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Wood anatomy of *Dalbergia retusa* (Fabaceae: Papilionoideae) and two similar, unidentified wood samples in Panama

Anatomía de la madera de *Dalbergia retusa* (Fabaceae: Papilionoideae) y dos muestras de maderas semejantes indeterminadas en Panamá

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ABSTRACT

We aimed to characterize the anatomical features of *Dalbergia retusa* and clarify the identity of two wood samples labeled "cocobolo" from East Panama. Each wood sample was morpho-anatomically described, measured, and compared following the International Association of Wood Anatomists (IAWA) Committee standards. Basic density and fluorescence tests were also conducted. The wood anatomy of both samples aligns with the typical characteristics of the order Fabales and the genus *Dalbergia*. The combination of these features: vessel frequency, vessel element length, axial parenchyma, fibers and wood density reveals significant structural and functional differences among the three tree samples, which are typically associated with distinct ecological environments. Fluorescence tests did not reveal distinct differences between the samples; however, the density measurements provided useful separation. *D. retusa* exhibited very *high*-density values, while sample 1 showed high-density, and sample 2 showed medium density, both of wich suggest variability in the wood properties. The observed anatomical and density differences indicate that the two "cocobolo" samples might represent a distinct taxon, separate from *Dalbergia retusa*.

KEYWORDS

Cocobolo; Darién; legumes; morpho-anatomy; rosewood.

RESUMEN

Nuestro objetivo fue caracterizar los caracteres anatómicos de la madera de *Dalbergia retusa* y aclarar la identidad de dos muestras de madera denominadas como “cocobolo" provenientes de Panamá Este. Cada una de estas tres maderas fueron descritas morfoanatómicamente, medidas y comparadas siguiendo los estándares de la Asociación Internacional de Anatomistas de madera (IAWA). También se realizaron pruebas básicas de densidad y fluorescencia. La anatomía de las dos muestras coincide con las características típicas del orden Fabales y el género *Dalbergia*. La combinación de las características observadas: frecuencia de vasos, longitud de elementos del vaso, parénquima axial, fibras y densidad de la madera reveló diferencias estructurales y funcionales significativas entre las tres muestras, las cual estan típicamente asociadas a entornos ecológicos distintos. Las pruebas de fluorescencia no revelaron diferencias distintivas entre las muestras; sin embargo, los valores de densdiad proporcionaron una separación útil. *D. retusa* exhibió valores de muy alta densidad, mientras que la muestra 1 mostró alta densidad y en la muestra 2 valores de densidad media, los cuales sugieren variabilidad en las propiedades de la madera. Las diferencias anatómicas y de densidad indican que las dos muestras de “cocobolo” podría representar un taxón distinto a *Dalbergia retusa*.

PALABRAS CLAVE

Cocobolo; Darién; leguminosa; morfo-anatomía; palo de rosa.

INTRODUCTION

Species of the genus *Dalbergia* L. f., a group commonly known as "rosewood," have kept attention, maintained interest, and preference in the global wood market for their excellent physical and mechanical properties (Record & Garrat 1923; Richter *et al*. 1996). There are currently 250 species of *Dalbergia* known to exist (Vatanparast 2013). These species are found in the tropics around the world; the majority are concentrated in Africa, Madagascar, South Asia, and Central and South America (Mabberley 1987; The WFO 2023; Vatanparast 2013). In Mesoamerica, approximately 40 species of the genus *Dalbergia* are reported, and seven of them are found in Panama; only three of these are arboreal: *D. cuscatlanica* (Standl.) Standl., *D. retusa* Hemsl., and *D. tilarana* N. Zamora (Linnaeus 1781; Standley & Record 1936; Dwyer & Hermann 1965; Croat 1978; Correa *et al*. 2004; Hammel *et al*. 2010; Linares & Sousa 2007; Parker 2008).

The wood of *Dalbergia retusa* Hemsl. (cocobolo) has a high commercial value in Panama; it has been prohibited from extraction since 2014, and it has been included in Appendix II of the Convention of International Trade in Endangered Species (CITES) of Wild Fauna and Flora, which regulates trade (CITES 2010; Gasson *et al*. 2011; CITES 2016, Vardeman & Velásquez 2020). *Dalbergia retusa* Hemsl. is one of the most prized species in Asia and the United States for its dark, hard, heavy, veined, beautiful, and resistant wood (Wilmé *et al*. 2009a; Testa 2018).

A family sought to engage in this venture since rosewoods are popular tonewoods for making musical instruments. However, local ecological authorities found that the timbers they wanted to export belonged to *D. retusa,* so exporting them was prohibited. Despite the fact that the morphological and organoleptic traits, including pigmentation, differed greatly from those of *D. retusa*. In order to properly describe and compare their anatomy with *D. retusa* wood, as various authors have done (Richter *et al*. 1996; Miller & Wiemann 2006; Gasson *et al*. 2010; Wiemann & Ruffinatto 2012; Ravaomanalina *et al*. 2017), two samples of wood that were simply identified as "cocobolo" were sent to the Laboratorio de Ecología y Maderas Tropicales del Instituto de Ciencias Ambientales y Biodiversidad of the Universidad de Panamá (LABICAB-UP) so their anatomy could be properly described and compared with *D*. *retusa* wood in 20016.

