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Identification of 20 species from the Peruvian Amazon tropical forest by the wood macroscopic features

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TECHNOLOGY OF FOREST PRODUCTS

ABSTRACT

Background: The biodiversity of the Peruvian Amazon tropical forests is one of the most expressive in the world, with 2500 forest species, although restricted to about 250 tree species used commercially. This species diversity indicates the challenge magnitude for research in taxonomy and timber species identification. Likewise, it implies the complexity of biodiversity conservation and restoration measures, which are directly related to the control of deforestation, cutting and transport of illegal wood. With this objective, the present study describes the macroscopic wood anatomical features in order to identify 20 tree species from Peruvian Amazon Forest, "*Selva Central*", including an identification key and tree species botanical validation.

Results: The wood species are included in 12 families commonly found in the tropical forests of Peru, highlighting the Fabaceae (25%), Moraceae (15%), Podocarpaceae and Lauraceae (10%) families and are sold as timber for several uses and applications in the internal market and for export. The wood species presented common anatomical features, such as diffuse porosity, visible axial parenchyma mainly distinct, and, eventually, with ray storied, *e. g*: *A. cearensis*, *M. balsamum* and *M. peruiferum*.

Conclusion: The tropical tree species identification is possible by analyzing their wood macroscopic anatomical structure. The results can be also applied in the wood trade traceability by controlling deforestation and illegal wood commerce and in proposing policies for biodiversity conservation and sustainable use of natural resources. They constitute, likewise, a database for the recent wood identification methodologies presented in the specialized literature.

Key words: Forensic wood identification; wood anatomy identification; Tropical timber species; Peruvian Amazon forests; misidentification; illegal logging

HIGHLIGHTS

Identification by anatomical structure enable wood trade traceability
Tree species identification is essential for controlling deforestation
Machine learning satisfactorily works for wood anatomy
Convolutional neural networks can identify tropical Peruvian Amazon species

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INTRODUCTION

In the context of Neotropical forests, Peru is one of the most important countries of South America, due to its mega diversity of flora and fauna distributed in a vast territory of 1,285,215.9 km^2. These areas are characterized by the typologies of mountains, coast and jungle, the latter classified as high, low, and central jungle (Selva Central). The country's forest area is 72 million ha, with 69 million Amazonian forests, 4 million seasonally dry forests and 200,000 ha of Andean forests (Ministry of Agrarian Development and Irrigation of Peru, 2022). It is estimated that between 2015-2020 the forest deforestation worldwide was about 10 million hectares per year (FAO, 2020).

The time series on forest area reduction recommend the implementation of measures and strategic actions for the protection and conservation of natural forest resources, with the support and partnership of institutions such as the International Union for Conservation of Nature (IUCN), as well as the compliance with the Convention on International Trade in Endangered Species (CITES) (SERFOR, 2016). Likewise, the implementation of initiatives to control illegal logging and the felling, transport and informal trade of tropical wood are necessary and essential, concomitant with the application of sustainable forest management practices (de Lima et al., 2018).

The implementation of measures to control illegal wood at SERFOR inspection posts requires the application of wood anatomy applied to species identification, not only in Peru but in other Latin America countries likewise Brazil, country that has, in its territory, most of the tropical Amazon. In this regard, for the conditions of the Peruvian Tropical Amazon "Selva Central" forest, the contribution of Ferreira et al. (2021) stands out, identifying and describing 20 wood species by their macroscopic anatomical structure. This work highlights that wood species originating from the Peruvian Amazon "Selva Central" are, in general, characterized by inappropriate common names and sometimes the same name is applied to different wood species. As an example, the common names "Moena" with different color belongs are different genus of Lauraceae: *Aniba* Aubl., *Ocotea* Aubl, *Persea* Mill. and *Pleurothyrium* Nees. In Ferreira and Inga (2022) added 13 more species commercialized as "Roble corriente" or "Moenas" with different colors in the Peruvian Amazon Forest with three more genera in addition to those mentioned: *Aiouea* Aubl., *Licaria* Aubl and *Nectandra* Rol. Ex Rottb., all of the last three with botanical validation. In this work, were found a vulnerable tree species *Aniba perutilis* Hemsl "comino" according to the IUCN (2023) traded as "moena amarilla". Other studies using forensic anatomy to identify woods worldwide highlight the need for training the anatomist responsible for the identification, reference material indexed in xilotecas associated with an herbarium with botanical identification (Carlquist, 2001; Gasson et al., 2011; Dormontt et al.2015; Ruffinato et al., 2015; Nascimento et al., 2017; Duarte et al., 2021; Santini Jr. et al., 2021; Ferreira et al., 2021; Ferreira and Inga, 2022).

Despite the traditional use of wood anatomy to tree species identification, in recent years in the specialized bibliography, new methodologies have been introduced for optimizing the process of the tropical wood identification in the trade segments. Among the several techniques are highlighted the traditional recognition of tree species using wood macroscopic images (Yusof et al., 2013; Zhao 2013; Zhao et al., 2014; Paula-Filho et al., 2014; Ravidran et al., 2018; Souza et al., 2020; Fabijanska et al., 2021; Gonçalves et al., 2022) and microscopic images (Mallik et al., 2011; Gurau et al., 2013; Guang- Sheng and Peng 2013). Other methodologies are mentioned, like the molecular markers or DNA Barcoding (Miranda et al., 2014; Yu et al., 2015; Jiao et al., 2020), NIR spectroscopy (Monteiro et al., 2010; Soares et al., 2017); chemometric processing of direct analysis (DART-TOFMS) and mass spectrometry-derived fingerprints (Musah et al., 2015; Evans et al., 2017; Ravindran and Wiedenhoeft, 2020; Price et al., 2021; Kitin et al., 2021). However, these promising technologies of tree species identification applying wood anatomy with aim to improve the wood trade traceability have the high cost of sample processing, expensive equipments and specialized personal. In addition, they need a previously the tree species wood database demonstrably botanically identified or even using a reliable complete wood collection.

In this way, the present study applies and evaluates the efficiency of the classic methodology of forensic tree species identification, applying the wood anatomy based on 20 relevant wood species from the Peruvian Amazon Selva Central. It included an wood identification key as an efficient and easy-to-use tool at inspection and logging control posts by the Peruvian government.

MATERIAL AND METHODOS

Peruvian amazon and the tropical tree wood species surveyed

The Peruvian Amazon "Selva Central" distinguishes the climate of the "Selva Alta "and the "Selva Baja", which are both a tropical climate. Located in the high forest are the provinces of Chanchamayo and Satipo (Junín province), which together with Oxapampa (Pasco province) make up the so-called "Selva Central" (Figure 1). The province of Chanchamayo has a tropical climate that is warm, humid, and rainy. The average annual temperature ranges from 18°C to 30°C and the precipitation is 2000 mm per year. Satipo has a tropical climate (classified as Af according to the Koppen system) located at 627 m above sea level, with an annual rainfall of 2446 mm per year and an average temperature of 20.7 °C. Oxapampa is located at 1810m above sea level, with a warm and temperate climate. The climate in Oxapampa is classified as Cfb according to the Koppen system, and the average temperature is 14.6 °C, with an annual rainfall of 3474 mm per year (Ministry of Environment - National Climate Classification Map of Peru, 2022, Ferreira et al., 2021).

