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ORIGINAL ARTICLE

Wood anatomy of the rare species *Dinizia jueirana-facao* (Fabaceae), "Tabuleiros" Atlantic Forest, Brazil

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Abstract
We present the first wood anatomy description for the rare species *Dinizia jueirana-facao* G. P. Lewis & G. S. Siqueira, which grows in a megadiverse tropical forest subjected to rainfall seasonality, in SE Brazil. Growth rings are visible to the naked eye and demarcated by thin marginal parenchyma bands and, sometimes, by thick-walled fibers in the latewood. Axial paratracheal parenchyma is vasicentric to lozenge aliform with short confluences. Rays are 2–6-seriate, homocellular (procumbent cells) and non-storied. Vessels are visible to the naked eye, some irregular clusters, with diffuse distribution, sometimes filled with gums. Crystals are absent. Intercellular canals of traumatic origin are present. In general, wood anatomical characteristics of *D. jueirana-facao* agree with those previously reported for other Mimosoid species. As other cooccurring Fabaceae, the studied species has visible growth rings, but more conspicuous than reported for its sister species. Growth rings in *D. jueirana-facao* are likely triggered by the marked rainfall seasonality.

Keywords Endemism · Seasonal climate · Tree rings · Xylem

1 Introduction

The family Fabaceae has cosmopolitan distribution and occurs in a wide variety of habitats (Lewis et al. 2005). Many of its species have a high metabolism of nitrogen and amino acids, often with root nodules containing nitrogen-fixing bacteria (Judd et al. 2009), contributing to soil fertility (Crews 1999). This botanic family comprises about 19,400 species distributed in 740 genera (Lewis et al. 2005). In Brazil, there are 223 genera and 2846 species (Flora do Brasil 2020 under construction 2015). For almost 100 years, *Dinizia* Ducke was considered an Amazonian monospecific genus, having *Dinizia excelsa* Ducke as the only described species (Flora do Brasil 2020 under construction 2015) and belonging to the subfamily Caesalpinioideae (Azani et al. 2017). Recently, another species was described for the genus, the canopy-emergent *Dinizia jueirana-facao* G. P. Lewis & G. S. Siqueira, known from a very small population in a well-preserved patch of "Tabuleiros" Atlantic Forest (TAF) (Lewis et al. 2017).

The TAF is a phytophysiognomy within the Brazilian Atlantic Forest domain, considered to have the highest trees species density per hectare in the globe (Thomas et al. 2008). The high biodiversity in the tropics is related

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to the fact that in these regions, most species are rare (Hubbell 2013). According to Gaston (1994), there is no consensus among researchers regarding the definition of the rarity. Rabinowitz et al. (1986) consider that rarity is not unique. In this sense, the authors proposed a methodology that makes it possible to segregate species into seven forms of rarity plus common species (Form 1 up to 7, plus common species). The closer to Form 7, the rarer the species. According to them, there are three variables that are common to all species: geographic range, habitat specificity, and number of individuals. Combining these variables with each other, we obtain the rarity classification of each species. This methodology was widely applied for the study of the rarity of species in different floras (Pitman et al. 1999; Broennimann et al. 2005; Caiafa and Martins 2010; Drever et al. 2010; Fontana et al. 2014), promoting a better understanding of species distribution.

Knowledge on species distribution patterns, especially of rare ones, is important for the conservation and management purposes. Understanding why some species are rare and others are common pervades various fields of science, such as phytogeography, ecology, genetics and physiology. Wood anatomy also adds valuable information since anatomical characteristics are also adjusted according to the complex environmental and physiological conditions that regulate plant life (see Carlquist 1977; Baas 1982; Barajas-Morales 1985; Alves and Angyalossy-Alfonso 2000; Fichtler and Worbes 2012). Researchers have also been concerned with the anatomical responses regarding water availability and climate change (Borchert 1998; Poorter et al. 2010; Baas and Wheeler 2011), which is a priority issue in a scenario of ongoing climate change.