Studies by Record & Garat (1923), Kirbs (1968), Richter & Dallwitz (2000), and Moya *et al*. (2013) have provided anatomical descriptions of *D. retusa*. In addition, there are morpho-anatomical descriptions of the order Fabales (Baas *et al*. 2000; Gasson *et al*. 2010), the subfamily Papilionoideae (Espinoza & León 2002), and the genus *Dalbergia* (Richter *et al*. 1996; Espinoza *et al*. 2015, Ravaomanalina *et al*. 2017).

Wood identification techniques are adequate to identify a wood sample to the genus level; however, there are non-anatomical techniques to accurately identify samples. Biological and ecological aspects of species within the *Dalbergia* genus are still unknown. Some species are only known from herbarium specimens, nor have there been anatomical descriptions of the wood of all the species of the genus in America or genetic analyses that help to separate them all. In Panama, this is the situation with *D*. *cuscatlanica* and *D. tilarana*. Non-anatomical techniques, such as chemotaxonomy (Yin *et al.* 2018), phytochemistry (Kite *et al*. 2010, Gutiérrez & Baez 2013, Saha *et al*. 2013), physiochemical properties (Richter *et al*. 1996, Wiemann & Ruffinatto 2012), and DNA barcoding (Hartvig *et al*. 2015, Yu *et al*. 2017, He *et al*. 2018), have been used to identify or separate species of the genus *Dalbergia*.

This research was developed to describe the anatomical characteristics, determine the density, and validate the fluorescence in the wood of *D. retusa* and the two samples, which we referred to as sample 1 and sample 2. We aimed to distinguish between them and ascertain how closely they matched the anatomical description of *D. retusa*.

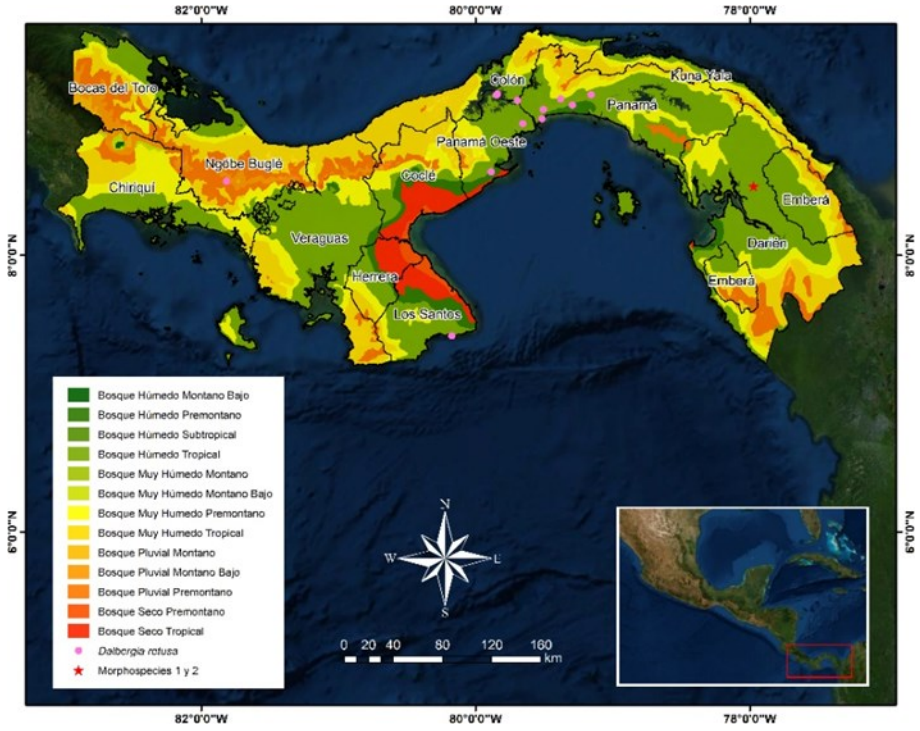
MATERIALS AND METHODS

Study site and samples

We only compared these two samples called "cocobolo" with the wood anatomy of *D. retusa*, according to the family's request and the fact that working with other species in the genus is not feasible. To describe the anatomy of *D. retusa* wood, a previously identified sample

belonging to the xylotheque collection of LABICAB-UP was used. It came from the humid tropical forest of the province of Darién. The two samples called “cocobolo” came from the East region, in Tortí, Panama province, Republic of Panama (Fig. 1). We called the two samples sample 1 and sample sample 2. Sample 1 came from a 5 x 4-inch board, and sample 2 came from a 10 x 3-inch branch of the tree.

