BRAZILIAN CERRADO SPECIES: WOOD CHARACTERISTICS

ESPÉCIES DO CERRADO BRASILEIRO: CARACTERÍSTICAS DA MADEIRA

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ABSTRACT: The characterization of wood anatomy and proprieties can provide subsidies for rational use of tree species. Enables, oftentimes, the definition of technological potential of wood - and wood products - through the assessment of quality information and also allows it´s correct identification, contributing to the timber production chain. The objective of this study was to contribute to the knowledge about wood properties of the Cerrado biome (Brazilian savanna) species trough the anatomical characterization and determination of density profile. Twenty trees species belonging to thirteen families occurring in Pirenópolis, Goiás and Brasília, Federal District, Brazil, was selected and radial samples were removed from the tree trunks at the DBH (1.30 m) in a non-destructive way using an incremental probe and a motorized extractor. The qualitative and quantitative anatomical parameters of vessels and fibers and the wood density were determined in the collected samples. Species presented fibers with mean values between 900.5 and 2052.9 µm for the length; 18.1 and 27.7 µm for the diameter; and 4.4 to 9.4 µm for the wall thickness. The species presented a variation in the vessel dimensions from 29.2 to 155.6 µm for the diameter; 17.7 to 32.5% for occupied area; and 2.6 to 165 to vessels.mm^{-2}. The apparent density presented mean values between 0.36 and 1.21 g cm^{-3}. The specie that presented the highest variation of wood density was *A. fraxinifolium*. According to the radial profiles two patterns of increasing and stable variation in the apparent density of the pith to bark were defined as a function of the wood anatomical characteristics.

KEYWORDS: Wood quality. Brazilian savanna. Sustainable use.

INTRODUCTION

With an area of approximately 2 million km² (24% of the Brazilian territory), the Cerrado is the second largest biome of the Brazil, it occupies the central part of the country (BRASIL, 2007), and it has about 30 million in habitants or 16% of the country's population (SERVIÇO FLORESTAL BRASILEIRO, 2010).

The Brazilian Cerrado is considered the richest savannah in the world with 11,627 species of catalogued native plants (BRASIL, 2007). Over the years there has been a shortage of studies on wood from species in the Cerrado from the anatomical and technological perspectives. Recent studies such as by Sonsin et al. (2014) and Costa et al. (2014) have demonstrated the importance of studying the Cerrado species, mainly the relation between the anatomical and physical characteristics to define the wood quality of these species. Despite the related studies, there is still little information about the wood quality of many native species of this biome.

Two of the main parameters for studies related to wood and which helps in analyzing the results and in the correct destination of the wood according to its use are the anatomical characteristics and the density (MEDEIROS NETO, 2012). The characterization of wood is an important tool to understand the relationship between the influence of the environmental conditions and the stage of development of trees on the structure of the wood, as well how these factors associated to the wood properties can help in the rational use of the species and to provide subsidies for future studies and the management of the natural resources. Thus, the objective of this study was to contribute to the knowledge about wood properties of the Cerrado biome (Brazilian savanna) species trough the anatomical characterization and determination of density profile.

MATERIALAND METHODS

Characterization of study areas

The study took place in two Cerrado areas located near the Parque Estadual dos Pireneus in Pirenópolis, Goiás, and in the Botanical Gardens in Brasilia (Jardim Botânico de Brasília) Federal

http://dx.doi.org/10.14393/BJ-v36n4a2020-48044
Received: 08/04/19
Accepted: 20/12/19

District, Brazil. According to the Köppen classification, the climate of the region is Aw with two well defined seasons (dry winter and wet summer), with average, maximum and minimum annual temperatures of 20.4, 28.5 and 12.0 ºC, respectively, and average annual precipitation of 1,500 mm concentrated in the months of October to March. A map with the points of areas can be seen at:https://drive.google.com/open?id=12JttLahqnAZbpIMRy0KHqkhEtcCEhk-P.

Selected forest species

Native trees of 20 generalists species (RATTER et al., 2003) belonging to 13 families were selected from the two areas (Pirenópolis and Brasilia). The species are: *Astronium fraxinifolium* Schott and *Tapirira guianensis* Aubl. (Anacardiaceae); *Aspidosperma tomentosum* Mart. (Apocynaceae); *Handroanthus aureus* (Silva Manso) Benth. & Hook. f. Ex S. Moore (Bignoniaceae), *Caryocar brasiliense* Cambess. (Caryocaraceae), *Kielmeyera coriacea* Mart. & Zucc. (Calophyllaceae), *Bowdichia virgilioides* Kunth, *Copaifera langsdorffii* Desf., *Hymenaea stigonocarpa* Mart. Ex Hayne, *Plathymenia reticulata* Benth., *Tachigali subvelutina* Benth. Oliveira-Filho and *Tachigali vulgaris* L.F. Gomes da Silva & H.C. Lima (Fabaceae); *Byrsonima verbascifolia* (L.) D.C. (Malpighiaceae); *Eriotheca pubescens* (Mart. & Zucc.) Schott & Endl. (Malvaceae); *Blepharocalyx salicifolius* (Kunth) O. Berg. and *Pouteria ramiflora* (Mart.) Radlk. (Sapotaceae); *Simarouba versicolor* A. St.- Hil. (Simarobaceae); *Qualea grandiflora* Mart.,*Qualea parviflora* Mart. and *Vochysia thyrsoidea* Pohl (Vochysiaceae).

Collection and preparation of wood samples

The wood samples were collected at breast height (1.30 m) from the trunk of three trees of each selected species (twenty species x three trees: sixty trees sampled) by a non-destructive method (an incremental probe and metal probe coupled to a motorized extractor). Two wood samples were selected per tree, totaling 120 samples: one was used to determination of anatomical characteristics and another for wood density.