Until recently, only 24 trees of *D. jueirana-facao* were found, distributed in a narrow TAF area (Lewis et al. 2017). On a Rabinowitz et al. (1986) basis, we assumed that the species would be classified as Form 6 of rarity. This category involves species with locally abundant individuals, i.e., non-singleton (species represented by only a single individual) or doubleton (species represented by up to two individuals) (Preston 1962), but distributed in a narrow geographic range with specific habitat. In this study, we characterize the three structural planes of the wood of the rare species *D. jueirana-facao* with macro- and microscopically anatomical analyses. We are interested in contributing to a better understanding of their wood anatomy which could be useful for future studies involving, i.e., ecological, functional and phylogenetic aspects, among others, of this rare species. In addition to providing the first anatomical description of *D. jueirana-facao*, the study may be useful for future metadata analyses on the anatomical characteristics of rare species and contribute to studies of rarity.

2 Materials and methods

Study site – The study was carried out in the Reserva Natural Vale (RNV), an area of 23,000 ha covered by a well-preserved tropical seasonal forest called “Tabuleiros” Atlantic Forest (TAF). It is located in the municipality of Sooretama, Espírito Santo State, southeastern Brazil (19°S–19°14′S, 39°12′W–40°W), between 30 and 150 m a.s.l. (Fig. 1).

Within a broader vegetation scheme, the region’s forest typology fits in between the “Lowland Dense Ombrophilous Forest” and the “Lowland Semideciduous Forest” (Veloso 1991; IBGE 2012), presenting a floristic mixture of Amazonian and Atlantic elements (Garay et al. 2003). *Dinizia jueirana-facao* is also a link between these forests since the only other species of the genus known until now has an exclusive Amazonian distribution.

According to the Koppen climate classification (Alvares et al. 2014), the climate type at TAF is Aw (seasonal tropical climate with a dry season). Mean annual precipitation is 1178 mm per year, with monthly averages for the unimodal rainy season (summer) of 130 mm to approximately 200 mm from October to April, during which 72% of the precipitation occurs (Rolim et al. 2016). Rainfall during the dry season (winter) does not exceed 25% of the annual total, and it is below 60 mm from April to September (Víncens et al. 2003). Severe droughts are related to strong “El Niño–Southern Oscillation” (ENSO) events (Rolim et al. 2016). The mean annual temperature is 23 °C, with the mean of the warmest month (February) of 25.6 °C, and the average of the coldest month (July) of 19.9 °C (Jesus 2001) (Fig. 1c).

The predominant soil type in the region is yellow Podzolic (yellow, tertiary), a dystrophic soil that exhibits low fertility, drastic differences in granulometry according to soil depth, and a rapid decomposition of the organic material (Garay and Silva 1995; Louzada et al. 1997; Garay et al. 2003).

Sample collection, preparation and description – In July 2014, we collected 5-mm-diameter wood cores at breast height (~ 1.30 m) with an increment borer from five adult trees, showing an average total height of 30 m (18–45 m) and diameter at breast height (dbh) of 79 cm (28–180 cm). Two to four radii per tree were collected. One of them was used in microscopic analyses and the others were used in the macroscopic description.

For macroscopic description, we analyzed the polished transverse surfaces of wood cores from the outermost ring to the pith. Cores were sanded with micro-abrasive paper (100 to 1200 grains) following Stokes and Smiley (1996)