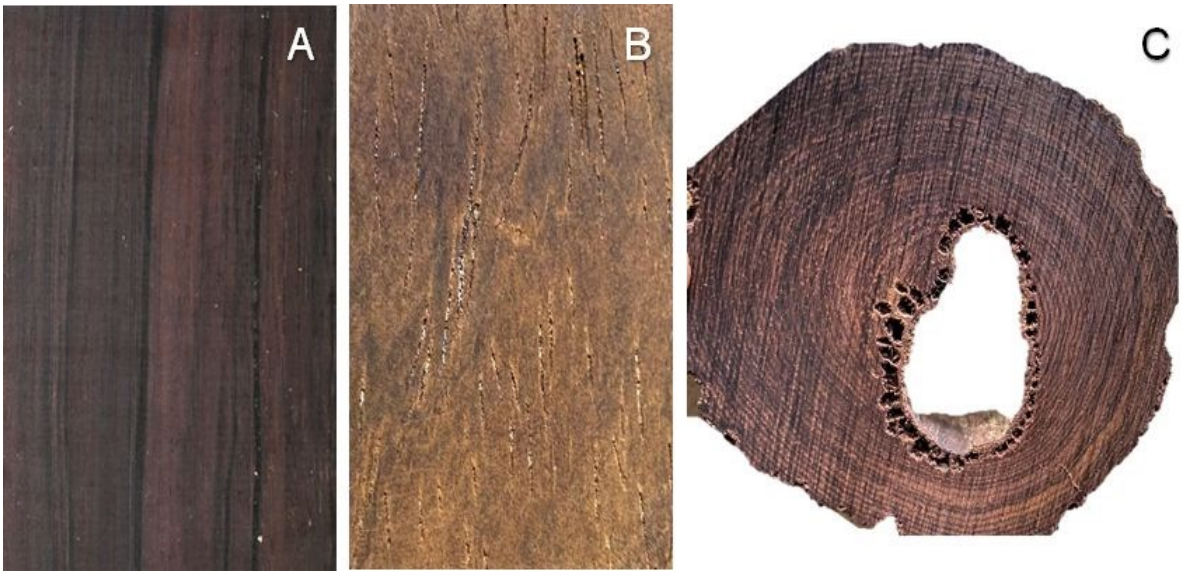
Figure 1.
Political and forest map of Panama showing the occurrences of Dalbergia retusa trees based on PMA Herbarium data. Sites where the samples 1 and 2 were collected.



Wood preparation and anatomical descriptions
The samples of the main trunk of *D. retusa*, sample 1, and the branch of sample 2 were softened until it was possible to cut them manually, cut into thin sections (18-30 µm), and stained with 1% aqueous safranin and alcoholic aniline blue as counterstain following the sample preparation and techniques for light microscopy of Tardif & Conciatori (2015) (Fig. 2). The maceration of cells was prepared using Jeffrey's technique (Jeffrey 1917). The samples were described and measured according to the guidelines of the International Association of Wood Anatomists List of Features for Hardwood Identification (IAWA) (IAWA Committee 1989; Wheeler 1986). Image J was used to perform the measurements of these features (Rasband 2011). General and macroscopic characteristics were determined

according to the criteria of the Pan American Commission for Technical Standards (COPANT), the Standards and Procedures in Wood Anatomy Studies (IBAMA), and the American Society for Materials Testing (ASTM) (COPANT 1973; ASTM 1969; IBAMA 1992). Wood color grading was described using the Munsell (2000) color chart. The comparison of the samples was made with descriptions and images available in the InsideWood database InsideWood (2004); Wheeler (2011) and Richter & Dallwitz (2000). Photographs were taken with a Leica EZ4 D stereo microscope. Microscopic features and fluorescence were photographed with a Nikon DS-Ri1 camera and Nikon Eclipse E 600 light microscope, Zeiss Evo 40 scanning microscope (SEM) on uncoated samples and Olympus FLUOVIEW FV 1000 fluorescence microscopes and Olympus FLUOVIEW FV3000, respectively. The specimens and anatomical slides remain in the LABICAB-UP collection. Replicas were not used.

Figure 2.
Figures and coloring of each analyzed sample. A) D. retusa. B) Sample 1. C) Sample 2.



Density measurement
Cubes of 2 cm^3 were cut to determine the density of all three samples. To estimate the density [ρ=m/V] of all three samples (g/cm3), the water displacement method, in which one gram of displaced water is equivalent to one cubic centimeter volume following the indications of Heinrichs & Lanssen (1970) and Chave (2006).

RESULTS

Diagnosis of *Dalbergia retusa*

General characteristics

In dry conditions, the heartwood of *Dalbergia retusa* is reddish to dark reddish (2.5YR 5/6) with very dark, almost black veins (2.5YR 2.5/1). The sapwood is yellow (10YR 6/6). Abrupt transition. Wood with medium texture, with a distinctive sweet and aromatic aroma, a medium glow, and cross-grained. The wood is very hard and heavy (Table 1).

Macroscopic features

Vessels are visible to the naked eye. Rays and axial parenchyma are visible with a 10x magnifying glass.

Microscopic features

GROWTH RINGS: Indistinct formation of growth rings delimited by condensed fibers withwalls with reduced diameter is accompanied by axial parenchyma in marginal bands (Fig. 3A).

VESSELS: Diffuse porosity. Vessels irregularly arranged. Vessels are solitary (66.66%) and in radial multiples of 2 to 4. The vessel outline is rounded. Simple perforation plates were found (Figure 3A, D). Mean tangential diameter of vessels lumina varied from 84.73 to 214.22 µm with an average of 160.87 µm ± 32.68 µm (Table 2, 6). Vessels per square millimeter varied from 1 to 4 vessels/mm^2 with an average of 1.8 vessels/mm^2 (Table 2, 6). Mean vessel element length varied from 132.21 to 296.82 µm with an average of 237.43 µm ± 36.59 µm, so they are classified as small. Gum deposits were found (Fig. 3A). Vessel elements are storied (Fig. 3D).

INTERVESSEL PITS: Intervessel pits are alternate, circular to polygonal, and ornamented (Fig. 3 E). They are of medium diameter and range between 5.27 to 10.7 µm with an average of 7.93 µm ± 1.48 µm (Table 2, 6). Radiovascular pits are similar to intervascular pits in shape and size.

FIBERS: Nonseptate libriform fibers present. Fibers with simple to small bordered pits. Fiber walls are thick to very thick; wall thickness varied from 3.37 to 9.60 µm and an average of 6.02 µm ± 1.57 µm (Table 3, 6). Fiber lumen varied from 3.22 to 18.90 µm with an average of 8.74 µm ± 3.46 µm (Table 3, 6). Fiber length varied from 795.91 to 1,544.084 µm with an average of 1,159.69 µm ± 143.46 µm (Table 3, 6). Fibers are storied (Fig. 3D).