The holes in the tree trunks were capped with wooden pegs previously treated with a fungicide solution. The wood samples were conditioned on wood supports and were kept immersed in water in the laboratory to avoid cracking and drying defects prior to the anatomical structure evaluation and microdensity analyses by X-ray densitometry.

Wood anatomical characteristics

Specimens were demarcated and cut from the wood samples (1.0 x 1.0 x 1.0 cm) in 3 radial positions (0, 50 and 100%), then sectioned with a steel knife in a sliding microtome. Cross sections (15-20 µm thick) were clarified (sodium hypochlorite 1:1), washed (distilled water, acetic acid 1%), dehydrated (alcohol series 30-100%), washed (xylol) and mounted in histological slides (under coverslip, Canada's balm). Anatomical observations were taken under light microscopy (40x) and the anatomical characterization was made following IAWA COMMITTEE (IAWA COMMITTEE, 1989). The growth rings in the wood were typified as: (i) distinct; (ii) a poorly defined; and (iii) indistinct or absent (without delimitation), considering the characteristics of the axial and marginal parenchyma, vessels and fibers (TOMAZELLO FILHO et al., 2004). Wood fragments taken from the 3 radial positions were cut, transferred to test tubes and dissociated (40°C, 24 h) using Franklin method (Johansen, 1940) and mounted in semi-permanent slides for fiber dimensions measurements (fiber length 40x; fiber diameter and wall thickness 400x) following IAWA COMITTEE standards (IAWA COMMITTEE, 1989).

Wood density by x-ray densitometry

The diametrical samples of tree trunks were glued on wooden supports and sectioned crosswise (2.0 mm thick) in a parallel double circular sawing machine. The wood sections were conditioned (12 h, 20°C, 50% RH) and then fixed onto a metal support, inserted into the QTRS-01X equipment and had their cross-section scanned radially under collimated x-ray bundles, obtaining microdensity values of the wood at a distance of 40 µm. The microdensity radial profiles were related to its anatomical structure, with an emphasis on delimiting the growth rings and potential application in dendrochronology, as well as characterizing the wood quality.

RESULTS AND DICUSSION

Wood anatomical characteristics

There are marked differences between the trees of the 20 analyzed species in relation to the wood anatomical structure (Table 1; Figures 1, 2, 3 and 4).

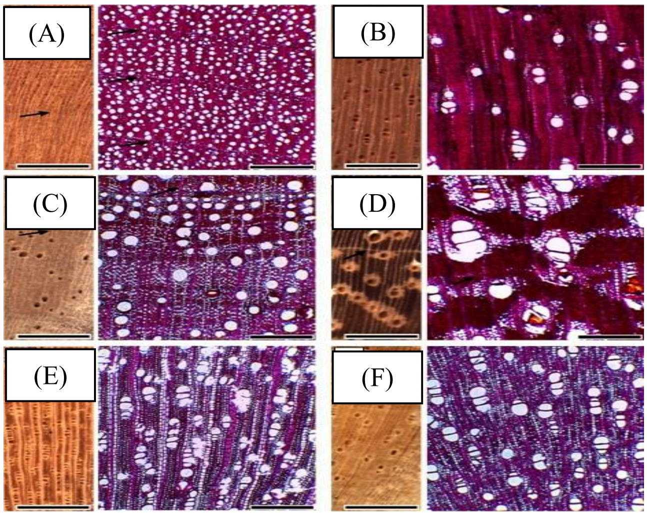

Figure 1. Transverse section macro (bar = 1mm; magnification: 10 x) and microscopic (bar = 500 µm; magnification: 40 x) of the wood: (A) *Aspidospermatomentosum*; (B) *Astroniumfraxinifolium*; (C) *Blepharocalyxsalicifolius*; (D) *Bowdichiavirgilioides;* (E) *Byrsonimaverbascifolia;* (F) *Caryocar brasiliense*.

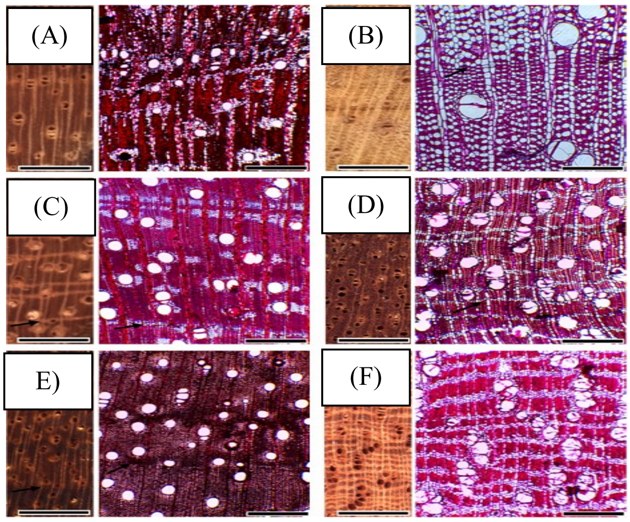

Figure 2. Transverse section macro (bar = 1mm; magnification: 10 x) and microscopic (bar = 500 µm; magnification: 40 x) of the wood: (A) *Copaifera langsdorffii*; (B) *Eriotheca pubescens*; (C) *Hymenaea stigonocarpa*; (D) *Kielmeyera coriacea*; (E) *Plathymenia reticulata;* (F)*Pouteria ramiflora*.

