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Cerrado Woods: Carbon Stock and Behavior of Physical Properties

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Abstract

The correct use of a particular species of wood depends on the knowledge of their physical properties for rational exploitation in a sustainable way. This study investigated the physical properties of nine Cerrado wood species and their potential to immobilize carbon. Ten trees of each species were felled, and five discs were removed from the main stem in longitudinal positions to determine the physical properties. The basic density was evaluated in all longitudinal positions, and the dimensional stability was only evaluated in the base discs. Carbon was estimated using a pantropical equation. The longitudinal density average was 0.599 g/cm³, with the Machaerium opacum *species having the highest and* Curatella americana *the lowest average. The longitudinal variation of the wood basic density decreased from the bottom to the top of the tree in eight species. The mean radial retraction was 4.75%, with* Magonia pubescens *having the highest and* Curatella americana *the lowest average. The tangential retraction was 8.13%, with the highest being observed for* Magonia pubescens *and the lowest for* Machaerium opacum. Magonia pubescens *showed the highest carbon immobilization with 0.401 t/m³.* Machaerium opacum *and Jacaranda brasiliensis showed the best physical properties and the ability to immobilize carbons.*

Keywords: basic density, carbon stock, retractability, specific mass, volumetric retraction, brazilian savanna

1. Introduction

The Cerrado biome has high fauna and flora biodiversity, with more than two hundred species of plants that have potential for use but have been little studied. Studies have been conducted mainly on energy resources in this biome (Silva and Vale 2018, Azevedo et al. 2020, Carrijo et al. 2020). However, it is necessary to enhance research to better understand the genetic structure of species for proper use and contribute to the establishment of sustainable strategies and conservation of the biome's biodiversity to make better use of its products, especially wood.

In this context, the importance of knowledge on the biodiversity and ecological components of Cerrado vegetation is highlighted since they are considered an important factor in forest functioning and their ecosystem services, especially when analyzing carbon cycle (Ali et al. 2019, Pennekamp et al. 2018).

This vegetation can retain and store large amounts of carbon in their wood from burning fossil fuels, which has been the leading emitter of greenhouse gases, generating significant consequences and enormous impacts on climate patterns (Keenan and Williams 2018, Le Quéré et al. 2018, Mitchard 2018, De Azevedo et al. 2020, Meira Junior et al. 2020). In forests, carbon is released from decomposing dead trees and harvest residues (Meira Junior et al. 2020), in addition to the carbon from burning wood as energy sources. The carbon dioxide captured in a new forest cycle offsets the emitted carbon. However, the demand for these studies is increasing to understand carbon stocking and carbon capture process of processed and unprocessed forest products, exerting great importance on the carbon cycle (Ferreira et al. 2018, Souza et al. 2019, Sullivan et al. 2020, Hung et al. 2009).

Wood is one of the main products that can be extracted from the Cerrado woods. Like all biological material, its characteristic is the high complexity due to the heterogeneity which occurs at the anatomical and chemical level, affecting wood quality (Jokanović et al. 2022a). Its ultrastructure, chemical composition, and physical and mechanical properties vary considerably between species, trees of the same species, and even between different parts of the same tree (Zobel and Van Buijtenen 1989).

Density, which is directly dependent on latewood proportion, is one of the most used and most important characteristics in studies related to wood quality and the one that best correlates with other properties (Dias et al. 2017, Rodrigues et al. 2018, Cruz et al. 2003). Basic wood density can be estimated by destructive (Brazilian Association of Technical Standards – ABNT 2003) and non-destructive methods (Olale et al. 2019, Silva et al. 2018). Density may influence the mechanical strength of wood and may interfere with hygroscopicity, retractability, and charcoal production (Resende et al. 2018, Sjökvist et al. 2019, Veiga et al. 2018).