AXIAL PARENCHYMA: Apotracheal axial parenchyma diffuse and diffuse in aggregates. Paratracheal axial parenchyma vasicentric. Banded axial parenchyma in marginal bands up to three cells wide (Fig. 3A, Table 4). Axial parenchyma cells per strand are mostly 2 fusiform cells (Fig. 3D). Axial parenchyma is storied (Fig. 3D, Table 4).

RAYS: Width up to 3 cells wide, predominantly uniseriate (Fig. 3D). Rays height less than 1 mm, it varied from 0.108 mm to 0.161 mm with an average of 0.135 mm, ± 0.014 mm, so they are classified as short or small (Table 5, 6). Rays composed of procumbent cells and procumbent cells with one row of upright and/or square marginal cells. It presents many rays per millimeter; the frequency varied from 17 to 20 rays/mm, with an average of 18.3 rays/mm ± 1.06 rays/mm (Tables 5, 6). Rays are storied (Fig. 3D).

MINERAL INCLUSIONS: Prismatic crystals positioned in chambered axial parenchyma cells (Fig. 3I).

All quantitative values in table 6.

Table 1.
Macroscopic characteristics of Dalbergia retusa and the samples 1 and 2.

Woods	Colour	Odour and taste	Luster	Grain	Texture	Weight and hardness
D. retusa	Dark reddish heartwood (2.5 YR 5/6). Abrupt transition.	Present	Medium	Crossed	Medium	Hard and heavy
Sample 1	Light reddish to chocolate heartwood (2.5 YR 6/4). No transition.	Absent	Medium	Crossed	Medium	Soft and light
Sample 2	Reddish chocolate heartwood (10 YR 5/6). No transition.	Absent	Medium	Crossed	Medium	Moderately hard and heavy

Table 2.
Vessels element characteristics of Dalbergia retusa and the samples 1 and 2.

Woods	Growth rings	Porosity	PF	VG	DVL	PP	IPAS	VP	VRP
D. retusa	D, I	Diffuse porous	1.8	2-4	160.87	S	A; 7.93	+	30
Sample 1	D, I	Diffuse porous	4.9	2-3	194.23	S	A; 4.46	+	30
Sample 2	D, I	Diffuse porous	5.2	2-3	150.66	S	A; 5.71	+	30

Vessel elements characteristics: D= distinct, I= indistinct, PF= pores frequency (vessels/mm^2), VG= vessel grouping, DVL= diameter of vessel lumina (µm), PP= perforation plates, S= simple, IPAS= intervessel pits arrangement and size (µm), A= alternate, VP= vestured pits, VRP= vessel-ray pitting according to IAWA class: 30: vessel-ray pits with distinct borders; similar to intervessel pits in size and shape throughout the ray cell. Symbol "+" anatomical feature present.

Table 3.
Fibers features of Dalbergia retusa and the samples 1 and 2.

Woods	GTF	SF	FWT	FL	FLD	FS	SG
D. retusa	61	-	6.02	1,159.69	8.74	+	0.76-(VH)
Sample 1	61	-	3.95	1,439.75	10.56	+	0.59-(M)
Sample 2	61	-	3.98	1,100.45	9.41	+	0.71-(H)

Fibers: GTF= ground tissue fibers, according to IAWA class: 61: simple to minutely bordered pits, SF= septate fibers, FWT= fiber wall thickness (µm), FL= fiber lengths (µm), FLD= fiber lumen diameter (µm), FS= fibers storied, SG= specific gravity (g/cm^3), VH= very high, H=high, M= medium. Symbol "+" anatomical feature present, "-"anatomical feature absent.

Table 4.
Axial parenchyma features of Dalbergia retusa and the samples 1 and 2.

Woods	AAP	PAP	BP	CT	APSL	APS
D. retusa	76; 77	79	89	F	1-2	+
Sample 1	76; 77	79; 80	89	F	1-2	+
Sample 2	76; 77	79; 82	89	F	1-2	+

Axial parenchyma: AAP= apotracheal axial parenchyma, according to IAWA class: 76: diffuse, 77: diffuse-in aggregaets. PAP= paratracheal axial parenchyma, according to IAWA class: 79: vasicentric, 80: aliform, 82: winged-aliform. BP= banded parenchyma, according to IAWA class: 89: axial parenchyma in marginal or in seemingly marginal bands. CT= cell type, F= fusiform, APSL= axial parenchyma strand length, APS: axial parenchyma storied. Symbol "+" anatomical feature present.

Table 5.
Rays features of Dalbergia retusa and the samples 1 and 2.