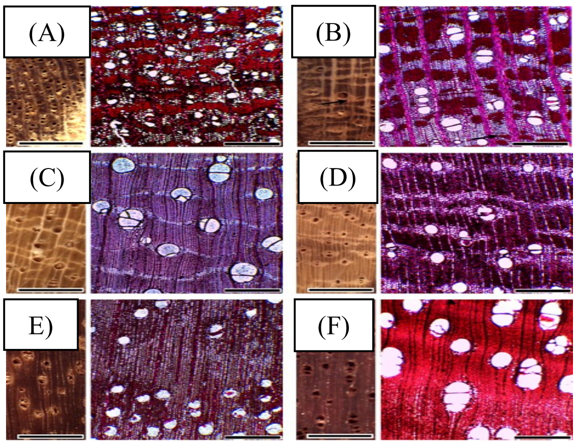

Figure 3. Transverse section macro (bar = 1mm; magnification: 10 x) and microscopic (bar = 500 µm; magnification: 40 x) of the wood: (A) *Qualea grandiflora*; (B) *Qualea parviflora*; (C) *Simarouba versicolor;* (D) *Tabebuia aurea;* (E) *Tachigali subvelutina; (F) Tachigali vulgaris*.

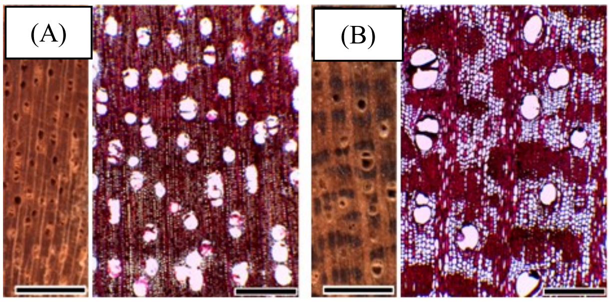

Figure 4. Transverse section macro (bar = 1mm; magnification: 10 x) and microscopic (bar = 500 µm; magnification: 40 x) of the wood: (A) *Tapirira guianensis;*(B)*Vochysia thyrsoidea*.

The presence of growth rings was observed in 10 of the 20 studied species (50%); a percentage similar to that found by Marcati et al. (2001) (61%) in the study of the wood anatomy of 48 representative species of the Cerrado in São Paulo State, Brazil. There was a predominance of diffuse-porous wood (95% of the species), a characteristic commonly found in arboreal species occurring in the Atlantic Forest (BARROS et al., 2006), in the Semi-deciduous Seasonal Forest (LISI et al., 2008), in the Cerrado (SONSIN et al., 2014) and in the Mixed Ombrophilous Forest (SOFFIATTI et al., 2016).

At the boundary portion of the growth layer (latewood), the following anatomical patterns were identified: (i) thickening of the fibers' cell wall; (ii) presence of a continuous marginal parenchyma band; and (iii) variation on vessel diameter occurring, in some cases, in association as observed in *A. tomentosum, B. salicifolius*, *B. virgilioides* and *C. langsdorffii* (Table 1). Determining patterns such as those presented is of great importance for tropical dendrochronology and also for studies of wood quality. Future research proving the annual frequency of forming the wood layers in these species will enable their application in dendrochronological studies such as climate reconstruction, ecology, and forest management, among others.

The periodic activity of the vascular cambium results in forming wood with distinct characteristics: the initial or springwood formed at the beginning of the vegetative period composed of cells with thinner walls and larger lumens, which is consequently less dense, and the late or autumnal wood formed at the end of the vegetative period with anatomical elements of thicker walls and smaller lumens, and therefore more dense (SCHMITT et al.; 2016). Regarding quality, the proportion of early and latewood conditioned mainly by the age of the tree and its growth rate is directly associated with its physical-mechanical performance (VIDAURRE et al., 2011) as juvenile and mature wood and also heartwood and sapwood proportions (PLOMION et al., 2001; CHERELLI et al., 2018).

In the same way, the wood porosity is associated with its permeability, which influences factors such as the preservative treatment (CHAGAS et al., 2015) and the mobility of adhesives inside the wood (LATORRACA; ALBUQUERQUE, 2000), in addition to being considered an inversely correlated property with the density.

Table 1. Tree-ring anatomical characteristics, axial parenchyma and vessels of the studied species.

Specie	Growth rings		Axial parenchyma	Vessels		Figure
	Distinction	Ring boundary structure		Size	Porosity	
A. tomentosum	Distinct	FW, CMP	Absent or extremely rare	Small	Diffuse-porous	2[a]
A. fraxinifolium	Indistinct or absent	-	Absent or extremely rare	Small	Diffuse-porous	2B
B. salicifolius	Distinct	FW, VD	Diffuse and vasicentric	Small to medium	Diffuse-porous	2C
B. virgilioides	Poorly defined	FW, CMP	Lozenge-aliform eventually forming confluence	Medium	Diffuse-porous	2D
B. verbascifolia	Indistinct or absent	-	Absent or extremely rare	Small	Diffuse-porous	2E
C. brasiliense	Indistinct or absent	-	Diffuse sparse	Medium	Diffuse-porous	2F
C. langsdorffii	Distinct	CMP, VD	Marginal and vasicentric scarce	Medium	Semi-ring-porous	3[a]
E. pubescens	Distinct	FW	Diffuse in aggregates	Large	Diffuse-porous	3B
H. stigonocarpa	Distinct	CMP	Marginal bands interspersed by zones of aliform or vasicentric parenchym	Medium	Diffuse-porous	3C
K. coriacea	Poorly defined	FW	Lines or band	Smalltomedium	Diffuse-porous	3D
P. reticulata	Poorly defined	FW	Vasicentric	Medium	Diffuse-porous	3E
P. ramiflora	Indistinct or absent	-	Lines or bands	Small	Diffuse-porous	3F
Q. grandiflora	Indistinct or absent	-	Indistinct or vasicentric	Small	Diffuse-porous	4A
			Lozenge - aliform or			