Variations in basic density in hardwood trees, such as Eucalyptus, occur at greater intensity in the radial direction than in the axial direction (Cruz et al. 2003). Maturation of vascular tissue is responsible for these variations and for the transition from juvenile wood to adult wood (Lima et al. 2011). Other factors such as moisture, earlywood, and latewood, species, annual growth rings, stem position, and survival conditions may also interfere with density values. Thus, correct sampling along the tree stem of native species, mainly from the Cerrado, is fundamental for good accuracy of basic wood density (Oliveira et al. 2018).

The dimensional stability of wood is another property of great importance, mainly for structural use and for the furniture industry. This property is related to the expansion or retraction of wood as a function of the moisture present in the wood, being influenced by the wood shafts (Redman et al. 2016). High contraction and swelling rates constitute undesirable wood characteristics, limiting its use for various purposes or requiring specific techniques for its use (Durlo and Marchiori 1992).

Knowledge about the physical wood properties of native Cerrado species can help to manufacture higher added value products such as objects, furniture, structures, and others. The potential for carbon immobilization in these timber products can be an important parameter as a correct ecological material and help reduce global warming. This knowledge can provide subsidies for public policies for the rational and sustainable exploitation of species depending on their technological characteristics and indicate potential species that are interesting for reforestation. Thus, the objective of the present work was to investigate the potential of Cerrado *stricto sensu* woods (typical phytophysiognomy of the Cerrado biome) for timber use, verifying wood quality through its basic density and dimensional stability in different regions of the stem, in addition to evaluating the potential of carbon immobilization in the pieces.

2. Materials and Methods

The data collection area is a legal reserve characterized by a transition range of Cerrado *stricto sensu* and Mata Seca, located in the northern region of the State of Minas Gerais in the municipality of Montes Claros. It is located at the geographical coordinates of 16° 40' 58.67" S and 43° 50' 31.59" W (Fig. 1), with an average altitude of 621 meters. According to Alvares et al. (2013), the region's climate is characterized as tropical semi-arid Aw type according to the Köppen classification, having a savanna climate with a dry season in the winter and hot and rainy summers.

A census was conducted to measure the diameter at breast height in an area of 1 hectare, measuring all individuals that met the inclusion criterion (DBH ≥5 cm). The nine species with the highest importance value (IV) were selected in a phytosociological analysis, as shown in Table 1. Ten trees were harvested for each species, thus a total of 90 trees were used in this research.

Discs, approximately 3 cm thick with bark, were removed in the longitudinal positions of 0, 25, 50, 75, and 100% of the commercial height of the tree from the main stem to determine wood physical properties. The position of 0% corresponds to the tree base, and the position of 100% corresponds to the height with a minimum circumference of 3 cm in the main stem of the individual, according to Fig. 2a. The variation of the properties in the different regions between the pith and the bark were only determined in the disk of the tree base of all species, since they are native trees of small size. The discs in the DBH position would not allow the specimens to be removed for some species for the analysis. Three wood samples were taken from the base disc in the central (near the pith), intermediate, and external (near the shell) regions to evaluate the dimensional retraction (Fig. 2b).

Basic density was determined according to NBR 11941 (Brazilian Association of Technical Standards – ABNT 2003). The equation used for the calculations was Eq. 1:

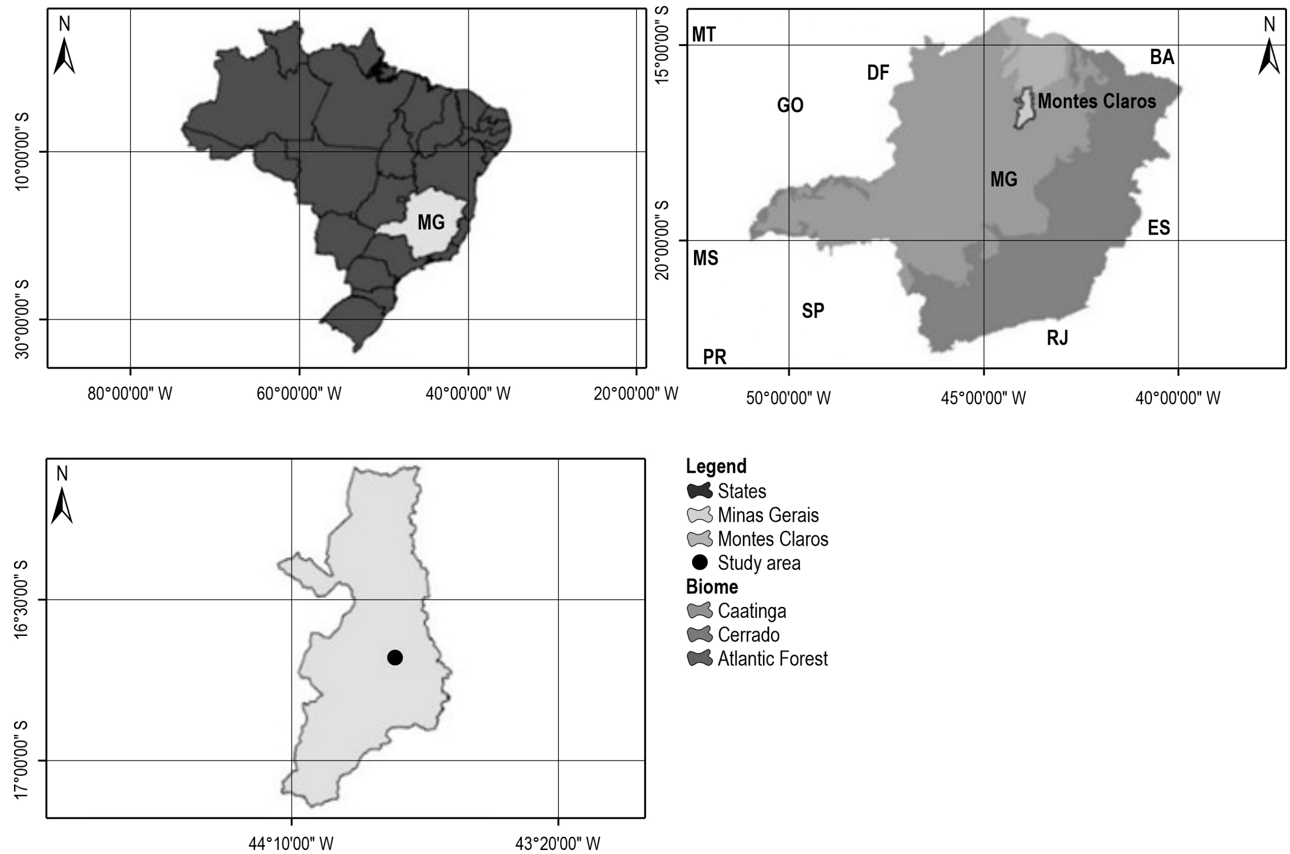

Fig. 1 Location of data collection area

$$Bd = \frac{m_3}{m_2 - m_1} * 100 \qquad (1)$$

Where:

Bd basic wood density, g/cm^3

m_3 mass of sample dried in a greenhouse at (105±2 °C), g

m_2 mass of container with water and immersed disc, g

m_1 mass of container with water, g.