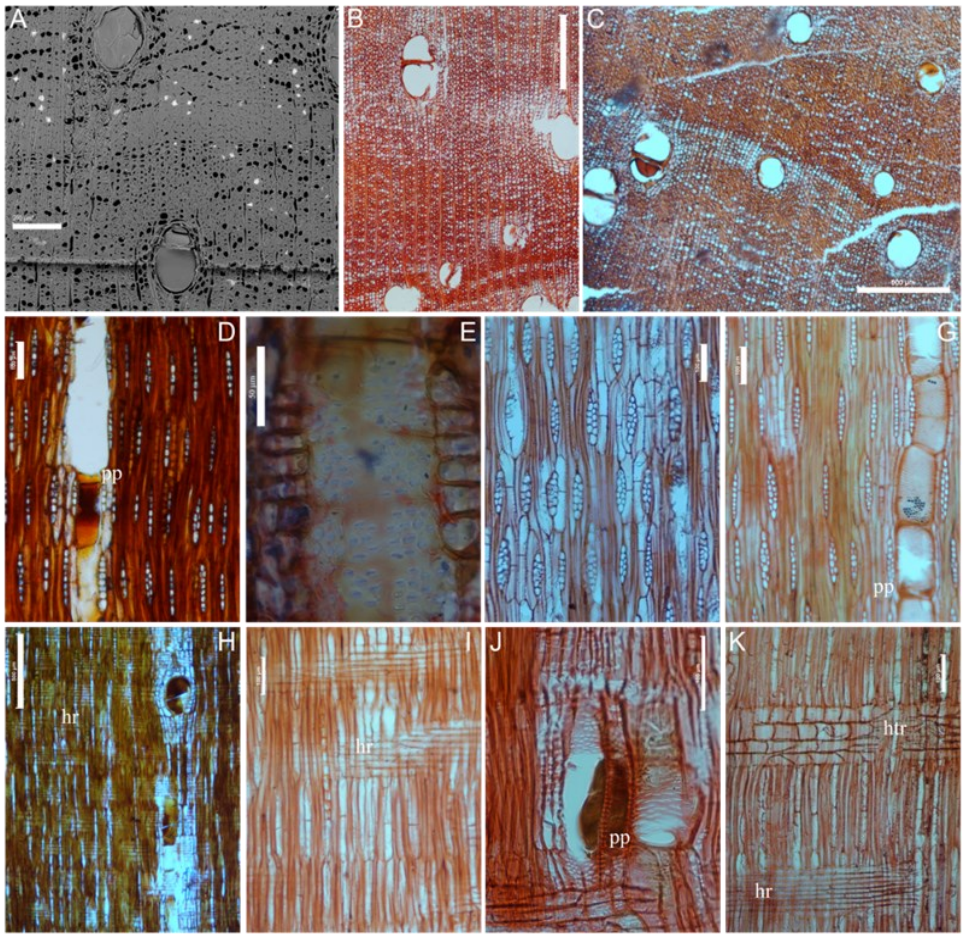
Woods	RH	RW	RF	RS	RT	RCC
D. retusa	0.135	1-3 (U)	18.3	+	Ho - Ht	104, 106
Sample 1	0.122	1-3 (B)	12.3	+	Ho - Ht	104, 106, 107
Sample 2	0.148	1-3 (A)	10.9	+	Ho - Ht	104, 106, 107

Ray parenchyma: RH= ray height (mm), RW=ray width cell, U: mainly uniseriate, B: mainly biseriate, A: alternates uniseriate and biseriate, RF= ray frequency (ray/mm), RS= ray storied, RT= ray type, Ht= heterocellular, Ho= homocellular, RCC= rays cellular composition, according to IAWA class: 104: all ray cells procumbent; 106: body ray cells procumbent with one row of upright and/ or square marginal cells; 107: body ray cells procumbent with mostly 2-4 rows of upright and/ or square marginal cells. Symbol "+" anatomical feature present.

Table 6.
Quantitative values of Dalbergia retusa and the samples 1 and 2. Means are given with standard deviation, maximum and minimum. Note: Freq. frequency, diam.= diameter, Len. = length, WT= wall thickness, SV= percentage of solitary vessels (%), v/mm^2= vessels per square millimeter, VEL=vessel element length (µm), DVL tangential diameter of vessel lumina (µm).

Features	Variables /Species	*Dalbergia retusa* Hemls.	Sample 1	Sample 2
Vessels	SV (%)	66.7	73.5	57.7
	Freq. (v/mm^2)	1.8 ± 1.03; 1-4	4.9 ± 1.97; 2-8	5.2 ± 2.57; 1-9
	VEL (µm)	237.43 ± 36.59; 132.21-296.82	260.91 ± 41.71; 198.31-352.6	239.21 ± 27.7; 184.8-306.96
	DVL (µm)	160.87 ± 32.68; 84.73-214.22	194.23 ± 63.72; 89-319	150.66 ± 42.23; 50-240.03
Pits	Diam. (µm)	7.93 ± 1.48; 5.27-10.7	4.46 ± 1.41; 2.95-8.46	5.71 ± 0.61; 4.22-7-67
	Height (mm)	0.13 ± 0.014; 0.108-0.161	0.12 ± 0.020; 0.074-0.16	0.15 ± 0.013; 0.11-0.17
Rays	Freq. (r/mm)	18.3 ± 1.06; 17-20	12.3 ± 1.77; 9-15	10.9 ± 1.59; 8-14
	Lumen (µm)	8.74 ± 3.46; 3.22-18.9	10.56 ± 5.14; 3.73-23.42	9.41 ± 3.45; 2.47-15.99
Fibers	WT (µm)	6.02 ± 1.57; 3.37-9.6	3.955 ± 0.86; 2.61-6.58	3.98 ± 1.06; 2.5-6.52
	Len. (µm)	1,159.69 ± 143.46; 795.91-1,544.08	1,439.75 ± 310.74; 768.89-2,083.66	1,100.45 ± 291.61; 566.65-1,587.59

Figure 3.
Comparison of anatomical features observed in the studied samples. A, D, E & H. Dalbergia retusa. B, F, I & J. Sample 1. C, G & K. Sample 2. Growth ring boundaries distinct (A, B, C). Radial multiples (A, B, C). Simple perforation plate (pp) (D, G, J). Vessels with gums deposits (D, H, J). Vasicentric axial parenchyma (A, B). Winged-aliform axial parenchyma (C). Axial parenchyma in marginal bands (A, B, C). Homocelular rays (hr) (H, I, K).
Heterocelular rays (htr) (K). Crystals (I). Scale bar A=200 u; B, C= 500 µm; D, E, F, G, H, I, J, K=100 µm.