Q. parviflora	Poorly defined	FZ	confluent in long stretches tending to form bands	Medium	Diffuse-porous	4B
S. versicolor	Indistinct or absent	-	Linear aliform forming confluences in long stretches	Medium	Diffuse-porous	4C
T. aurea	Poorly defined	CMP	Lozenge - aliform forming confluences in short and long stretches	Medium	Diffuse-porous	4D
T. subvelutina	Indistinct or absent	-	Absent or extremely rare	Mediumtolarge	Diffuse-porous	4E
T. vulgaris	Indistinct or absent	-	Absent or extremely rare	Smalltomedium	Diffuse-porous	4F
T. guianensis	Indistinct or absent	-	Absent or extremely rare	Smalltomedium	Diffuse-porous	5A
V. thyrsoidea	Indistinct or absent	-	Confluent in long stretches tending to form bands	Medium	Diffuse-porous	5B

FW: changes in fiber wall thickness or fiber radial size; CMP: continuous marginal parenchyma; DMP: discontinuous marginal parenchyma; VD: changes em vessel diameter; FZ: fiber zone.

Dimension of fibers and vessels

According to the results, the fibers of the species presented variations from 900.5 (*T. subvelutina*) to 2052.9 µm (*E. pubescens*) for length; from 18.1 (*A. dasycarpum*) to 27.7 µm (*B. verbascifolia*) for diameter; and from 4.4 (*S. versicolor*, *T. subvelutina* and *T. guianensis*) to 9.4 µm (*A. fraxinifolium*) for wall thickness (Table 2).

Table 2. Dimensions of fibers and vessels of species. Average values followed by standard deviation. L- length; D - diameter; WT - Wall thickness; A – occupied area; F- frequency.

Specie	Fibers			Vessels		
	L (µm)	D (µm)	WT (µm)	D (µm)	A (%)	F (nº mm^{-2})
A. dasycarpum	1167.5 (152.3)	18.1 (3.3)	6.1 (1.7)	78.9 (20.5)	25.1 (9.7)	16.0 (4.5)
A. tomentosum	1083.2 (146.1)	18.5 (2.4)	5.9 (1.0)	29.2 (11.8)	32.5 (12.8)	165.0 (12.9)
A. fraxinifolium	1022.4 (215.9)	25.5 (2.4)	9.4 (1.9)	77.3 (26.1)	17.7 (5.3)	7.9 (1.4)
B. salicifolius	1130.2 (212.9)	20.5 (3.5)	6.8 (1.9)	95.9 (5.0)	21.1 (11.7)	4.8 (1.5)
B. verbascifolia	1379.5 (220.4)	27.7 (3.9)	7.4 (1.3)	103.5 (12.7)	26.2 (7.5)	26.3 (8.6)
C. brasiliense	1988.0 (354.7)	21.5 (4.6)	7.9 (2.2)	106.6 (16.2)	22.5 (8.0)	7.2 (1.2)
C. langsdorffii	1098.7 (247.5)	25.6 (3.0)	8.7 (2.1)	96.2 (9.7)	20.2 (7.0)	5.5 (1.5)
E. pubescens	2052.9 (334.8)	26.5 (5.0)	9.2 (2.3)	95.8 (7.9)	21.3 (3.6)	2.6 (0.7)
H. stigonocarpa	1063.1 (160.5)	25.2 (2.6)	9.2 (1.6)	99.3 (5.0)	21.2 (5.5)	5.0 (1.8)
K. coriacea	1620.6 (138.6)	21.5 (5.1)	5.8 (2.5)	107.7 (17.5)	28.7 (6.0)	14.4 (2.8)
P. reticulata	963.9 (165.9)	21.5 (4.1)	5.6 (1.6)	90.6 (20.7)	20.4(5.6)	9.2 (2.2)
P. ramiflora	1008.1 (155.5)	18.7 (2.9)	6.3 (1.1)	79.8 (43.1)	30.4 (10.2)	10.7 (4.4)
Q. grandiflora	1140.2 (137.5)	20.0 (5.5)	8.0 (2.7)	72.7 (7.9)	26.7 (14.0)	14.1 (4.1)
Q. parviflora	1072.6 (199.0)	18.5 (3.3)	7.3 (1.2)	110.0 (34.5)	18.0 (8.5)	6.9 (2.1)
S. versicolor	1013.2 (141.5)	20.8 (3.1)	4.4 (0.8)	139.4 (21.1)	30.9 (6.6)	6.6 (3.6)
T. aurea	1018.4 (297.7)	18.4 (3.7)	5.7 (1.3)	120.4 (27.8)	28.5 (2.2)	6.5 (1.3)
T. subvelutina	900.5 (145.0)	20.9 (3.1)	4.4 (0.7)	147.5 (33.6)	31.7 (8.2)	6.2 (2.0)
T. vulgaris	901.1 (170.5)	18.4 (5.4)	5.7 (2.7)	100.3 (13.5)	29.3 (8.2)	6.1 (1.1)
T. guianensis	1066.0 (207.3)	25.0 (4.2)	4.4 (1.3)	107.6 (16.5)	24.6 (6.9)	12.9 (2.6)
V. thyrsoidea	1203.5 (295.9)	21.8 (4.9)	6.7 (3.0)	155.6 (47.9)	24.0 (5.2)	5.4 (3.7)

Based on the results, the species presented a variation in the vessel dimensions from: 29.2 (*A. tomentosum*) to 155.6 µm (*V. thyrsoidea*) for diameter; 17.7 (*A. fraxinifolium*) to 32.5% (*A. tomentosum*)of occupied area; and from 2.6 (*E. pubescens*) to 165.0 vessels/mm^2(*A. tomentosum*) (Table 2).