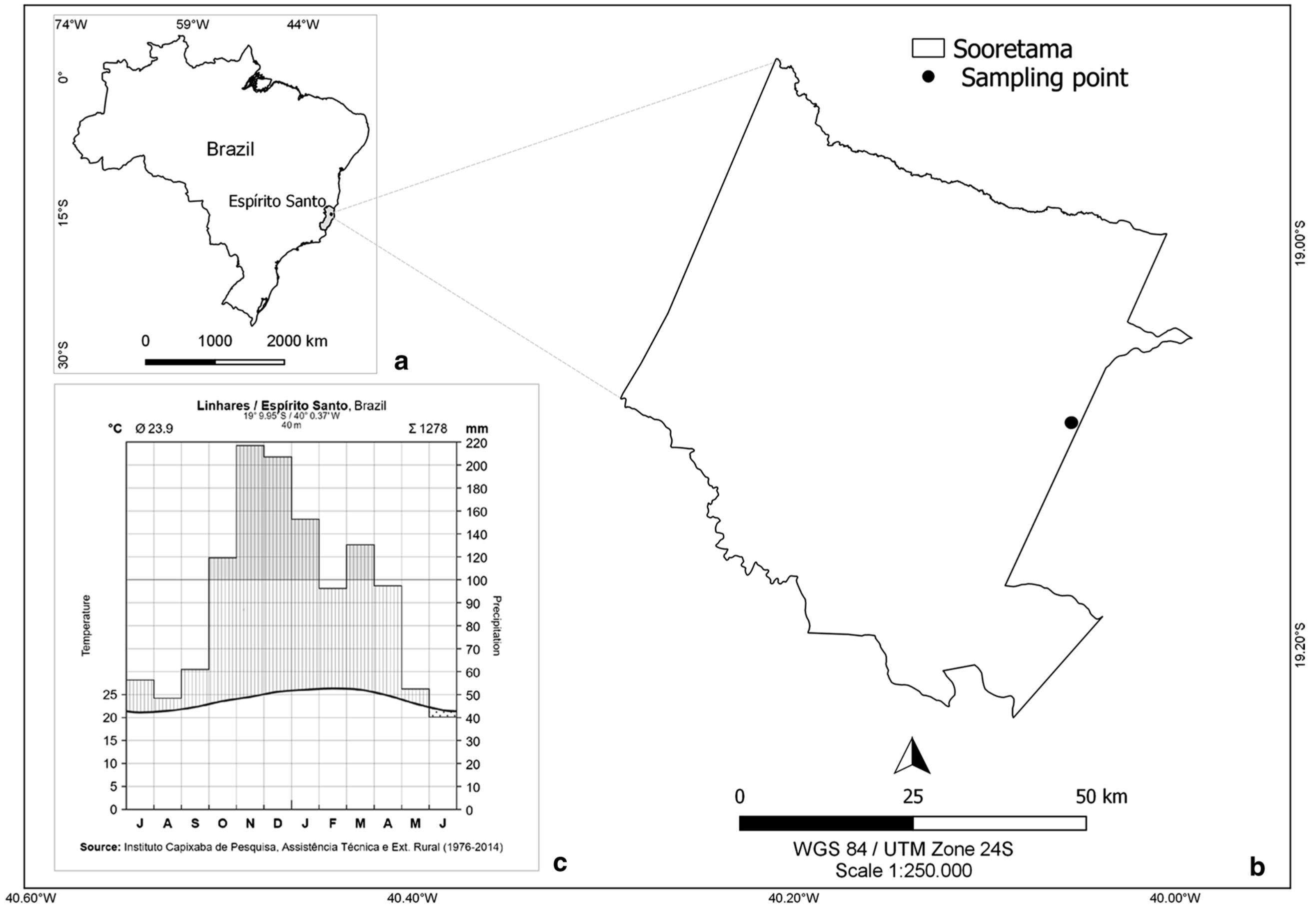

Fig. 1 Study area in Sooretama, state of Espírito Santo, southeastern Brazil (**a**). Sampling points of *Dinizia jueirana-facao* G. P. Lewis & G. S. Siqueira at Reserva Natural Vale, Sooretama, Brazil (**b**). Climatic diagram of the study area (**c**)

and photographed using a camera attached to a stereomicroscope. We analyzed the anatomical characteristics and the details of the tree rings.

For the microscopic analyses, we produced histological slides of wood boiled in water and glycerin from five trees. For the three anatomical planes (transversal, tangential, and radial), sections of 10–15 µm thick were obtained on a sliding microtome (Leica 2000R) and stained with safranin according to standard techniques in wood anatomy (Johansen 1940; Sass 1958). Digital images were captured by a camera attached to a light microscope (Zeiss Axio 5.6). Cell dimensions were measured using the Image Pro Plus 4.5 software (Media Cybernetics 2001). Quantitative and qualitative descriptors follow the IAWA Committee (1989).