Diagnosis of sample 1

General characteristics
In dry conditions, the heartwood of sample 1 is light reddish to chocolate color (2.5YR 6/4). Wood with medium texture, without distinctive aroma, medium shine, and cross-grained. The wood is soft and light (Table 1).

Macroscopic features
Vessels are visible to the naked eye. Axial parenchyma is visible with a 10x magnifying glass. Rays are barely visible with a 10x magnifying glass.

Microscopic features
GROWTH RINGS: Indistinct formation of growth rings delimited by condensed fibers with walls with reduced diameter is accompanied by axial parenchyma in marginal bands (Fig. 3B).

VESSELS: Diffuse porosity. Vessels irregularly arranged. Vessels are solitary (73.5%) and in radial multiples of 2 to 3 (Fig. 3B). The vessel outline is rounded. Simple perforation plates were found (Fig. 3J). Mean tangential diameter of vessel lumina varied from 89 to 319 μm with an average of 194.23 μm ± 63.72 μm (Table 2). Vessels per square millimeter varied from 2 to 8 vessels/mm^2 with an average of 4.9 vessels/mm^2. Mean vessel element length varied from 198.31 to 352.6 μm with an average of 260.91 μm ± 41.71 μm, so they are classified as small. Gum deposits were found (Fig. 3J). Vessel elements are storied.

INTERVESSEL PITS: Intervessel pits are alternate, polygonal, and ornamented. They are small to medium in diameter and range between 2.95 to 8.46 μm with an average of 4.46 μm ± 1.41 μm (Table 2). Radiovascular pits are similar to intervascular pits in shape and size.

FIBERS: Nonseptate libriform fibers present (Fig. 3F). Fibers with simple to small bordered pits. Fibers are thin to thick walled; wall thickness varied from 2.61 to 6.58 μm and an average of 3.95 μm ± 0.86 μm. Fibers lumen varied from 3.73 to 23.42 μm with an average of 10.56 μm ± 5.14 μm. Fibers length varied from 768.89 to 2,083.66 μm with an average of 1,439.75 μm ± 310.74 μm (Table 2, 4). Fibers are storied (Fig. 3F).

AXIAL PARENCHYMA: Apotracheal axial parenchyma diffuse and diffuse in aggregates (Fig. 3B). Paratracheal axial parenchyma vasicentric and aliform (Fig. 3B). Banded axial parenchyma in marginal bands up to three cells wide (Fig. 3B). The cells of the axial parenchyma are mostly made up of 1 to 2 fusiform cells (Fig. 3F; Table 3). Axial parenchyma is storied (Fig. 3F).

RAYS: Width up to 3 cells, predominantly biseriate and up to 3 cells wide (Fig. 3F). Rays height less than 1 mm, ranging from 0.0744 to 0.162 mm with an average of 0.122 mm ± 0.020 mm, so they are classified as short or small. Rays composed of procumbent cells and procumbent cells with one row of upright and/or square marginal cells. It presents many rays per millimeter; the frequency varied from 9 to 15 rays/mm, with an average of 12.3 rays/mm ± 1.77 rays/mm (Tables 2, 4). Rays are storied (Fig. 3F).

MINERAL INCLUSIONS: Prismatic crystals positioned in chambered axial parenchyma cells.

Diagnosis of the sample 2

General characteristics
In dry conditions, the heartwood of sample 2 is reddish (10YR 5/6) with dark veins (10YR2.5/1). No transition was observed. Wood with medium texture, without characteristic aroma, medium shine, and cross-grained. The wood is moderately hard and heavy. The wood sample had insect damage (Table 1).

Macroscopic features
Vessels are visible to the naked eye. Axial parenchyma is visible with a 10x magnifying glass. Thin rows of rays are visible only with a 10x magnifying glass.

Microscopic features
GROWTH RINGS: Indistinct formation of growth rings delimited by condensed fibers with walls with reduced diameter is accompanied by axial parenchyma in marginal bands (Fig. 3C).

VESSELS: Diffuse porosity. Vessels irregularly arranged. Vessels are solitary (57.69%) and in radial multiples of 2 to 3 (Fig. 3C). The vessel outline is rounded. Simple perforation plates were found (Fig. 3G). Mean tangential diameter of vessel lumina varied from 50 to 240.03 µm with an average of 150.66 µm ± 42.23 µm. Vessels per square millimeter varied from 1 to 9 vessels/mm^2 with an average of 5.2 vessels/mm^2. Mean vessel element length varied from 184.8 to 306.96 µm with an average of 239.21 µm ± 27.7 µm, so they are classified as small. Gum deposits were found (Table 1, 4). Vessel elements are storied (Fig. 3G).

INTERVESSEL PITS: Intervessel pits are alternate, polygonal, and ornamented. They are small in diameter and range between 4.22 to 7.67 µm with an average of 5.71 µm ± 0.61 µm. Radiovascular pits are similar to intervascular pits in shape and size (Table 1, 4).