In their studies on ecological anatomy of *Blepharocalyx salicifolius* wood in Campos de Cima da Serra, Rio Grande do Sul, Brazil, Denardi; Marchiori (2005) found the following values for the fiber dimensions: 1026 µm for the length; 16.5 µm for the diameter; and 3.4 µm for the wall thickness. The remarkable differences found in the present study (1130.2 for the length; 20.5 µm for the diameter; and 6.8 µm for the wall thickness) can be justified by the sampling environments of the species, since the same author points out that the wood's anatomy may undergo changes as a result of the environment where the plant lives. The average fiber length value of *Caryocar brasiliense* found by Voigt et al. (2010) was 2085.05 µm in the Cerrado environment. According to the results by Melo Júnior et al. (2011) in their study on the ecological anatomy of *Copaifera langsdorffii* wood of the South Brazilian Cerrado, the fiber dimensions were 1095 µm for length, 22 µm for diameter and 9 µm for wall thickness; similar to the values found in the present study.

Larger vessel diameter associated with lower frequency per mm² is observed in *Q. grandiflora* (diameter of 72.7 µm and a frequency of 14.1 vessels mm^{-2}) and in *V. thyrsoidea* (diameter of 155.6 µm and a frequency of 5.4 vessels mm^{-2}). In the results by Melo Júnior et al. (2011) on the ecological anatomy of *Copaifera langsdorffii* wood of the South Brazilian Cerrado, the average vessel diameter was 89 µm and its average frequency was 8 vessels mm^{-2}, thus presenting similarity to the results found in this work. The specie *A. tomentosum* had a high average value for vessel diameter when compared to the other species. However, a similar value was described by Sonsin et al. (2012), which found a frequency of 154 vessels mm^{-2} for the same specie. The results found by Denardi; Marchiori (2005) in their studies about ecological anatomy of *Blepharocalyx salicifolius* in Campos de Cima da Serra, Rio Grande do Sul, Brazil, were 98.8 vessels mm^{-2} and 42.2 µm for vessel diameter, while in the present work it was found 4.8 vessels mm^{-2} and 95.9 2 µm for vessel diameter. The different results could be explained by the sampling environments and by the methodology used to collect them. In the study by Voigt et al. (2010), the average results of the vessel dimensions in *Caryocar brasiliense* in Santa Rita do Passa Quatro, São Paulo State, Brazil, were 144.52 µm for diameter; 6.84 vessels mm^{-2} for frequency; and 12% of occupied area. The differences found in the results may be explained by the methodology adopted in the sample collection by Voigt et al. (2010), where the specimens were only obtained from the outermost portion of the trunk.

The radial variation in the anatomical parameters of the wood fibers and vessels in the Cerrado species is presented in Tables 3 and 4. We can observe that the species have a general radial variation model for the fiber length, thereby indicating an increasing tendency in the pith-bark direction, as found by Nisgoski et al. (2012) in native species.

According to Tomazello Filho (1999), the increase in fiber length is related to the tree's age due to the increase of the fusiform initial cells until they reach stabilization and begin to form adult wood. The adult wood presents a physiologically mature cambium and is in the outermost part of the trunk with higher fiber length and density values, and juvenile wood is that which forms around the pith with larger growth rings formed during the initial period of the plant.

The fiber wall thickness demonstrates a common variation model between the studied species, indicating an increase in the pith-bark direction. This corroborates the model found by Lobão et al. (2012) for native species. According to Tomazello Filho (2004), the cell wall thickness has a strong influence on wood density; the density tends to increase as a function of the tree's age because of the increased cell wall thickness.

The diameter variables of the fibers did not present common radial variation models among the species according to the radial position. Some species increased fiber diameter, while others showed a decreased pith-bark direction value. This is due to the specificity of each species.

According to Longui et al. (2012), there are species that present an increase and some decrease in both the size and the frequency of cells in the pith-bark direction, and in some cases present almost no variation. Roque; Tomazello Filho (2009) found an increase in the radial variation of these variables for *Gmelina arborea* in the pith-bark direction, whereas Lobão et al. (2012) observed reduced fiber diameter in the pith-bark direction for *Schizolobium parahyba* var. *amazonicum*.

In this study, the *Plathymenia reticulata* specie presented similar values to those observed by Longui et al. (2012) for the region near the pith and bark, with a reduction in the value between the two positions.

The *A. tomentosum* specie presented 165 vessels mm^{-2}, higher than the values for other species, but similar to that found in the literature. A similar value was also described by Sonsin et al. (2014) who found a frequency of 154 vessels/mm² for this same species.

According to the results we can see that all the vessel parameters presented a common radial variation model between the species. Regarding the vessel frequency, the species showed a tendency to decrease the values in the pith-bark direction. Some authors reported a significant variation between the radial positions for vessel frequency with a reduction in the pith-bark direction: Chagas et al. (2007) for *Eremanthus erythropappus*; Ishiguri et al. (2009) for *Paraserianthes falcatari*; Roque; Tomazello Filho (2009) for *Gmelina arborea*; Lima et al. (2011) for *Cariniana legalis*; and Longui et al. (2012) for *Plathymenia reticulata*. Lima et al. (2010) found no significant difference in the radial variation of vessel frequency in *Croton floribundus* wood. According to Rao et al. (1997), this variable is related to wood density, and woods with low vessel frequency present high density.

The values of the vessel diameter indicated an increase in the pith-bark direction. This tendency was also verified by Dünisch et al. (2004), Chagas et al. (2007), Roque and Tomazello Filho (2009) and Melo et al. (2013). Carlquist (1989) reports that the increase in vessel diameter in the radial direction (pith-bark) as a function of the tree'sage can be considered an anatomical adaptation of the xylem to increase the sap volume, and to consequently increase its photosynthetic capacity.