3 Results

Wood Anatomy – Dinizia jueirana-facao

Macroscopic wood description

Growth rings visible to the naked eye, but sometimes with difficulty, demarcated by thin marginal parenchyma bands (Fig. 2). Variation of fiber wall thickness, sometimes resulting in distinct tangential fiber zones in the latewood. Confluent parenchyma bands are especially frequent in juvenile wood. Near the pith, the rings are less distinct. In general, heartwood color is darker than sapwood color. Paratracheal parenchyma vasicentric to lozenge aliform with short confluences. Rays visible to the naked eye, narrow and few (< 5/mm), in straight lines, irregularly spaced. Wood diffuse-porous, with medium-sized vessels visible to the naked eye; vessels are solitary or in radial multiples of 2–3(5); some irregular clusters present, partially filled with gum deposits.

Microscopic wood description

Growth rings boundaries distinct delimited by marginal parenchyma and fiber wall thickness (fiber zones). ***Vessels*** solitary or in radial multiples up to 6; wood diffuse-porous, without typical arrangement, circular to oval outline and medium to large diameter, 166 µm (107–219, SD ± 31), length 337 µm (176–545, SD ± 70), frequency low, 6 per mm^2 (4–9, SD ± 1.50), sometimes partially filled with gum

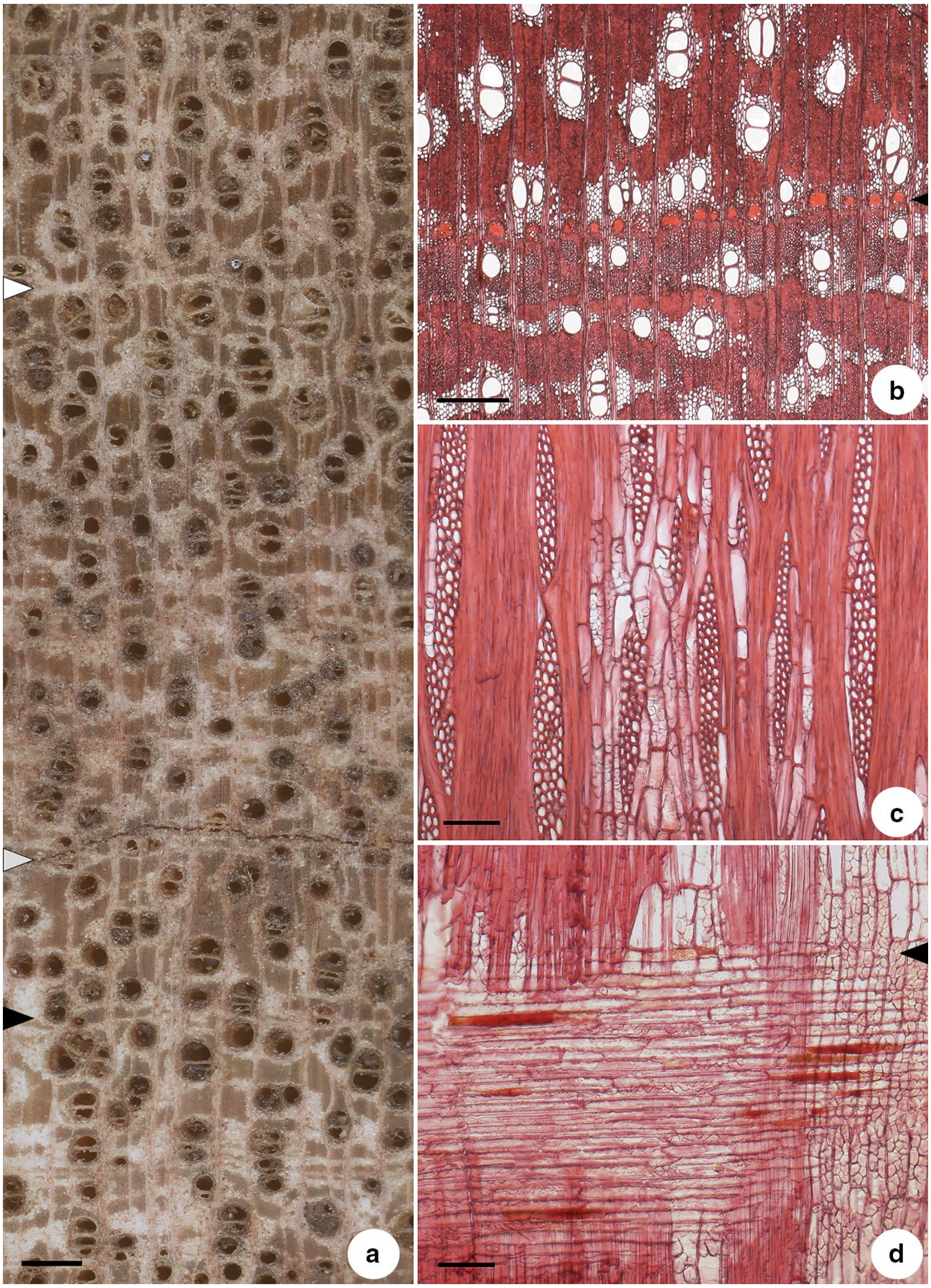

