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Cambial patterns of *Paullinia* (Sapindaceae) in southwestern Amazonia, Brazil

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ABSTRACT

Paullinia comprises 220 species. In Brazil, there are 99 species of the genus distributed mainly in Amazonian forest and the Atlantic Forest, where there are 73 and 26 species, respectively. Until now, the stem anatomy of only 13 species of *Paullinia* has been investigated. Given the importance of information on cambial variants to the taxonomy of Sapindaceae, studies on the stem anatomy of species in the family are very relevant. The present study described the stem diversity of ten species of *Paullinia*, which were collected in areas difficult to access in Amazonian forest, in the state of Acre. Micro- and macroscopic analyses were carried out. Two types of cambial variants were identified: lobed stem and xylem interrupted by phloem wedges. The latter type was recorded for the first time in the genus. The anatomical study recorded different traits that might be useful for distinguishing taxa, including morphologically similar species, such as *P. bracteosa* and *P. imberbes* and *P. fimbriata* and *P. rugosa*. We believe that the results enrich the taxonomic descriptions of the analyzed species and will provide data for future evolutionary studies of the group.

1. Introduction

The cosmopolitan family Sapindaceae comprises about 1751 species grouped in 138 genera (The Plant List, 2016). Its major center of distribution is in tropical and subtropical areas, with only a few genera in temperate zones (Buerki et al., 2009; Acevedo-Rodríguez et al., 2010). Representatives of the family present several types of growth forms, i.e., trees, shrubs, vines and lianas (Acevedo-Rodríguez et al., 2011). Tribe Paullinieae contains all the lianas in the family, and is composed of 6 genera, *Cardiospermun* L., *Lophostigma* Radlk., *Paullinia* L., *Serjania* Mill., *Thinouia* Triana & Planch., and *Urvillea* Kunth. (Acevedo-Rodríguez et al., 2017).

Paullinia and *Serjania* are the largest and have numerous species with some type of variation in wood anatomy (Acevedo-Rodríguez, 1993). Among the known cambial variants, those that have already been documented for the group are the following: lobed vascular cylinder, compound vascular cylinder, divided vascular cylinder, corded vascular cylinder, fissured vascular cylinder, successive cambia and phloem wedges (Schenck, 1893; Pfeiffer, 1926; Obaton, 1960; Carlquist, 1991; Tamaio, 2011; Bastos et al., 2016; Cunha Neto et al., 2018).

Paullinia L. comprises 220 species with a Neotropical distribution, except for *P. pinnata* L. that occurs also in Africa and Madagascar (Croat, 1976; Medeiros et al., 2016; Radlkofer, 1931; Somner, 2001). Its center of diversity is in western Amazonia, where there are 73 described species (Acevedo-Rodríguez, 1993; Somner et al., 2015).

The state of Acre is in southwestern Amazonia, Brazil, and is about 164,840 km^2, which corresponds to 4% of the total area of the Amazon forest (ZEE-Acre, 2006). It is considered the center of genetic diversity of *Paullinia*, with 45 species, which corresponds to 44% of the species in the genus in Brazil (Somner et al., 2015; Medeiros et al., 2016).

Besides the ecological importance of *Paullinia* species in Amazonian forest, it is estimated that 39 of these species are used for ethnobotanical and industrial purposes, such as *P. cupana* Kunth, which is popularly known as guaraná (Acevedo-Rodríguez, 1990; Medeiros et al., 2016).

Paullinia species are woody vines (or rarely shrubs) that may or may not present some type of cambial variant (Medeiros et al., 2016). Cambial variants can form different anatomical patterns that are useful sources of information for distinguishing taxa (Radlkofer, 1875; Metcalfe and Chalk, 1983; Schenck, 1893). Specifically, for *Paullinia* the cambial variants in the wood of some species have already been observed and described: simple cylinder in *P. anodonta* Radlk., *P. bracteosa* Radlk., *P. globosa* Killip & Cuatrec., *P. latifolia* Benth. ex Radlk., *P. rufescens* Rich. ex Juss., and *P. carpopodea* Cambess. (Klaassen, 1999; Bastos et al., 2016); lobed vascular cylinder in *P. marginata* Casar.

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Table 1
List of *Paullinia* species analyzed and records in RBw – Wood collection of the Rio de Janeiro Botanical Garden Herbarium; RB – Rio de Janeiro Botanical Garden Herbarium; LABEV - Laboratório de Botânica e Ecologia Vegetal da Universidade Federal do Acre.