Likewise, the percentage of occupied area by vessels showed a tendency to increase in the pith-bark direction, as reported by Chagas et al. (2007), Roque; Tomazello Filho (2009) and Lobão et al. (2012). The increase in both occupied area by vessels and vessel diameter is due to the increased sap flow activity in the sapwood in relation to the heartwood.

Table 3. Length, diameter and wall thickness of the fibers by radial position in the wood.

Specie	Fibers											
	L (µm)			T	D (µm)			T	WT (µm)			T
	RP (%)				RP (%)				RP (%)			
	0	50	100		0	50	100		0	50	100	
A. dasycarpum	1137	1176	1190		17.8	17.5	19.0		4.7	6.7	7.0	
A. tomentosum	1055	1086	1108		19.0	17.7	18.6		5.4	6.2	6.1	
A. fraxinifolium	984	1049	1034		25.1	25.5	25.9		8.6	9.4	10.2	
B. salicifolius	1001	1193	1198		19.4	20.7	21.5		6.6	6.9	7.0	
B. verbascifolia	1315	1372	1452		27.8	28.2	27.2		6.9	7.5	7.9	
C. brasiliense	1832	2048	2084		20.2	21.8	22.4		7.5	8.0	8.2	
C. langsdorffii	961	1156	1179		25.6	25.5	25.9		8.1	8.9	9.1	
E. pubescens	1913	2099	2123		24.7	25.4	29.3		7.9	9.4	10.3	
H. stigonocarpa	1044	1042	1112		25.3	25.9	24.5		8.8	9.3	9.6	
K. coriacea	1548	1686	1628		20.8	21.4	22.2		8.9	8.5	9.6	
P. reticulata	942	948	1001		20.4	20.9	23.1		4.9	5.6	6.1	
P. ramiflora	963	1012	1049		18.5	17.9	19.8		6.1	6.3	6.6	
Q. grandiflora	1054	1152	1215		17.8	21.8	20.2		6.8	8.5	8.6	
Q. parviflora	1027	1072	1117		18.0	18.0	19.5		7.2	7.2	7.6	

S. versicolor	941	1028	1071		20.4	19.6	22.5		4.4	4.2	4.6	
T. aurea	838	812	1045		16.6	20.8	17.5		4.9	5.4	7.3	
T. subvelutina	838	915	948		21.2	21.0	20.6		4.4	4.2	4.8	
T. vulgaris	850	877	975		17.2	17.7	20.5		5.0	5.7	6.5	
T. guianensis	1067	1029	1101		25.7	24.7	24.7		4.1	4.4	4.6	
V. thyrsoidea	1004	1278	1329		21.4	20.9	22.9		5.7	6.9	7.7	

L:length; D: diameter; WT: wall thickness; RP: radial position; T: tendency.

Table 4. Diameter, occupied area and frequency of the vessels by radial position in the wood.

Species	Vessels											
	D (µm)			T	A (%)			T	F (nº/mm²)			T
	RP (%)				RP (%)				RP (%)			
	0	50	100		0	50	100		0	50	100	
A. dasycarpum	59.6	76.8	100.5		18.8	20.1	36.3		14.2	12.7	21.1	
A. tomentosum	110.0	122.5	134.0		25.3	25.0	47.3		176.9	166.7	151.3	
A. fraxinifolium	63.6	69.1	99.1		13.8	16.4	23.0		8.8	7.9	7.1	
B. salicifolius	92.3	96.3	99.1		18.3	19.8	25.1		6.1	4.9	3.4	
B. verbascifolia	96.2	102.8	111.6		21.1	24.5	32.9		35.3	24.3	19.3	
C. brasiliense	93.3	104.2	122.4		18.3	22.3	26.9		8.3	7.1	6.1	
C. langsdorffii	92.2	96.7	99.7		15.3	16.9	28.5		7.1	5.1	4.3	
E. pubescens	92.7	95.8	98.9		18.5	22.2	23.1		3.1	2.7	2.1	
H. stigonocarpa	94.9	98.8	104.1		18.0	22.1	23.4		5.4	5.1	4.5	
K. coriacea	93.3	102.6	127.2		24.4	26.1	35.6		17.2	14.1	11.7	
P. reticulata	75.6	92.2	104.1		16.7	19.0	25.5		11.1	9.2	7.1	
P. ramiflora	57.2	64.2	117.9		24.8	26.9	39.6		14.1	10.8	7.2	
Q. grandiflora	64.8	72.7	80.7		12.6	26.8	40.7		18.3	13.7	10.1	

Q. parviflora	95.2	108.3	126.7		13.0	19.6	21.5		8.5	7.0	5.3	
S. versicolor	124.5	140.8	152.7		26.5	29.3	36.9		9.4	5.8	4.6	
T. aurea	88.6	132.5	140.0		26.5	28.1	30.8		7.7	6.7	5.0	
T. subvelutina	120.7	142.6	179.2		26.4	28.8	39.8		8.0	6.5	4.1	
T. vulgaris	88.7	99.2	112.9		20.9	30.7	36.3		6.9	6.3	5.1	
T. guianensis	92.8	102.3	127.7		17.6	24.0	32.3		15.1	13.2	10.4	
V. thyrsoidea	117.3	157	192.5		21.5	24.3	26.2		8.2	4.9	3.1	

D: diameter; A: occupied area; F: frequency; RP: radial position; T: tendency

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Wood density by x-ray densitometry

The wood apparent density presented mean values between 0.36 (*V. thyrsoidea*) and 1.21 g cm^{-3} (*A. fraxinifolium*). The specie that presented the highest variation of the value was the *A. fraxinifolium* (Table 5).