Fig. 2 Macroscopic transversal plane showing the growth-ring boundaries distinct (black arrows), probably climate fluctuations—false rings (white arrow) and canals of traumatic origin (gray arrow) (**a**). Microscopic transversal section showing the distribution of the intercellular canals of traumatic origin (arrow) (**b**). Tangential longitudinal section (**c**). Radial longitudinal section with high concentration of starch in the axial parenchyma cells (arrow) (**d**). Scale bars: A = 5 mm; B = 500 μm; C, D = 100 μm

deposits; perforation plates simple; intervessel pit alternate, tangential diameter medium to large, 10 μm (8–11, SD ± 1.0); vessel-ray pits with distinct borders, similar to intervessel pits in size and shape throughout the ray cell, small to medium sized, 6 μm (5 to 8, SD ± 0.85). ***Fibers*** libriform with simple to minutely bordered pits, of thick-walled and thin lumen, with intrusive growth, length 1247 μm (99–1901, SD ± 557) and wall thickness 56 μm (9–121, SD ± 21). ***Axial parenchyma*** paratracheal vasicentric to lozenge aliform with short confluences in oblique arrangement and, eventually, forming tangential and/or marginal bands, with 3- to 6-cell-wide sheaths; also in 2- to 5-cell-wide marginal bands, with high concentrations of starch grains. ***Rays*** predominantly homocellular, consisting of procumbent cells and sometimes with square marginal cells; non-storied, 2–6-seriate, with a mean width of 58 μm (38–81, SD ± 12) μm and a mean height of 404 μm (199–603, SD ± 102); frequency was on average of 6 rays mm^{-1} (5–8 rays mm^{-1}, SD ± 1.0 ray mm^{-1}). ***Crystals*** absent. ***Intercellular canals*** of traumatic origin present, delimiting some growth layers (rare) (Fig. 3).

