus *Amburana* (Leguminosae, Papilionoideae)," *Phytotaxa* 212(4), 249-263.
- Silva, C. E. d., Nascimento, C. S. d., Freitas, J. A. d., Araújo, R. D. d., Nascimento, C. C. d., and Higuchi, N. (2024). "Application of infrared spectroscopy in the identification of fallen trees from the Amazon rainforest (Myristicaceae)," *Forest Science* 70(2), 102-112. DOI: 10.1093/forsci/fxae001
- Silva, C. E. S., Martins, B. C., Carvalho, P. C. L., Reis, C. A., Maciel, N. S. R., Pereira, M. G., Gomes, F. J. B., Rolim, S. G., Piotto, D., Carvalho, A. M., and Latorraca, J. V. F. (2021). "Physical, mechanical, and workability characterization of woods from six Atlantic Forest species," in: *Native and Planted Woods of Brazil: Quality, Research, and Updates*, pp. 19-41. DOI: 10.37885/210303812
- Silva, J. M. C. d., Barbosa, L. C. F., Topf, J., Vieira, I. C. G., and Scarano, F. R. (2022). "Minimum costs to conserve 80% of the Brazilian Amazon," *Perspectives in Ecology and Conservation* 20(3), 216-222. DOI: 10.1016/j.pecon.2022.03.007
- Silva-Luz, C. L., Pirani, J. R., Pell, S. K., and Mitchell, J. D. "Anacardiaceae in Flora and Funga of Brazil," *Jardim Botânico do Rio de Janeiro*, (<https://floradobrasil.jbrj.gov.br/FB4382>), Accessed 5 August 2024.
- Silva, M. S., Funch, L. S., and Silva, L. B. (2019). "The growth ring concept: seeking a broader and unambiguous approach covering tropical species," *Biological Reviews* 94(6), 1-18. DOI: 10.1111/brv.12495.

- Souza, D. V., Santos, J. X., Vieira, H. C., Naide, T. L., Nisgoski, S., and Oliveira, L. E. S. (2020). “An automatic recognition system of Brazilian flora species based on textural features of macroscopic images of wood,” *Wood Science and Technology* 54(4), 1065-1090. DOI: 10.1007/s00226-020-01196-z
- Souza, E. P., Gomes, B. M., Fagg, C. W., Marques, L. F., Gontijo, A. B., and Sonsin-Oliveira, J. (2024). “Distinguishing Amazonian ipê species (*Handroanthus*, Bignoniaceae) using macroscopic wood anatomy and leaf morphology,” *IAWA Journal* 45(4), 476-502. DOI: 10.1163/22941932-bja10153
- Souza, M. M., Bufalino, L., and Gomes, L. G. (2020). “Caracterização Madeira de Marupá (*Simarouba amara* Aubl, Simaroubaceae) Visando Utilização na Indústria Moveleira,” *Brazilian Journal of Development* 6(12), 98163-98185. DOI: 10.34117/bjdv6n12-347
- Souza, R. K., da Silva, M. A., de Menezes, I. R., Ribeiro, D. A., Bezerra, L. R., and Souza, M. M. (2014). “Ethnopharmacology of medicinal plants of carrasco, northeastern Brazil,” *Journal of Ethnopharmacology* 157, 99-104. DOI: 10.1016/j.jep.2014.09.001
- Teixeira, J. N., Wolenski, A. R. V., Aquino, V. B. d. M., Panzera, T. H., Silva, D. A. L., Campos, C. I., Silva, S. A. M., Lahr, F. A. R., and Christoforo, A. L. (2021). “Influence of provenance on physical and mechanical properties of Angelim-pedra (*Hymenolobium petraeum* Ducke.) wood species,” *European Journal of Wood and Wood Products* 79(5), 1241-1251. DOI: 10.1007/s00107-021-01692-4
- The Wood Database. (2024). “Wood Database,” (<https://www.wood-database.com>), Accessed 20 December 2024.
- Ticahuanca, R. C. A., Jihuallanca, E. Á. C., and Cahuana, L. A. P. (2020). “Características anatómicas y propiedades físicas de la madera de *Cedrela odorata* L., de 22 años, San Gabán – Perú,” *Revista de Investigación de Agroproducción Sustentable* 4(3), article 564. DOI: 10.25127/aps.20203.564
- Valverde, J. C., Aguilar, D. A., Arias, K., Castillo, M., Miller, C., Aguilar, H., and Flores, D. (2020). “Identificación de patrones de reflectancia espectral y colorimétricos en madera seca de *Peltogyne purpurea* Pittier,” *Revista Cubana de Ciencias Forestales* 8, 262-281.
- Zepner, L., Karrasch, P., Wiemann, F., and Bernard, L. (2020). “ClimateCharts.net – an interactive climate analysis web platform,” *International Journal of Digital Earth* 14(3), 338–356. DOI: 10.1080/17538947.2020.1829112

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