Part of this wood samples were collected in 13 sawmill companies that exploited and processed wood from tropical tree species and in two Native communities Tres Unidos Matereni and Tincabeni in the Peruvian Amazon “Selva Central”. These sawmills and these two native communities were in the 3 Peruvian provinces: Satipo (districts of Satipo, Mazamari, S.M. de Pangoa), Chanchamayo (district Pichanaqui), and Oxapampa (district Villa Rica). In the sawmills, the collected wood samples were in their primary transformation process, being collected woody disks and identified by the vernacular name. In tree species located at forestry areas - concessions authorized by the National Service of Forestry and Wildlife (SERFOR) - wood samples and, also, botanical material were collected from tree species for further botanical identification at the “Herbarium Selva Central Oxapampa (HOXA), Oxapampa, Pasco, Peru.

In Peruvian native forestry communities, non-destructive wood samples were extracted of the tree species pole by a Stihl BT45 motor with a metal drill (3 cutting teeth of 3.0 × 2.5 and 10 cm; external and internal diameter and length) and preventively treating the trunk holes with chromium copper borate (CCB) to avoid contamination by microorganisms and insects. At the same time, the correspondent common names and primary wood applications were collected and stored in plastic bags previously to transportation to the laboratory.

Wood samples preparation, macroscopic analysis, and tree species identification

The woods specimens belonging to the sampled tree species were previously identified and grouped by common names, were kept in the laboratory to allow for natural drying. Then, the wood specimens were cut (5 cm x 5 cm x 5 cm), oriented in cross and radial-tangential longitudinal sections. The wood samples were polished with paper sheets (80 to 1500 grain) and then cleaned with air spray. Wood macroscopic anatomical analysis were performed with the 10x hand lens (Coradin and Muñiz, 1992). Wood sections were observed using a Leica 9Si stereomicroscope (10x) coupled with a digital camera connected to a computer to obtain high quality images of the macroscopic anatomical structure. The tree species identification was based on the “IAWA Standards”, “Macroscopic Identification of Commercial Woods” and specialized literature (Wheeler et al., 1989; Coradin and Muñiz 1992; Maguiña 2008; Coradin et al., 2010; Zenid and Ceccantini 2012; Ruffinatto and Crivellaro 2015; Chavesta 2015; Ugarte and Mori 2018; Ferreira et al., 2021; Ferreira and Inga 2022). The wood samples were deposited at the Wood Collection of the Wood Anatomy Laboratory, Continental University, *Campus* Huancayo, Huancayo, Peru.

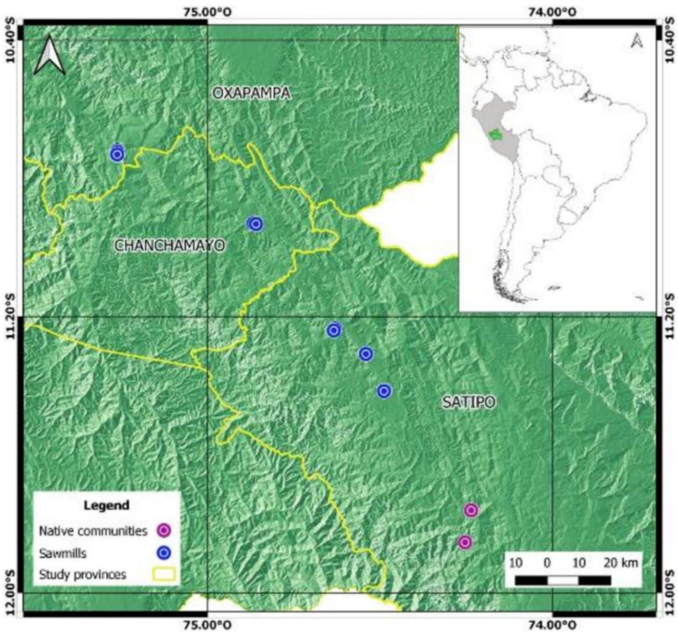

Figure 1. Peruvian “Selva Central” in the Satipo, Chanchamayo, and Oxapampa Provinces and the location of the sawmill companies: A) Province of Satipo (Distrito of Satipo: 1. Nematsa, SRL/11°14’17.9”S/74°37’57.2”O; and 2. Corporación Erick, 11°14’35.2”S/74°38’09.5”O; Distrito of Mazamari: 3. Industrias de la Madera SA.C; and 4. Machu Picchu Perú SAC; Distrito of S.M. de Pangoa: 5. Maderas Pangoa, 11°25’02.5”S/74°29’19.7”O; and 6. Maderera Alexis, 11°25’08.3”S/74°29’27.4”O); Province of Chanchamayo (Distrito of Pichanaqui: 7. Forestal Luis Solarzano EIRL, 10°55’59.3”S/74°52’08.6”O; and 8. Industrial Maderera Roble, 10°56’06.5”S/74°51’42.8”O; and Province of Oxapampa (Distrito of Villa Rica: 9. Maderera Rainforest Arbocco, 10°43’27.6”S/75°15’50.5”O; 10. Tulpay y Vidalon, 10°43’20.2”S/75°15’49.4”O; 11. Ind. Forestales Villa Rica SAC, 10°44’6.4”S/75°15’51.9”O; 12. Mavir Forestales EIRL, 10°43’36.4”S/75°15’47.2”O; and 13. Industrias Villa Rica IRL, 10°44’0.9”S/75°15’51.2”O). B) Native communities: Tres Unidos de Matereni 11°45’51.02”S/74°14’18.03”O and Tincabeni 11°51’25.45”S/74°15’21.26”O.

RESULTS

Tree species identified by their wood anatomical structure

A total of 20 tropical tree species were identified, 11 were botanically certified by the HOXA herbarium and 9 were identified according by wood anatomical macroscopic and organoleptic features detailed described in the specialized literature (Table 1) (Acevedo and Kikata, 1994; Chavesta, 2005, 2015; Caceres, 2008a, 2008b; Maguiña, 2008; Gonzales, 2011; Osinfor, 2015; Ruffinatto and Crivellaro, 2015; Osinfor, 2017; Ugarte and Mori, 2018; Marcelo-Peña and Tomazello Filho, 2020; SERFOR, 2020; Florsheim et al., 2020; Santini Jr. et al., 2021; Ferreira et al., 2021; Tropics, 2022; Ferreira and Inga, 2022).