FIBERS: Nonseptate libriform fibers present. Fibers with simple to small bordered pits (Fig. 3K). Fibers thin to thick wall; wall thickness varied from 2.50 to 6.52 µm and an average of 3.98 µm ± 1.06 µm. fiber's lumen varied from 2.47 to 15.99 µm with an average of 9.41 µm ± 3.45 µm. Fiber length varied from 566.65 to 1,587.59 µm with an average of 1,100.45 µm ± 291.61 µm (Table 2, 4). Fibers are storied (Fig. 3G).

AXIAL PARENCHYMA: Apotracheal axial parenchyma is diffuse and diffuse in aggregates (Fig. 3C). Paratracheal axial parenchyma vasicentric and winged-aliform (Fig. 3C). Banded

axial parenchyma in marginal or apparently marginal bands up to three cells wide (Fig. 3C). The axial parenchyma cells are made up of 1 to 2 fusiform cells (Fig. 3G; Table 3).

RAYS: Width up to 3 cells, predominantly biseriate and alternating with uniseriate rays (Fig. 3G). Rays height less than 1 mm, ranging from 0.113 to 0.177 mm with an average of 0.148 mm ± 0.013 mm, so they are classified as short or small. Rays composed of procumbent and procumbent with mostly 2-4 rows of upright and/or square marginal cells (Fig. 3K). It presents few rays per millimeter; the frequency is 8 to 14 rays/mm with an average of 10.9 rays/mm ± 1.59 rays/ mm (Tables 2, 4). Rays are storied (Fig. 3G).

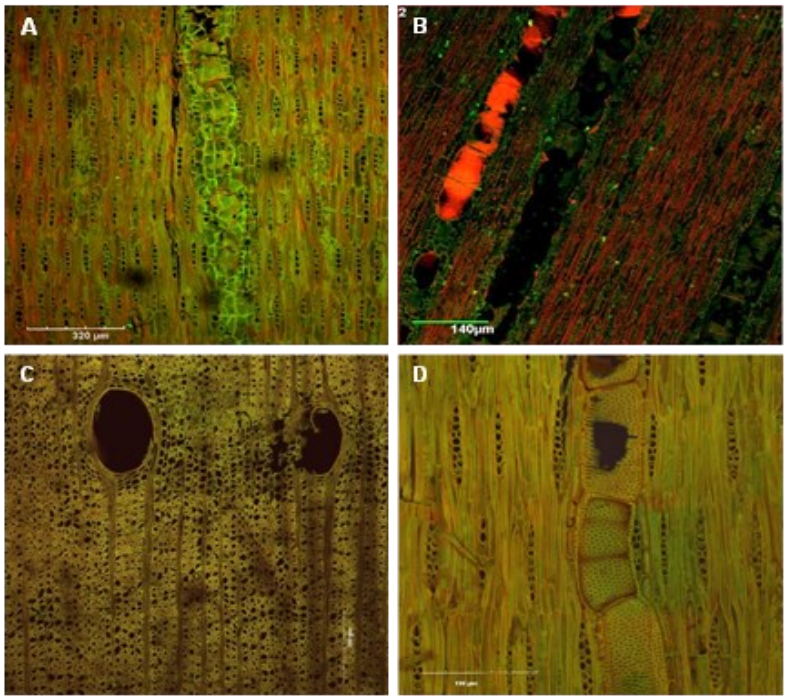
MINERAL INCLUSIONS: Prismatic crystals positioned in chambered axial parenchyma cells.

Fluorescence test

All three samples showed fluorescence. *D. retusa* wood and sample 1 presented the colors: red and green. The wood of sample 2 presented the following colors: red and a weak green and yellow color (Fig. 4).

Figure 4.

Comparison of anatomical features observed in the samples studied. A-B. D. retusa. B-C. Sample 1 and 2.



Samples basic density
The basic density of D. retusa wood, the sample 1 and the sample 2 was 0.76 g/cm^3 (very high), 0.59 g/cm^3 (high), and 0.71 g/cm^3 (median), respectively.

DISCUSSION

General, qualitative, and quantitative features of *Dalbergia retusa* observed matched the descriptions of Record & Garrat (1923), Gottald (1958), Kribs (1968), Richter *et al*. (1996), Richter & Dallwitz (2000), Wiedenhoeft (2011), and Moya *et al*. (2013). The paratracheal axial parenchyma observed is vasicentric but not scarce as reported by Moya *et al*. (2013) and Record & Garrat (1923). Axial parenchyma strands are mainly composed of 2 cells or scarcely 4 cells, as described by Kribs (1968), Richter & Dallwitz (2000), and Moya *et al*. (2013); and it does not present or is weakly confluent and cross-linked as Kribs (1968) described.

According to Record (1919, 1942), Record & Garrat (1923), Jane (1956), Carlquist (1966, 2001), Kribs (1968), Quirk & Miller (1985), Richter *et al*. (1996), Baas *et al*. (2000), Espinoza & León (2002), Gasson *et al*. (2010), Espinoza *et al*. (2015), and Ravaomanalina *et al*. (2017), the qualitative anatomical characteristics of samples 1 and 2 show diagnostic features consistent with the Fabaceae family and the *Dalbergia* genus. Both samples' voucher specimens have been deposited in the PMA herbarium. There are fruits and leaves in one sample and just leaves in the other. This made it possible for us to verify that both samples are from *Dalbergia* trees, which match the morphology described in the Flora of Panama (Dwyer & Hermann 1965). A specialist also examined the fruits of sample 2 and, as expected, found significant differences compared to *Dalbergia retusa*.