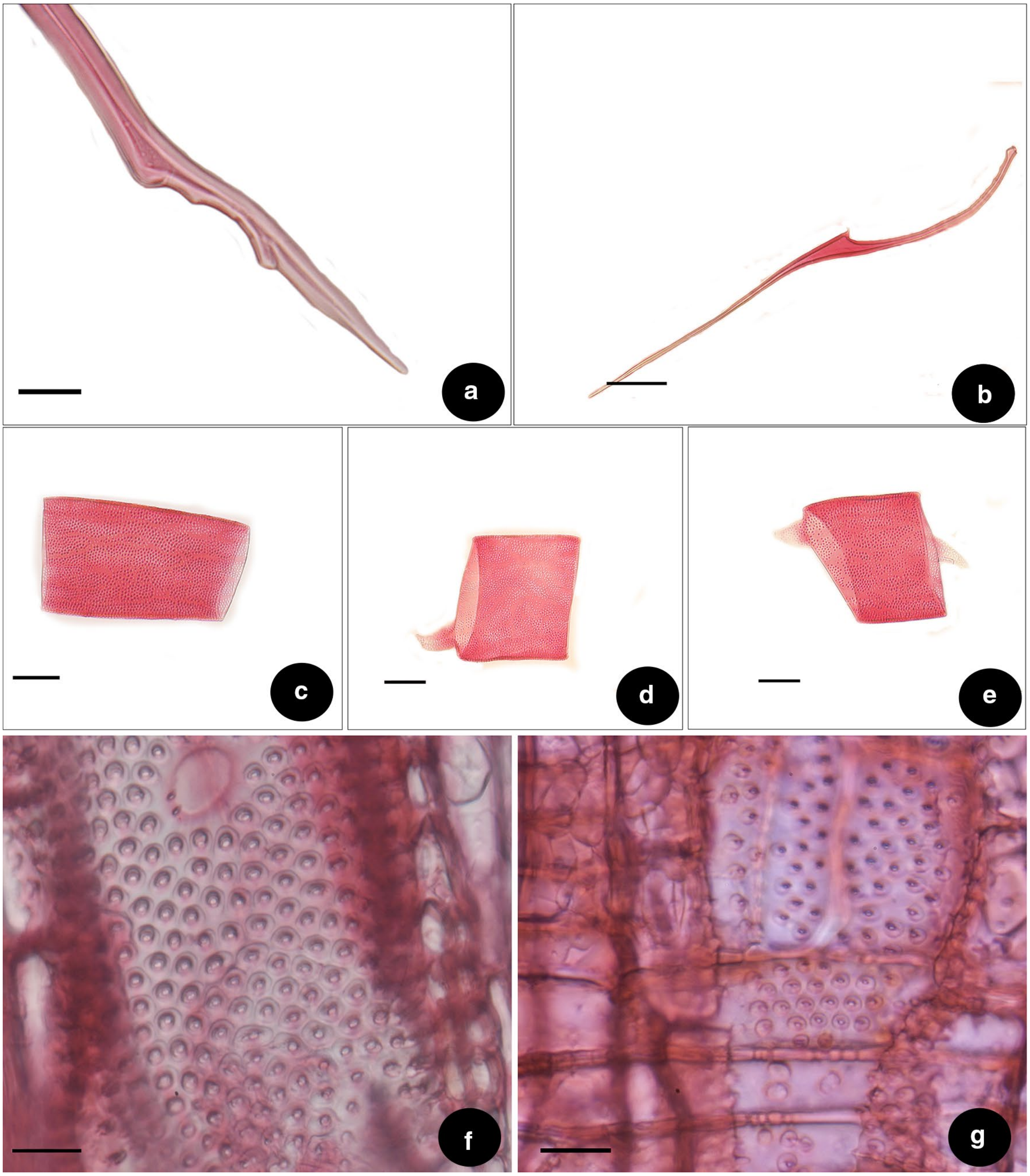

Fig. 3 Cells dissociated from *Dinizia jueirana-facao* (**a–e**): intrusive growth of fibers (**a–b**); vessel elements without appendix (c); with appendix on one side (**d**); appendix on both sides (**e**). Longitudinal tangential section showing intervessel pits (**f**); radial section showing vessel-ray pits (**g**). Scale bars: A–E = 100 µm; F, G = 10 µm

4 Discussion

The general **macroscopic** wood anatomical characteristics of *D. jueirana-facao* are in accordance with most of the descriptions for the Caesalpinioideae and Mimosoid clade (Fabaceae), such as growth rings delimited by marginal parenchyma, diffuse-porous wood structure and vasicentric parenchyma (Metcalfe and Chalk 1950; Mainieri et al. 1983; Alves and Angyalossy-Alfonso 2000; InsideWood-onwards 2004, cf Wheeler 2011; dos Santos et al. 2019). Annual growth-ring formation has been reported for other Fabaceae in TAF forests: *Dalbergia nigra* (Vell.) Allemão ex Benth., *Pterocarpus rohrii* Vahl, *Schizolobium parahyba* (Vell.) Blake, *Senna multijuga* (Rich.) H.S.Irwin & Barneby, *Copaifera langsdorffii* Desf. and *C. lucens* Dwyer (Costa et al. 2015; Fontana et al. 2018a, b).

Comparing *D. jueirana-facao* with *D. excelsa* Ducke, it was observed similarity to the aliform and confluent axial parenchyma and diffuse-porous wood (Mainieri et al. 1983; Ferreira et al. 2004; InsideWood-onwards 2004; Chipaia et al. 2015). In *D. jueirana-facao,* solitary vessels occur and thus in multiples radial, whereas in *D. excelsa* solitary vessels (78%) occur predominantly (Mainieri et al. 1983). We observed that *D. jueirana-facao* has visible growth rings that are marked by a thin line of axial parenchyma and sometimes by thicker walled fibers, while for *D. excelsa*, the growth-ring boundaries are described as indistinct or absent (InsideWood-onwards 2004; Chipaia et al. 2015) or yet slightly marked by a darker fibrous zone (Ferreira et al. 2004). However, analyzing figures in Ferreira et al. (2004) and the online platform InsideWood-onwards (2004), we notice fine lines of axial parenchyma that seem to delimit growth layers. Mainieri et al. (1983) also observed growth rings slightly demarcated by fibrous zone and by cells of marginal parenchyma in *D. excelsa*. Therefore, we consider these species are similar in their growth ring.