These tree species are reported in the Peruvian scientific literature and are sold as timber for several uses and applications in the internal market and for export. The tree species are included in 12 families commonly found in the tropical forests of Peru, namely, Fabaceae (25%), Moraceae (15%), Podocarpaceae and Lauraceae (10%) and, also, including families with a 5% of representativeness, like Calophyllaceae, Caryocaraceae, Chrysobalanaceae, Juglandaceae, Meliaceae, Rhizophoraceae, Rubiaceae and Theaceae. The genus *Ficus* L. (Moraceae) and *Myroxylon* L. F. (Fabaceae) were represented by 2 species each, *Ficus insipida*, *Ficus* sp, *Myroxylon balsamum* and *M. peruiferum*.

In the Peruvian forest, the tree species represented by family, scientific and common names, are as follows: (1) *Fabaceae: Amburana cearensis* – isphingo; *Cedrelinga cateniformis* – tornillo; *Copaifera paupera* – copaiba; *Myroxylon balsamum* – estoraque; *Myroxylon peruiferum* – quina quina; (2) Moraceae: *Brosimum utile* – leche caspi; *Ficus insipida* – ojé; *Ficus* sp. – matapalo amarillo; (3) Lauraceae: *Aiouea montana* – moena blanca; *Caryodaphnopsis fosteri* – palo caramelo; (4) Podocarpaceae: *Podocarpus* sp. – diablo fuerte; Retrophyllum rospigliosii – ulcumano; (5) Calophyllaceae: *Calophyllum brasiliense* – palo azufre; (6) Caryocaraceae: *Caryocar glabrum* – almendro; (7) Chrysobalanaceae: *Hymenopus heteromorphus* – sachapalta; (8) Juglandaceae: *Juglans neotropica* – nogal; (9) Meliaceae: *Guarea guidonia* – requia; (10) Rhizophoraceae: *Sterigmapetalum obovatum* – palo verde; (11) Rubiaceae: *Calycophyllum spruceanum* – capirona; (12) Theaceae: *Gordonia fruticosa* – huamachilca (Table 1).

DISCUSSION

Tree species general dendrological features

The family Fabaceae with 5 species identified is the most representative in this study and constitutes one of the most representative in the world. *Amburana cearensis* tree species known as ispingo, cerejeira, cumaru de cheiro, umburana, are abundant in the Pachietea river area, in tropical dry forests, preferably in sandy-clay soils, deep and well drained. The trees can reach up to 40 m of height and 0,65 m trunk, rounded and straight, bark dark brown, 20 mm thickness (Caceres, 2008a).

Table 1. Forest tree species identified in the "Selva Central", Peru.

No.	Scientific Name	Common Name	Family	Botanic
I	*Aiouea montana* (Sw.) R. Rohde	Moena blanca	Lauraceae	x
II	*Amburana cearensis* (Allemão) A.C.Sm.	Isphingo	Fabaceae	-
III	*Brosimum utile* (Kunth) Oken	Leche Caspi	Moraceae	x
IV	*Calophyllum brasiliense* Cambess.	Palo Azufre	Calophyllaceae	x
V	*Calycophyllum spruceanum* (Benth) Hook.f.ex K.Schum.	Capirona	Rubiaceae	-
VIII	*Caryocar glabrum* (Aubl.) Pers.	Almendro	Caryocaraceae	x
VII	*Caryodaphnopsis fosteri* Van der Werff	Palo caramelo	Lauraceae	-
VIII	*Cedrelinga cateniformis* (Ducke) Ducke	Tornillo	Fabaceae	x
IX	*Copaifera paupera* (Herzog) Dwyer	Copaiba	Fabaceae	x
X	*Ficus insipida* Willdenow	Ojé	Moraceae	x
XI	*Ficus* sp. L.	Matapalo amarillo	Moraceae	x
XII	*Gordonia fruticosa* (Schrad.) H. Keng	Huamachilca	Theaceae	-
XIII	*Guarea guidonia* (L.) Sleumer	Requia	Meliaceae	-
XIV	*Hymenopus heteromorphus* (Benth.) Sothers & Prance	Sachapalta	Chrysobalanaceae	x
XV	*Juglans neotropica* Diels	Nogal	Juglandaceae	x
XVI	*Myroxylon balsamum* L. Harms	Estoraque	Fabaceae	-
XVII	*Myroxylon peruiferum* L.f	Quina Quina	Fabaceae	-
XVIII	*Podocarpus* sp. L´Hér. Ex Pers.	Diablo fuerte	Podocarpaceae	-
IXX	*Retrophyllum rospigliosii* (Pilg.) C.N. Page	Ulcumano	Podocarpaceae	-
XX	*Sterigmapetalum obovatum* Kuhlm.	Palo verde	Rhizophoraceae	x

Cedrelinga caterniformis known as tornillo, cedro tana, cedro ahogado, aguano maldonado, pino peruano and pashaco, occurs in regions with 1200 m altitude, with high and regular rainfall areas common in Amazon region; the trees have cylindrical trunk, 20-40 m height and 0.50-2.0 m diameter; bark grey, brownish to reddish, with fissured rhytidome. *C. caterniformis* was in 2019 the tree species of Peruvian Selva Central with the largest number of interventions by Serfor (Reynel et al., 2003; Caceres, 2008a; Osinfor, 2017; Serfor, 2020). *Copaifera paupera* trees known as copaiba presented cylindrical and straight trunk up to 35m of height, 60-120 cm diameter; outer bark light brown grayish with lenticels and rhytidome scales; occurs mainly in high rainfall and continued areas of Amazonian region, usually below 700 m altitude. Relevant species for biosynthesizing an essential oil used in popular medicine and pharmaceutical application (Reynel et al., 2003; Osinfor, 2015). *Myroxylon peruiferum* and *M. balsamum* that are popularly known as quina quina y estoraque, respectively; presented trunk cylindrical and straight; 20-35 m height, 50-100 cm diameter; bark smooth, grayish with lenticels; internal bark present very strong smell resin. Occurs in the Amazon forests under 700 m altitude with high and continuous rainfall and well-marked dry season (Reynel et al., 2003; Gonzales, 2011; Ugarte and Mori, 2018).

For the Moraceae family, 3 species were identified, 2 of them belonging to the genus *Ficus* (*Ficus sp*. and *Ficus insipida*) and the third, Brosimum utile. The genus Ficus known as matapalo amarillo, ojé, renaco, renaquillo and the Ficus insipida as ojé, dr. ojé, oji (Gonzales, 2011; Acevedo and Kikata, 2008). Tree species with cylindrical trunk, straight, with 18-40 m of height, 4-200 cm diameter, with tabular roots up to 1.5 m, characteristic of the Amazon forests, with high and constant rainfall, at 1500 m altitude (Reynel et al., 2003; Osinfor, 2017). Bark with lentils, grayish to light brown color, arranged in horizontal rows; inner bark, when cut, exudes an abundant white latex with rapid flow. *Brosimum utile* known as leche caspi and panguana (Gonzales, 2011; Ugarte and Mori, 2018) and the trees occur in flooded environments from Mexico to the Amazon. Tree species with cylindrical trunk, 20-25 m height, the bark exudes of white latex (Caceres 2008a).