Table 5. Values of average, minimum and maximum wood apparent density of the studied species.

Specie	Apparent density (g cm^{-3})		
	Average	**Minimum**	**Maximum**
A. dasycarpum	0.75 (0.01)	0.59 (0.01)	0.94 (0.02)
A. tomentosum	0.71 (0.01)	0.56 (0.02)	0.87 (0.03)
A. fraxinifolium	0.99 (0.07)	0.72 (0.08)	1.21 (0.05)
B. salicifolius	0.79 (0.07)	0.61 (0.04)	1.06 (0.04)
B. verbascifolia	0.73 (0.04)	0.57 (0.07)	0.90 (0.05)
C. brasiliense	0.84 (0.09)	0.67 (0.10)	1.06 (0.08)
C. langsdorffii	0.84 (0.00)	0.61 (0.04)	0.98 (0.05)
E. pubescens	0.71 (0.14)	0.49 (0.18)	0.97 (0.06)
H. stigonocarpa	0.90 (0.02)	0.69 (0.05)	1.09 (0.05)
K. coriacea	0.73 (0.03)	0.49 (0.02)	0.89 (0.03)
P. reticulata	0.76 (0.03)	0.53 (0.05)	0.99 (0.00)
P. ramiflora	0.75 (0.01)	0.55 (0.01)	0.96 (0.06)
Q. grandiflora	0.86 (0.03)	0.62 (0.15)	1.07 (0.02)
Q. parviflora	0.87 (0.05)	0.56 (0.08)	1.12 (0.02)
S. versicolor	0.57 (0.02)	0.44 (0.07)	0.75 (0.04)
T. aurea	0.69 (0.03)	0.48 (0.02)	0.94 (0.02)
T. subvelutina	0.77 (0.10)	0.45 (0.04)	1.09 (0.13)
T. vulgaris	0.76 (0.07)	0.43 (0.11)	1.07 (0.04)
T. guianensis	0.64 (0.09)	0.45 (0.11)	0.85 (0.10)
V. thyrsoidea	0.63 (0.05)	0.36 (0.08)	1.14 (0.09)

Average values followed by standard deviation.

According to the radial profiles, two apparent density variation patterns of the pith to bark were defined. The species *A. dasycarpum*, *B. verbascifolia*, *C. brasiliense*, *E. pubescens*, *H. stigonocarpa*, *K. coriácea*, *P. reticulata*, *T. aurea*, *T. subvelutina*, *T.vulgaris*, *T. guianensis* and *V. thyrsoidea* presented a model of increasing apparent density variation of the pith to bark with values from 0.46 to 0.91 g cm^{-3} in the region near the pith and from 0.72 to 1.07 g cm^{-3} in the region near the bark, with lower values of wood density in the internal trunk region (juvenile wood) followed by a transition region, and in turn a gradual increase of density towards the bark (adult wood) (Figure 5; e.g. *E. pubescens*). The most common model reported in the literature (LIMA et al., 2011; LOBÃO et al., 2012) indicates an increase in the wood density with the trees' age due to modifications in the cambium vascular forming the adult wood.

The species *A. fraxinifolium*, *P. ramiflora*, *S. versicolor*, *A. tomentosum*, *B. salicifolius*, *C. langsdorffii, Q. grandiflora* and *Q. parviflora* presented stable values for all densitometric profiles, while sometimes presenting higher values in the pith region. (Figure 6; e.g. *P. ramiflora*).

The higher density values near the pith can be related to the presence of crystals and starch in parenchyma cells, as verified by Tomazello Filho et al. (2008) in *Eucalyptus* wood, in addition to the apparent density fluctuations in the profiles due to variations in vessel diameter/frequency and thicker fiber wall bands. A similar methodology to the one applied in the present work was previously used by many authors to analyze the wood from trees of different species (WIMMER et al., 2002; SETTE Jr et al., 2009; LOBÃO et al., 2012).

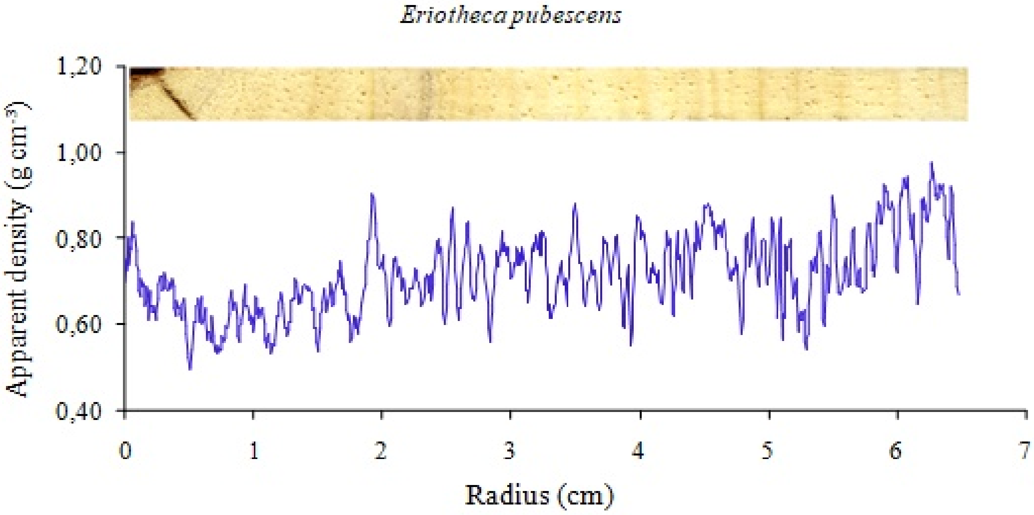

Figure 5. Radial profiles of the *E. pubescens* wood apparent density.