The **microscopic** characteristics of *D. jueirana-facao* are in agreement with many species of other genus of Caesalpinioideae such as vessel typically medium-sized, parenchyma predominantly aliform (e.g., *Caesalpinia* L., *Copaifera* L. and *Hymenaea* L.) and homogeneous ray cells procumbent (e.g., *Caesalpinia* L., *Erythrophleum* Afzel. ex R.Br., *Gleditsia* L. and *Schizolobium* Vogel) (Metcalfe and Chalk 1950; Mainieri et al. 1983; Alves and Angyalossy-Alfonso 2000; InsideWood-onwards 2004; dos Santos et al. 2019). Chambered crystals also were not observed in species of the genus *Erythrophleum* Afzel. ex R.Br., *Gleditsia* L., *Peltophorum* (Vogel) Benth. and *Schizolobium* Vogel (Metcalfe and Chalk 1950), but rare crystals in crystalliferous cells were observed in *D. excelsa* (Mainieri et al. 1983). In relation to *D. excelsa*, the size and shape of the vessels are similar, being circular to oval, of medium to large size, diffusely distributed in a low frequency, with simple perforation plates and vestured pits (Mainieri et al. 1983; Ferreira et al. 2004; InsideWood-onwards 2004). As in *D. excelsa*, vessels obstructed by gums and other deposits also occur in *D. jueirana-facao* (Mainieri et al. 1983; Ferreira et al. 2004; InsideWood-onwards 2004). The qualitative and quantitative characteristics for axial parenchyma and rays are also similar for both species, except that we did not find crystals in *D. jueirana-facao* (Ferreira et al. 2004; InsideWood-onwards 2004).

Considering the general characteristics expected for tropical forests, the wood anatomical characteristics of *D. jueirana-facao* fit those described for mesic environments (Barajas-Morales 1985; Alves and Angyalossy-Alfonso 2000; Barros et al. 2006). Trees subjected to constant water availability (mesic environments) in general have larger vessels to transport high amounts of water (Carlquist 1977, 1989; Barajas-Morales 1985). Despite the high rainfall common to tropical forests, TAF has some climatic peculiarities. From May to September (winter), there is a marked reduction in precipitation, dropping below 60 mm per month (Fig. 1c). In spite of this marked seasonality, the species maintains the wood characteristics of rainforests. Poorter et al. (2010) showed that tall trees are also characterized by wide vessels in low density to transport large amounts of water to the canopy because tall canopy species experience more severe drought stress.

According to Worbes (1995), rainfall below 60 mm monthly can trigger growth-ring formation in tropical trees. In addition to presenting this characteristic in the winter months, TAF has a strong year-to-year variation in precipitation that can vary up to 50% (Garay et al. 2003) and this climate type can experience precipitations below 25 mm monthly (Alvares et al. 2014). Phytosociological studies where *D. excelsa* has a high value of importance (VI) present the climate in these regions according to Koppen as “Am,” with annual rainfall of 1355 to 2839 mm (da Silva et al. 2008; Dionisio et al. 2016). In this climate type, the driest months present monthly precipitation above 25 mm (considering Alvares et al. 2014). This may be the reason why growth rings are well defined in *D. jueirana-facao* and less conspicuous in *D. excelsa* (Mainieri et al. 1983; Ferreira et al. 2004; InsideWood-onwards 2004; Chipaia et al. 2015).

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Author contribution CF conceived the presented idea, described the results and discussion, and wrote the first version of the manuscript; LSJ contributed to sample preparation and description of results, prepared the plate and supervised CAS in the measurements of anatomical structures; JMO contributed to sample collection and manuscript review; PCB contributed to manuscript review; MTF gave final approval of the final version.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflicts of interest.

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