The Lauraceae family is represented by 2 species in the present work. The first, *Aiouea montana*, moena blanca, tree species with trunk straight, 10-20 m height, genus *Aiouea* extends from Atlantic to Ocean Pacific coast, between 15-30° S in tropical rainforest; 7 of 19 species occurring in nebulous montane forests and the highest species density is reported Brazilian Amazon forests in Pará and Amapá states (Völtz and Blum, 2020). The second, *Caryodaphnopsis fosteri*, palo caramel, trees 50 m height, 100 cm trunk diameter and bark darker, thick, occurring in Peru, Colombia, Ecuador and Bolivia (Bendezú 2018).

Juglans neotropica, nogal peruano or cedro negro, represents the Juglandaceae family, one of the most important wood species of the Peruvian Amazon Selva Central Central; trees 15-50 m height of 15-48 m, 30-120 cm diameter, trunk straight and cylindrical; bark darker gray with lenticels. In Peru, it is distributed in Amazonas, Cajamarca, Cusco, Huancavelica, Junín, La Libertad, Lambayeque and Pasco. The range of altitudinal distribution between 500 and 3000 meters, in jungle, premontane and montane rainforest (Manrique et al., 2015).

Belonging to the Chrysobalanaceae family, *Hymenopus heteromophus* has trees that reach 21-25m in height and 96-130 cm in diameter. The trees trunk is circular and the base consists of tree buttresses. Rhytidome is crosslinked, gray mall, vertically striated closer to the base, and the lenticels are circular. The bark is reddish and when cut, a pink or transparent exudation can be observed. According with Royal Botanical Garden (2022) the species has your distribution in Amazon Forest, above 80-900 meters.

From the Calophylaceae family, *Calycophyllum spruceanum* trees, capirona, have a straight and regular trunk, can reach 20-35 m in height and 50-120 cm in trunk diameter: smooth, green, homogeneous, shiny bark. The trees occur in regions with high and constant rainfall; may occur, however, it may occur in regions with well-marked seasons (Reynel et al., 2003; Osinfor, 2017).

Belonging to the family Theaceae, *Gordonia fruticosa* trees, huamachilca, occur in Bolivia, Costa Rica, French Guiana, Panama, Brazil and Peru. Evergreen tree, 10-40 m tall; trunk diameter of 70 cm. Bark brown and smooth on young trees, grayish slightly cracked on mature trees. Leaves simple, spirally, spatulate, asymmetric, glabrous on the ventral surface and pubescent on the dorsal surface. Flowers with white to yellowish petals, fragrant, measuring up to 3 cm length (Carvalho, 2006).

From Meliaceae family, *Guarea guidonia*, requia, the trees trunk is 30 m tall, smooth bark, coming to crack with age. It blooms and bears fruit throughout the year (Pennington, 1981; Sánchez-Vindas & Poveda, 1997 apud Bendezú, 2018).

The Caryocaraceae family is represented by *Caryocar glabrum*, almendro; trees 30-40 m tall, cylindrical trunk, dark brown bark, fissured, occurring in Peru, Colombia, Venezuela, Guyana, French Guiana, Suriname, Brazil. Trees grow in Amazonas, Cusco, Huánuco, Junín, Loreto, Pasco, San Martín and Ucayali (Prance & Freitas, 1973; FAO, 1987; Reynel et al., 2003; Dávila et al., 2008; Cardona et al., 2010; IPCC, 2006 apud Bendezú, 2018).

Belonging to Callopyllaceae family, Calophyllum brasiliense, palo azufre, occurs in Peru (Yurimaguas, Pucalpa, Iquitos, etc.) in tropical humid forests, alluvial soils and t24 °C temperature, 1000-2000 mm/year. Trees reaches 40 m height, 0.7-1.5 m trunk diameter, cylindric, bark, dark brown, with pale yellow (Caceres, 2008a).

The Rhizophoraceae is represented by *Sterigmapetalum obovatum*, palo verde, trees with 40 m of height and 65 cm, trunk diameter. It is distributed in Peru, Brazil, Bolivia, Colombia, Ecuador; in Peru is reported in Loreto, Pasco and Ucayali (Steyermark and Liesner 1983; Prance 2005 apud Bendezú 2018).

Gymnosperms are also present and traded in Peruvian forests. Two genus, belong to the family Podocarpaceae, *Podocarpus sp*., diablo fuerte and *Retrophyllum rospigliosii*, ulcumano (Gonzales, 2011). *Podocarpus sp*. is a dominant tree species with straight and cylindrical trunk, 1,0 m trunk diameter and wood volume can exceed 20m^3/tree. Found in the Montane High Forests or Ceja Groves, eastern part of the Andes, and natural distribution reaches the pre-montane rainforests and the mist forests at altitudes from 1700 to 2600m (Caceres, 2008b). *Retrophyllum rospigliosii*, 30-45m height, 50-180 cm trunk diameter, cylindrical and straight. Bark brown color, grayish with scaly rhytidome. Found in Bolivia, Colombia, Costa Rica, Venezuela and Peru. This country can be found in the Alto Montana forests or Ceja Forest between 1500 and 4000 m altitude, also in the mountains of Piura, Cajamarca, Pasco and Junín (Reynel and Marcelo, 2009).

Common names and tree species identification *via* wood anatomical features

Amburana cearensis, isphingo (Figure 2B1, B2), was identified by the axial paratracheal parenchyma winged-aliform, storied rays, brown color and the pleasant characteristic smell that make this species easily recognized. However, Seleme et al. (2015) in a review of *Amburana* (Fabaceae) in South America described the occurrence of *Amburana acreana* (Ducke) A. C. Sm and not A. cearensis in Peruvian tropical forests, coincident with Vazquez et al. (2018). On the other hand, Tropicos (2022) reports this species occurring in the Selva Central of Peru presenting stratified ray as diagnostic feature, not described for *A. acreana* (Coradin et al., 2010).