The radial profiles of the wood apparent density allowed to verify important and significant responses of the density pith-bark variation, as well as to determine the medium values for each studied species. In a study on the energetic quantification and characterization of the wood and bark of Cerrado species, Vale et al. (2002) found the following values of wood basic density: *A. dasycarpum* (0.74 g/cm³); *A. tomentosum* (0.58 g/cm³); *B. verbascifolia* (0.48 g/cm³); *B. salicifolius* (0.46 g/cm³); *C. brasiliense* (0.61 g/cm³); *E. pubescens* (0.38 g/cm³); *H. stigonocarpa* (0.78 g/cm³); *K. coriacea* (0.46 g/cm³); *P. ramiflora* (0.70 g/cm³); *Q. grandiflora* (0.69 g/cm³); *Q. parviflora* (0.69 g/cm³) and *V. thyrsoidea* (0.49 g/cm³).

The values described by these authors are lower than the values found in the present study. The differences in results can be associated to the amounts of juvenile and adult wood and the trees' age, since the juvenile wood present in young trees have a lower density than in adult trees (SETTE Jr. et al., 2009), due to density variation with the heartwood formation process. In addition, the method used to determine density is an important source of variation; the high precision of the x-ray microdensitometry method applied in this study with readings of apparent density at 40 µm intervals makes it possible to detect all variations in the radial samples. Furthermore, basic density was evaluated in the cited work, while the apparent density was analyzed in the present study (12%). The difference in the moisture humidity for the density determination may also be responsible for the differences in results.

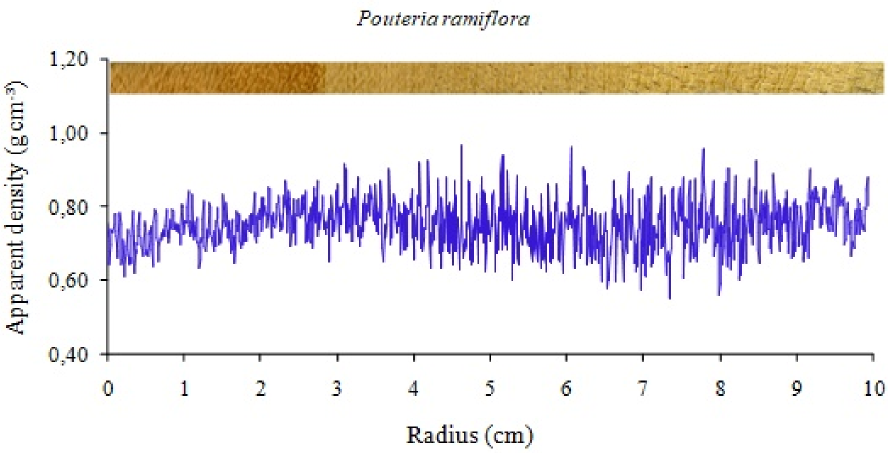

Figure 6. Radial profiles of the *P. ramiflora* wood apparent density.

The x-ray densitometry technique differs from the conventional gravimetric method because it enables evaluating the wood density at small intervals through graphs of the radial variation pattern. The technique provides development evaluations of individuals of a certain species, as well as helping in selecting species that present higher or more uniform densities.

Due to the lack of works related to the density and anatomical characterization of Brazilian Cerrado species, this study will be the basis for later work. The x-ray densitometry technique was efficient because it was possible to detect all variations in the radial sample by obtaining the densitometric profiles, thus contributing to the elaboration of the results found.

The characterization of wood carried out in this study, with a large number of Brazilian Cerrado species provide relevant information that can be applied in the anatomical identification of species (eg. wood structure), in the evaluation of wood quality (eg density, morphological parameters of fibers and vessels), helping in the rational use, and also in future studies involving these species (eg dendrochronology; wood technology).

RESUMO: A caracterização anatômica e das propriedades da madeira pode auxiliar na tomada de decisão quanto ao uso racional de espécies. Possibilita, muitas vezes, a definição do potencial tecnológico da madeira - e produtos - fornecendo acesso a informações sobre a sua qualidade, além de sua correta identificação, contribuído com a cadeia produtiva madeireira. O objetivo deste estudo foi investigar e caracterizar as propriedades da madeira de espécies arbóreas do Cerrado, através da descrição anatômica e determinação do perfil de densidade. Foram selecionadas 20 espécies pertencentes a treze famílias, na cidade de Pirenópolis, Goiás e Brasília, Distrito Federal, Brasil, e amostras radiais foram retiradas dos troncos das árvores no DAP (1,30 m) de forma não destrutiva, utilizando-se uma sonda de incremento e um extrator motorizado. Nas amostras coletadas, foram determinados os parâmetros anatômicos qualitativos e quantitativos dos vasos e das fibras e a densidade aparente da madeira. As espécies apresentaram fibras com valores médios entre 900,5 a 2052,9 µm para o comprimento; 18,1 a 27,7 µm para o diâmetro e 4,4 a 9,4 µm para a espessura da parede; e variação nas dimensões dos vasos de 29,2 a 155,6 µm para o diâmetro; 17,7 a 32,5% para área ocupada; e 2,6 a 165 vasos.mm^{-2} para a frequencia dos vasos. A densidade aparente apresentou valores médios entre 0,36 e 1,21 g cm^{-3}. A espécie que apresentou a maior variação de densidade de madeira foi *A. fraxinifolium*. De acordo com os perfis radiais, dois padrões de variação crescente e estável na densidade aparente, da medula para casca, foram definidos como uma função das características anatômicas.

PALAVRAS-CHAVE: Qualidade da madeira. Savana brasileira. Uso sustentável.

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