Species	RBw	Voucher	Collection Sites (city; site)
Paullinia boliviana Radlk.	10265	RB 588885	Marechal Thaumaturgo; Bacia do Rio Juruá. Rio Tejo. Reserva Extrativista do Alto Juruá.
Paullinia bracteosa Radlk.	10261	RB 588915	Marechal Thaumaturgo; Bacia do Rio Juruá. Rio Tejo. Reserva Extrativista do Alto Juruá
Paullinia echinata J. Huber	10264	RB 588893	Marechal Thaumaturgo; Bacia do Rio Juruá. Rio Tejo. Reserva Extrativista do Alto Juruá.
Paullinia fimbriata Radlk.	10263	RB 588948	arechal Thaumaturgo; Bacia do Rio Juruá. Rio Arara. Reserva Extrativista do Alto Juruá.
Paullinia globosa Killip & Cuatrec.	10267	RB 575586	Porto Acre; Reserva Florestal Humaíta.
	10270	RB 575580	Porto Acre; Reserva Florestal Humaíta.
Paullinia imberbis Radlk.	10269	RB 588925	Porto Walter; Bacia do Rio Juruá, Rio das Minas.
Paullinia ingifolia Rich. ex Juss.	10285	LABEV 4841	Xapuri; Projeto de Assentamento Cachoeira, BR 317.
	10266	RB 588952	Marechal Thaumaturgo; Bacia do Rio Juruá. Rio Rejo. Reserva Extrativista do Alto Juruá.
Paullinia itayensis J.F. Marcb.	10262	RB 593480	Porto Walter; Bacia do Rio Juruá. Rio das Minas.
Paullinia obovata (Ruiz & Pav.) Pers.	10271	RB 575357	Porto Acre; Reserva Florestal Humaitá.
	10286	LABEV 5066	Marechal Thaumaturgo; Bacia do Rio Juruá. Rio Tejo. Reserva Extrativista do Alto Juruá.
Paullinia rugosa Benth. ex Radlk.	10268	RB 577810	Sena Madureira; Floresta Estadual do Antymari, Ramal do Uirapuru.

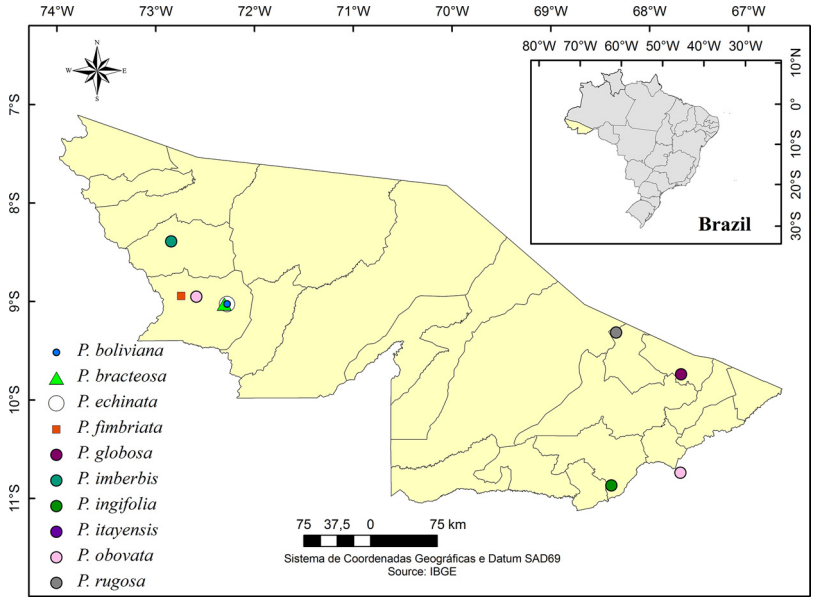

Fig. 1. Map of Acre State (Brazil) with distribution of collection points for each species.
Adapted from: ZEE-Acre (2006).

(Bastos et al., 2016); compound vascular cylinder in *P. pinnata* L. (Obaton, 1960; Van der Walt et al., 1973); and successive cambia in *P. micranta* Cambess, *P. pseudota* Radlk., *P. racemosa* Wawra and *P. trigonia* Vell, and *P. weinmanniifolia* Mart. (Bastos et al., 2016; Cunha Neto et al., 2018). Among these species, only *P. bracteosa* and *P. globosa* are found in Amazonian forest.

Species of *Paullinia* in southwestern Amazonian forest, in Brazil, have similar non-reproductive and/or reproductive features that make them difficult to delimit (Medeiros et al., 2016). This can be seen in herbarium collections, especially for species from Amazonian forest where collections have only been made along a few waterways and roads (Hopkins, 2007; Medeiros et al., 2016).

Considering the abovementioned information, this work aimed to describe the wood anatomy and document the cambial variations of 10 *Paullinia* species from southwestern Amazonian forest, in Brazil, in order to provide useful anatomical characteristics for segregating species.

2. Materials and methods

2.1. Stem material

All material was collected in the state of Acre, Brazil (Table 1), by the specialist in *Paullinia* and one of coathors of this paper (H. M.), from 2012 to 2014 during the development of his dissertation; collection sites are shown in Fig. 1. Due to difficulties in the field, such as knowledge and access to material, especially in the Amazon region where there are very few roads and plant collecting is limited to waterways, a minimum stem diameter was not established for collections. Stem diameters varied from 12 mm to 39.5 mm and all material was dried in the open air.

All sampled individuals were deposited at the Rio de Janeiro Botanical Garden Herbarium (RB), its wood collection (RBw, Table 1), and the Laboratório de Botânica e Ecologia Vegetal Universidade Federal do Acre. (LABEV, UFAC).

2.2. Macroscopic analysis

Samples were polished using sandpaper with increasing granulometry (100–1200) (Antonio C.F. Barbosa, personal communication). To determine the presence and type of cambial variant, the entire area of the sample was analyzed with the naked eye and a hand lens. Photographs were taken using a DSLR T3i camera with a 200 mm zoom lens and an Olympus SZ61 stereomicroscope attached to an Olympus SC30 camera.