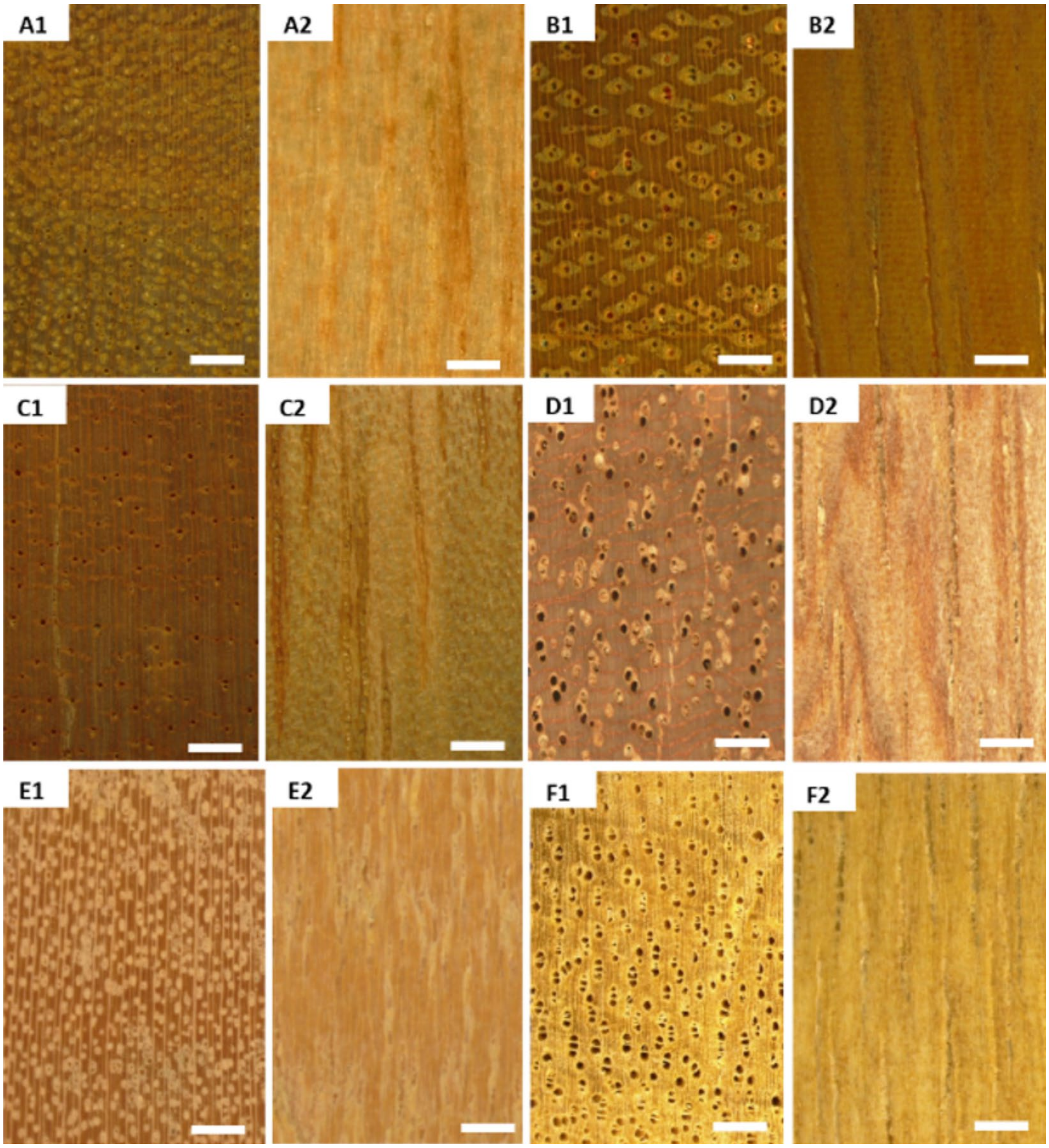

Figure 2. Wood cross (20) and longitudinal tangential (20) sections of the 20 tree species: *Aiouea montana* (A1 and A2); *Amburana cearensis* (B1 and B2); *Brosimum utile* (C1 and C2); *Calophyllum brasiliense* (D1 and D2); *Calycophyllum spruceanum* (E1 and E2); and *Caryocar glabrum* (F1 and F2) Note: Bar is 1000 µm.

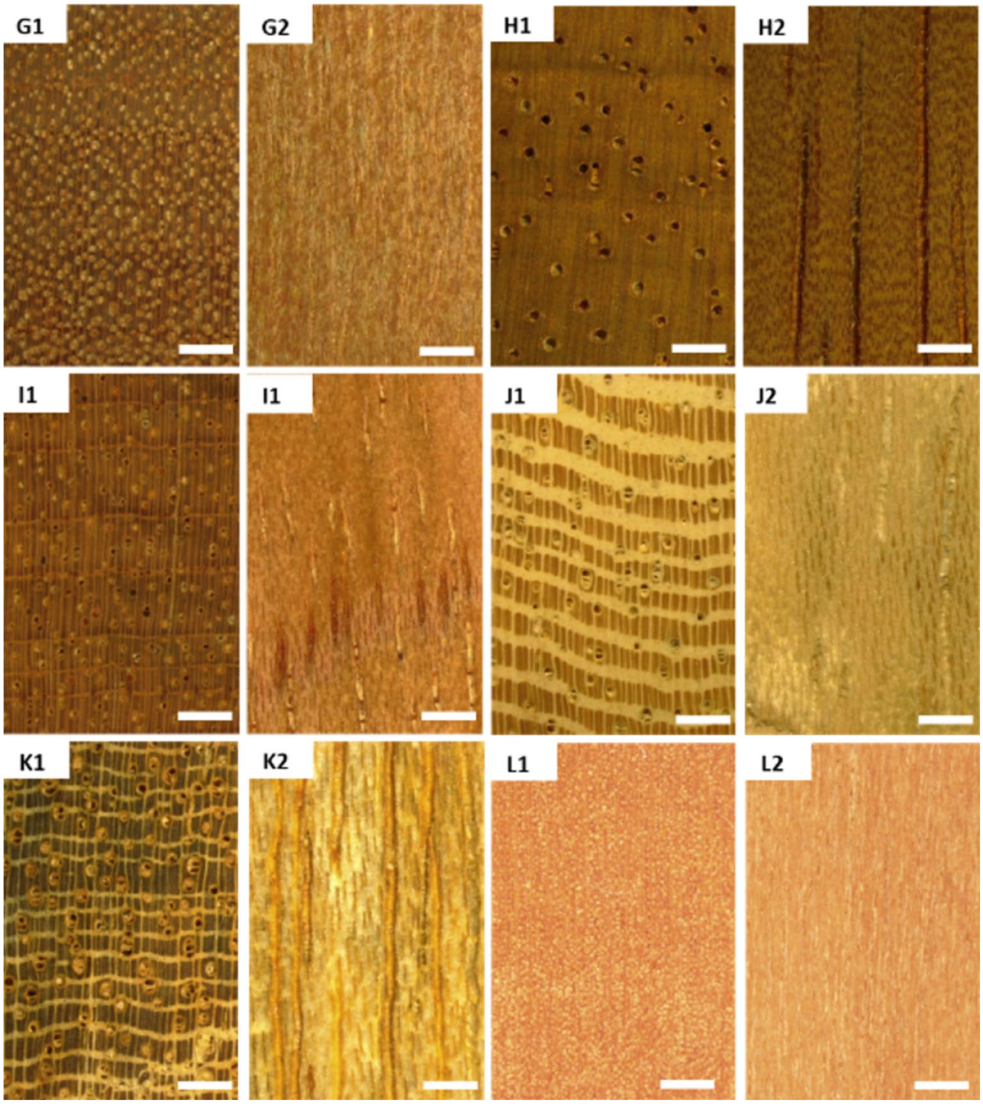

Figure 2 (cont.). Wood cross (20) and longitudinal tangential (20) sections of the 20 tree species: *Caryodaphnopsis fosteri* (G1 and G2); *Cedrelinga cateniformis* (H1 and H2); *Copaifera paupera* (I1 and I2); *Ficus insipida* (J1 and J2); *Ficus* sp. (K1 and K2); and *Gordonia fruticosa* (L1 and L2). Note: Bar is 1000 μm.