While samples 1 and 2 show a higher vessel density, *D. retusa* has fewer and smaller vessels per square millimeter. Samples 1 and 2 exhibit 2 to 3 vessel multiples, whereas *D. retusa* develops vessel multiples of 2 to 4. There is very little difference in the average vessel element length between *D. retusa* and the two samples; sample 1 has the longest average length. Furthermore, compared to samples 1 and 2, the vessels of *D. retusa* are shorter.

The paratracheal axial parenchyma type in *D. retusa* is more limited in range. Such differences in axial parenchyma types influence water storage and flow; species with different axial parenchyma types may occupy distinct ecological niches (Carlquist 2001). According to Carlquist (2001), vessel frequency is frequently higher in trees from wet tropical forests where quick water conduction is essential, as seen in the forests where samples 1 and 2 were collected. In contrast, species from dry or seasonal forests, such as *D. retusa*, tend to have lower vessel frequencies, which helps prevent cavitation and water loss during droughts, minimizing the risk of water loss and cavitation (Carlquist 2001; Hacke *et*

al. 2006; Martínez-Cabrera *et al*. 2009). Demonstrating functional and structural differences. Additionally, the correlation between vessel element length and water availability supports species differentiation in response to ecological conditions and their efficiency in water conduction (Hacke *et al*. 2006). The rays in *D. retusa* are predominantly uniseriate, while the rays in sample 1 are mostly biseriate rays, and sample 2 primarily features biseriate rays, alternating with uniseriate rays.

The walls of the fibers of *D. retusa* are medium to very thick; while those of sample 2 are thin to thick, therefore, the lumen of the fibers of sample 2 is larger than that of the fibers of *D. retusa.* According to Martínez-Cabrera *et al*. (2009), while the proportion of the fiber wall slightly declines in areas with higher rainfall, like those found in the region of origin of samples 1 and 2, which is 2,000 to +2,500 mm/year, the proportion of fiber lumen is inversely correlated with temperature and positively correlated with precipitation (Instituto Nacional de Estadística y Censo 2010). Since *D. retusa* thrives in deciduous forests with drought and nutrient stress, its fiber' walls are thick (Martin 1984; Hall & Ashton 2016).

D. retusa exhibited very high density values, high density values for sample 1, and medium density values for sample 2. This character can vary due to environmental elements like temperature and precipitation (Barajas-Morales 1987; Wiemann & Williamson 2002; Swenson & Enquist 2007; Martínez-Cabrera *et al*. 2009). Wood density seems to differ significantly among coexisting species despite this broad climate-related pattern (Wiemann & Williamson 2002; Muller-Landau 2004). Plumptre (1984) claims that trees that grow at low altitudes and latitudes, with a high humidity deficit or in climates with a distinct dry season, tend to have higher wood densities due to the presence of fewer vessels and thicker walls, an adaptation that lowers water loss and increases structural support, as in the case of *D. retusa*. However, Martínez-Cabrera *et al*. (2009) and Ziemińska *et al*. (2015) noted that density is lowest when there is a substantial amount of parenchyma or a high proportion of lumen in fibers, as seen in samples 1 and 2. These features can help differentiate species based on their ecological adaptations, influencing their survival strategies in various forest types and climates.

CONCLUSSIONS

This research aims to increase awareness and safeguard native *Dalbergia* species populations. The combination of vessel frequency, vessel element length, axial parenchyma, fibers, and wood density reveals significant structural and functional differences between the three samples. These differences are usually linked to different ecological environments.
Numerous tree species that are significant from an ecological and economic standpoint are found in the genus *Dalbergia*. It is possible to trace both legal and illicit logging of *Dalbergia* species, manage conservation efforts, and create laws that guarantee sustainable harvesting by knowing and distinguishing the wood anatomy of these species.

Mi Ambiente must establish a forensic botany department responsible for researching and expanding this field of study nationwide in order to aid in the preservation of *Dalbergia* species and deter the illicit trade in endangered species. Effective conservation measures may be hampered by misidentification or a failure to distinguish between species, which may mask significant ecological significance. Numerous economically important timber species can be found in Panama, although their full potential is yet mostly unknown. There are many opportunities to learn about ecological processes, forecast how species may respond to climate change, find underappreciated species that might be suitable for high-value markets, and support ecological sustainability.

Furthermore, this research could be applied to botanical studies of families like Rubiaceae and Melastomataceae, as these families encompass a large number of woody species under several genera. Creating detailed wood anatomical descriptions could help unlock their potential for both economic and ecological uses.

Although the evidence is not enough to guarantee that samples 1 and 2 are different taxa, the results obtained suggest that this could be the case. It is possible that, with phytochemical, physicochemical, phylogenetic, and chromatographic analyses, together with the comparison of the botanical material of both samples of the genus *Dalbergia*, these can be separated as taxa different from the species *Dalbergia retusa*. Determining whether these samples are *D. tucurensis*, which has been reported in Belize, Costa Rica, El Salvador, Guatemala, Honduras, México, and Nicaragua (Tropicos 2025a), and is moderately hard and heavy, with a violet to chocolate color when dry, or *D. stevensonii,* which has been reported in Belize, Guatemala, Honduras, and Mexico (Tropicos 2025b), which is heavier than the previous one and pink in color, some species have already been reported in Panama and Costa Rica, or whether the samples may be new species for science.

It is extremely important from a taxonomic standpoint to have anatomical descriptions of commercially valuable woods, their physical and chemical characteristics, and information about the species' origin and distribution in Panamanian territory.

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