Cedrelinga cateniformis, tornillo (Figure 2J1, J2), is currently the wood with the highest number of records by the Peruvian "Selva Central" Inspectorate (SERFOR 2020). The wood has larger vessels observed with the naked eye, vasicentric and aliform paratracheal parenchyma, brown color with distinct and dark vascular lines. In the Selva Central forests, tornillo wood due to its pink color and odor, can be confused with *Cedrela* L. (Meliaceae) wood, despite the characteristic marginal axial parenchyma and semi-porous rings.

Calycophyllum spruceanum, capirona (Figure 2F1, F2), family Rubiaceae family, has an intense yellow wood, indistinct axial parenchyma, numerous vessels of smaller diameter and with differences from the tornillo wood (*Cedrelinga cateniformis*) by the visible axial paratracheal vasicentric parenchyma.

The *Gordonia fruticose* wood, huamalchica (Figure. 2C1, C2) (Chavesta, 2015) can be confused by its yellow color with that of Calycophyllum spruceanum and Caryocar glabrum, but nevertheless has a remarkable anatomical signature, due to the indistinct axial parenchyma and smaller diameter vessels.

The *Calophyllum brasilienses* wood, achapalta (Figure 2E1, E2) has a distinct anatomical structure compared to *Gordonia fruticosa*, characterized by not continuous thin bands of axial parenchyma, vessels diagonal disposition and reddish-brown coloration.

Copaifera pauper wood, copaiba (Figure 2J1, J2), an important tree species for the production of oil with anti-inflammatory and antibiotic properties, has brown color wood, solitary vessels and axial marginal parenchyma and oil resin ducts delimiting the tree-rings, which can be confused with *Swietenia macrophylla* King, *Hymenaea oblongifolia* Huber and *Cedrela* spp. L. (Olivia and Zerpa, 2018).

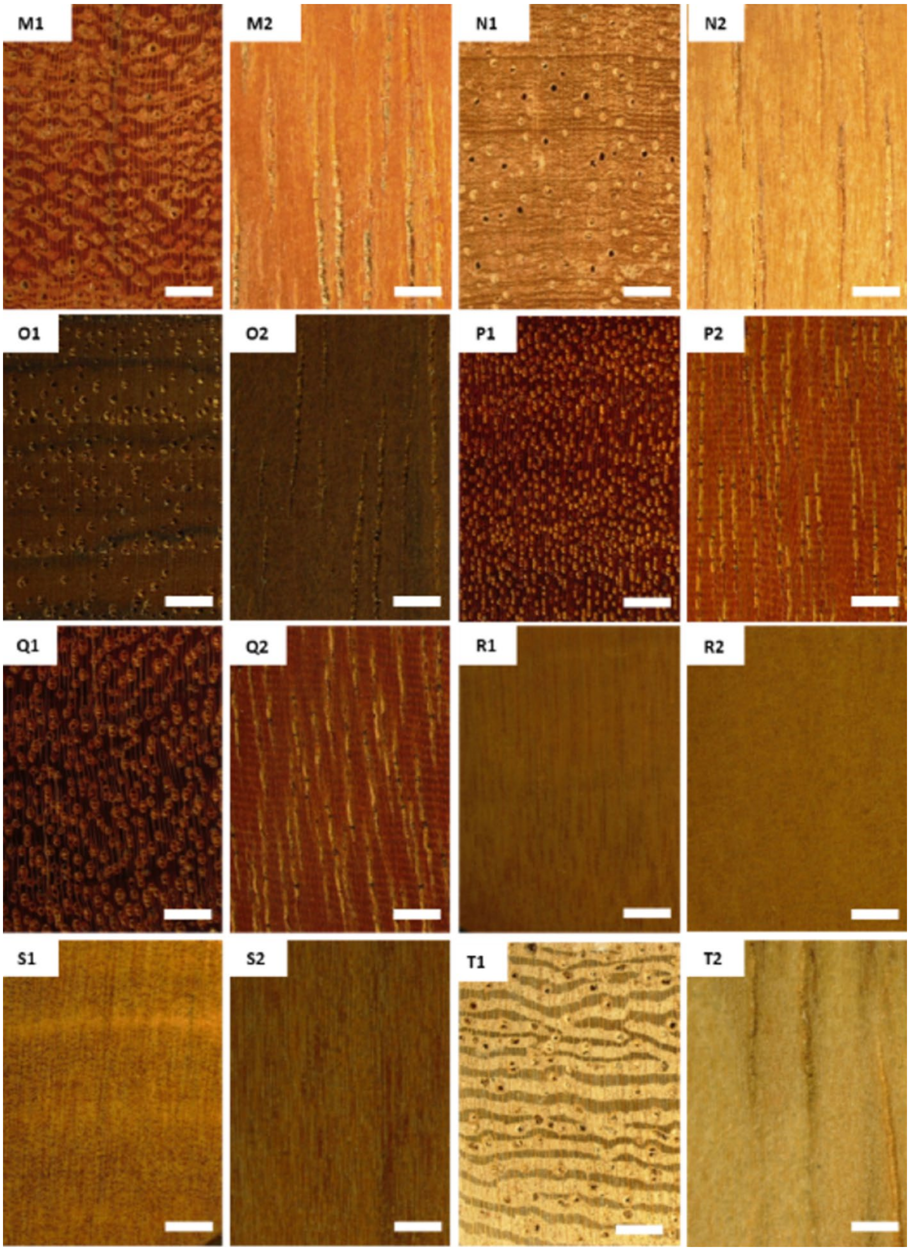

Figure 2 (cont.). Wood cross (20) and longitudinal tangential (20) sections of the 20 tree species: *Guarea guidonia*. (M1 and M2); *Hymenopus heteromorphus* (N1 and N2); *Juglans neotropica* (O1 and O2); *Myroxylon balsamum* (P1 and P2); *Myroxylon peruiferum* (Q1 and Q2); *Podocarpus sp* (R1 and R2]); *Retrophyllum rospigliosii* (S1 and S2); and *Sterigmapetalum obovatum* (T1 and T2) Note: Bar is 1000 µm.

The cellular elements storied - mainly the radial parenchyma - is considered an important parameter in the identification of tropical species. In this sense, the *Myroxylon peruiferum* wood (Figure 2Q1, Q2) and *M. balsamum* (Figure 2P1, P2) quina quina and estoraque are confused in the wood trade (Gonzales, 2011). Despite showing similarity in the radial parenchyma, diffuse porosity and axial parenchyma, they are distinct in color, being purplish to M. balsamum and reddish with vessels of large diameter to *M. peruiferum*.

Ocotea spp., sachapalta (Figure 2N1, N2) is also applied to *Ocotea argyrophylla*, *O. gracilis* and *Persea caerulea* (Gonzales, 2011; SERFOR, 2020). However, *Hymenopus heteromorphus* or its basonym *Licania heteromophus*, are known throughout Peru as "true Sachapalta", although the wood coloring is quite similar, that is, a more reddish the anatomical characteristics as *e.g*, the abundant presence of diffuse apotracheal axial parenchyma in aggregating forming thin lines is an important characteristic in the identification of this species in relation to Lauraceae that have the same common name and vasicentric axial paratracheal parenchyma (Figure 2N1 and N2).

The genus *Ficus* is widely marketed with the ojé common name (Caceres 2008a, 2008b; Gonzales 2011) but there are anatomical and organoleptic differences, like yellow coloration and the axial parenchyma in thick bands in *Ficus insipida* (Figure 2K1, K2), and thin and non-uniform bands of axial parenchyma in *Ficus sp*., (Figure 2L1, L2) known as matapalo amarillo.

Sterigmapetalum obovatum, palo verde (Figure 2T1, T2) (Gonzales 2011) has a yellowish color wood, with axial parenchyma in wide bands and also characterized by the included phloem associated with the axial parenchyma.

Guarea guidonia, cedrillo (Figure 2M1, M2) can be confused and marketed as *Vochysia vismiifolia*, *Vochysiaceae, chancaquero* (Gonzales, 2011) by the presence of axial aliform parenchyma forming thin lines or even a little thicker.

Brosimum utile, leche caspi (Figure 2B1, B2) wood is darker brown, with a larger vessels diameter and axial aliform parenchyma (Gonzales, 2011; Olivia and Zerpa, 2018) and can be confused as *Brosimum alicastrum* Sw. (congona) and *Simarouba amara* Aubl. (marupa) by the parenchyma paratracheal aliform, sometimes confluents.

Caryocar glabrum wood, almendro e piquiá (Figure 2G1, G2), and other species of the same genus, as *Caryocar villosum* (Aubl.) Pers., C.coccineum Pilg. (Caceres 2008; Gonzales, 2011; Santini et al., 2021) are often confused and marketed as being the same. However, *C. glabrum* has yellowish wood color, growth rings better demarked by the fibrous zone

Juglans neotropica wood, nogal (Figure 2O1, O2) has a dark-black characteristic heartwood and sapwood lighter color, with diffuse apotracheal axial parenchyma useful for correct identification (Gonzales, 2011).

Lauraceae, representative family in the central forests of Peru, mainly in the Selva Central, are marketed as moenas and often confused due to similar wood anatomical and organoleptic characteristics. *Aiouea montana*, moena blanca (Figure 2A1, A2) and *Caryodaphnopsis fosteri*, palo caramelo (Figure 2H1, H2) present wood with similar characteristics, like paratracheal axial parenchyma and medium texture. Moena blanca has paratracheal parenchyma aliform and palo caramelo has a reddish color and the presence of vessels with smaller diameter compared to moena blanca which has a browner color, vessels with larger diameters

Podocarpaceae has a two species *Podocarpus* sp, diablo fuerte (Figure 2R1, R2) and Retrophyllum rospigliosii, ulcumano (Figure 2S1, S2). Tropical woods traded in the "Selva Central" Jungle that do not have the presence of conductive vessels, being differentiated by the presence of visible axial parenchyma in ulcumano.

Comparative wood anatomy of tree species

The comparative wood anatomy of the tree species shows relevant taxonomical characteristics such as diffuse porosity, common in trees occurring in a climate characterized by high temperatures and rainfall, such as those recorded in the Selva Central. Furthermore, distinct, and well-demarcated tree-rings were recorded in 50% of the tree species, including the two species of Gymnosperms. In this aspect, Marcelo-Peña et al., (2020), working with 183 species of Peruvian forest trees, noted that 42 species (23%) had growth rings with high distinction, 60 species (33%) had moderately visible rings, 60 species (33%) had poor ring distinction, and 21 species (11%) had absented or indistinct growth rings (Table 2).

The tree-rings formed in the trunk of tropical tree species are, in general, related to the seasonality of the cambial meristem activity, influenced by the climatic seasons: alternating periods of soil water availability and stress. The trees intrinsic physiological process, associated with climatic factors, influences the phenological phases, from the deciduous leaf in the dry season to the sprouting and restoration of the tree canopy in the rainy season (Ferreira et al., 2021).

An important wood anatomical feature is related to the presence and type of axial parenchyma that are very useful as a taxonomic parameter in the species identification and physiological parameter, in the storage of reserve substances, available to the plants when demanded. In this aspect, Moraceae family is characterized by the visible axial parenchyma commonly in *Ficus* and *Brosimum genus*.

It was found that the sparse paratracheal axial parenchyma occurred in 30% of the tree species and the vasicentric paratracheal aliform in bands or lines in 20% of the species. In addition, diffuse aggregated apotracheal parenchyma occurred in 10% of the tree species. According to Duarte et al. (2021) the visibility of the axial parenchyma of the tree trunk allows the segregation of numerous tropical species. Evaluating the wood anatomy of Brazilian tree species, (Alves e Alfonso, 2002) demonstrated the relationship between the presence of paratracheal parenchyma in warmer climates and apotracheal parenchyma in colder climates. This correlation is of great importance for the trees physiological processes, and temperature is associated with precipitation rates and soil conditions are the main inducers of the proper functioning of vascular functions and, consequently, plant growth and development.

The cambial meristem is responsible for adding new cells to the trees body, producing xylem cells to the inside and the phloem cells to the outside. However, in some species, the cambium can produce cells that will form structures to the standard organization of plant tissue. Likewise, injuries sustained on the trees trunk can also favor the formation of these structures, as included phloem (Santini Jr. et al., 2021). The presence of this characteristic cambial variation in the species *Sterigmapetalum obovatum* where the phlegmatic tissue occurs in association with the axial parenchyma in thick bands (Figure 2T1 and T2).

The xylem vessels were predominantly blocked by tyloses, gums and resins, which were detectable in cross section (pore filling) and tangential longitudinal (vascular lines). Extractives, substances from the secondary metabolism of trees and the chemical characteristics of the non-functional xylem region generally confer natural resistance to xylophagous organisms (Ferreira et al., 2021). Biosynthesized in the wood of species, gums, resins and tyloses are considered important characteristics in the chemical composition and are applied in the identification of tropical species, for example. *Copaifera* L. (Fabaceae) (Figure 2J1 - J2), which has characteristic oil-secreting channels in its anatomical structure.

Table 2. Main wood macroscopic features used for the tree species identification.

Species				Aiouea montana	Amburana cearensis	Brosimum utile	Calophyllum brasiliense	Calycophyllum spruceanum	Caryocar glabrum	Caryodaphnopsis fosteri	Cedrelinga cateniformis	Copaifera paupera	Ficus insipida	Ficus sp	Gordonia fruticosa	Guarea guidonia	Hymenopus heteromorphus	Juglans neotropica	Myroxylon balsamum	Myroxylon peruiferum	Podocarpus sp.	Retrophyllum rospigliosii	Sterigmapetalum obovatum
General characteristics	color		White																				
			Yellow				X	X				X	X	X						X	X	X	
			Redish			X			X						X			X					
			Brown	X	X					X	X												
			Black														X						
			Purple																X				
			Pinkish													X							
	texture		Fine					X							X						X	X	
			Medium	X	X	X		X	X	X	X		X			X	X	X	X			X	
			Coarse									X			X								
	Growth rings		Not visible 10x				X	X					X	X	X	X				X	X	X	
			visible 10x	X	X			X	X	X	X					X	X	X					
Macroscopics characteristics	Vessels	Visible	Absence																		X	X	
			Simple vista	X	X	X	X		X	X	X	X	X	X		X	X	X	X	X			X
			Visible 10x					X							X								
		porosity	Ring porous																				
			Semi ring																				
			Diffuse	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			X
	Parenchyma axial	Visible	Not visible 10x					X		X					X				X	X	X		
			visible 10x	X	X	X			X				X	X			X	X				X	X
		APO	Diffuse																			X	
			Difuse Agregate						X								X	X					
		PAR	Vasicentric	X						X	X	X											
			Aliform	X	X	X					X					X							
			Confluent		X											X							
			Scarse					X		X					X			X	X	X			
		Bands	Marginal									X						X					
			Fine				X		X					X			X						
			Wide										X										X
			Reticulate																				
	Rays	Visible	Fine	X	X		X	X			X				X		X	X			X	X	
			Medium			X			X	X		X	X	X		X			X	X			X
			Widths																				
		Storied			X														X	X			
		Not storied		X		X	X	X	X	X	X	X	X	X	X	X	X	X			X	X	X
	Others		Phloem included																				X
			Gums	X	X	X				X	X					X	X	X	X			X	
			Axial channels								X												
			Tyloses					X	X								X						

Identification key of the forest tree species via wood anatomical characteristics

The identification key of the 20 forest tree species was elaborated based on the main and most striking wood anatomical and organoleptic characteristics of the analyzed species and that are part of the primary productive chain in the region called central jungle (Selva Central) of the Peruvian Amazon.

The Amazon rainforests are well known for their diversity of plant and animal species, and for their abundance of tree species. The identification of the wood producing tree species along the production chain is possible by utilizing the wood anatomy, based on the types of cells and tissue diversity (Ferreira et al., 2021; Ferreira and Inga, 2022). The description of the wood anatomical structure allows them to be grouped into taxonomic groups with common characteristics, following the identification specific of each species. This principle underlies the constructed identification keys of the tropical tree species using the wood anatomical structure, while some are available in the specialized literature (Florsheim et al., 2020; Santini Jr et al., 2021; Ferreira et al., 2021; Ferreira and Inga, 2022). This identification key will allow the inclusion of new wood species from the Peruvian "Selva Central" and can also be applied as a basis for the development of a new identification method *via* artificial intelligence (Fabijańska et al., 2021).

Key for wood macroscopic identification

A. Absence of conductive vessels

1a. Absence of vessels, indistinct growth layers, axial parenchyma visible under 10x lens, diffuse .... *Retrophyllum rospigliosii*
1b. Absence of vessels, indistinct growth layers, indistinct axial parenchyma under 10x lens .... *Podocarpus sp.*

B. Presence of conductive vessels

B.1 Indistinct axial parenchyma

1a. Indistinct axial parenchyma, yellow color, fine texture, and diameter of very small vessels .... *Gordonia fruticosa*
1b. Indistinct axial parenchyma, yellow color, fine texture and medium diameter of vessels, with radial disposition .... *Calycophyllum spruceanum*

B.2 Distinct axial parenchyma

B.2.1Distinct axial apotracheal parenchyma
1a. Distinct axial apotracheal diffuse aggregate parenchyma, yellow heartwood and radial arrangement of vessels .... *Caryocar glabrum*.
1b. Distinct axial apotracheal diffuse aggregate parenchyma and another colors 2
2a. Distinct axial apotracheal diffuse aggregate parenchyma, black heartwood, radially flattened latewood delimitated growth layers .... *Juglans neotropica*
2b. Distinct axial apotracheal diffuse aggregate parenchyma, pinkish heartwood, fibrous zones delimiting the growth layers .... *Hymenopus heteromorphus*

B.2.2 Axial paratracheal parenchyma

1a. Axial scarce paratracheal parenchyma 2
1b. Axial paratracheal parenchyma others 3
2a.Axial scarce paratracheal parenchyma, medium texture, and brown heartwood .... *Aiouea montana*
2b.Axial scarce paratracheal parenchyma, medium texture, and reddish heartwood .... *Caryodaphnopsis fosteri*
3a. Axial paratracheal parenchyma vasicentric .... *Cedrelinga cateniformis*
3b. Axial paratracheal parenchyma aliform 4
4a. Axial paratracheal parenchyma aliform with linear extension .... *Brosimum utile*
4b. Axial paratracheal parenchyma aliform with lozenge extension form confluent .... *Guarea guidonia*

B.2.3 Axial marginal or band parenchyma

1a. Axial parenchyma in marginal bands or thin bands 2
1b. Axial parenchyma thin or large bands 3
2a.Axial parenchyma in marginal bands, brown heartwood and axial canals .... *Copaifera paupera*.
2b.Axial parenchyma in thin bands, diagonal arrangement of vessel and reddish heart .... *Calophyllum brasiliensis*
3a. Axial parenchyma in thin bands and yellow heartwood .... *Ficus sp*.
3b. Axial parenchyma in wide bands 4
4a. Axial parenchyma in Large bands and yellow heartwood .... *Ficus insipida*.
4b.Axial parenchyma in large bands, yellow heartwood and include phloem .... *Sterigmapetalum obovatum*

C. Storied rays

1a. Storied rays and aliform axial parenchyma .... *Amburana cearensis*
1b. Storied rays and scarce axial parenchyma 2
2a. Storied rays and scarce axial parenchyma, heartwood reddish and indistinct growth layer ...... *Myroxylon balsamum*
2b. Storied rays and scarce axial parenchyma, heartwood purple and distinct growth layer .... *Myroxylon peruiferum*

CONCLUSION

The main conclusions of the work are (i) the 20 tree species of the Peruvian Amazon, Selva Central, can be identified through the wood anatomical structure; (ii) 11 of these species have botanical identification, confirming the forensic identification; (iii) the wood species presented common anatomical features, such as diffuse porosity, visible axial parenchyma mainly distinct, and, eventually, with storied, *e.g.*: *A. cearensis*, *M. balsamum* and *M. peruiferum* (Fabaceae); (iv) two species presented specific anatomical characteristics, axial gum resin canals and diffuse included phloem; (v) the tree species identification by the wood macroscopic anatomy allows an efficient tool for inspection and control of illegal wood logging and transport; (vi) the results constitute an effective database for the implementation of convolutional neural networks methodology for tropical Peruvian Amazon species identification by their wood anatomy.

AUTHORSHIP CONTRIBUTION

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