For basic density analysis, the volume of saturated samples was determined by a digital electronic scale with an accuracy of 0.01 g by the mass displacement method. After determining the volume, the samples

Table 1 Description of Cerrado stricto sensu species and tree parameters for the analysis of wood physical properties

Species	Common name	Family	DBH, cm	HT, m
Terminalia fagifolia Mart.	Capitão do Mato	Combretaceae	4.64	4.42
Copaifera langsdorffii Desf.	Copaíba	Fabaceae	7.37	5.61
Heteropterys byrsonimifolia A. Juss.	Farinha seca	Malpighiaceae	6.73	4.65
Tocoyena formosa (Cham. and Schlechtd.) K. Schum.	Genipapo do Campo	Rubiaceae	4.20	4.23
Machaerium opacum Vogel	Jacarandá	Fabaceae	11.61	6.48
Curatella americana L.	Lixeira	Dilleniaceae	8.33	4.75
Combretum leprosum Mart.	Pau Lepro	Combretaceae	5.24	4.52
Jacaranda brasiliensis	Perobinha	Bignoniaceae	6.11	5.02
Magonia pubescens	Tingui	Sapindaceae	8.20	5.55

Note: DBH is the average diameter to 1.3 meters high from the ground; HT is the total average height

Fig. 2 Sampling tree scheme for the study of physical properties of wood (a), sampling scheme of base disc for analysis of physical properties of wood (b)

were dried in an oven with air circulation at 105±2°C until constant mass was achieved; the dry weight of each sample and the basic density were then determined.

On the other hand, the dimensional retraction of orthotropic directions was calculated according to the NBR7190 (ABNT 1997) using Eq. 2:

$$\varepsilon_{r,n} = \left(\frac{L_{n,s} - L_{n,d}}{L_{n,s}} \right) * 100 \quad (2)$$

Where:

$\varepsilon_{r,n}$ specific deformation of wood, with r being retraction, %

$L_{n,s}$ dimension of saturated axis, n {1,2,3}, radial, longitudinal and tangential, respectively, mm

$L_{n,d}$ length of dry section n, mm

Rectangular samples with varying dimensions were used for such procedures. Initially saturated, the samples were weighted on a digital electronic scale with an accuracy of 0.01 g and measured linearly with a digital caliper with 0.001 mm precision, and the volume with immersion in water was determined by the mass displacement method. The sample dimensions and volume were again obtained after drying in an air circulation oven at 105±2°C until constant mass and dry mass were achieved.

After determining the basic density for each sample, the mean basic density per species was calculated by the arithmetic mean of the samples obtained in each longitudinal position for the respective species.

The volumes of the five sections were estimated from the data cubing of the respective trees, corresponding to the longitudinal heights where the discs were sampled. The volumes were estimated according to the strict Smalian cubing methodology and the average density weighted by volume was subsequently calculated according to the methodology detailed by Trugilho (2009).

Carbon was estimated for each individual sampled by estimating Above Ground Biomass (AGB). For this biomass estimation, the diameter values measured at 1.30 m of soil height (DBH), total height (HT) and the basic wood density were considered. The AGB values in kilos were obtained through the compute AGB function of the BIOMASS package (Réjou-Méchain et al. 2017) of the R software program (R Core Team 2019).

The methodology proposed by Thomas and Martin (2012) was applied to obtain the average carbon concentration in the tissues in which the carbon stock corresponds to the multiplication of AGB values by the constant 0.471 (47.1±0.4%). The mean carbon immobilization per cubic meter was estimated in each evaluated species to enable comparison between species.

Analysis of variance (ANOVA) was performed to detect whether there was a statistical difference between the basic density in the different longitudinal and radial positions of each species, and the Tukey Test was subsequently applied.

An analysis of variance and Tukey Test were also carried out to evaluate radial retraction, tangential retraction, and anisotropy coefficient. These analyses were performed in the R software (R Core Team 2019), considering a statistical significance level of 5%.

3. Results

Species had a mean basic wood density of 0.599 g/cm^3 and 0.602 g/cm^3 for weighted basic density. The analysis of variance identified statistical difference between species (Table 2). The *Machaerium opacum* wood had the highest mean basic density in the longitudinal direction, while the *Curatella americana* wood had the lowest values, 0.699 and 0.499 g/cm^3, respectively. A

Table 2 Variation of basic wood density of Cerrado stricto sensu species in different longitudinal positions

Species	Longitudinal position, BD g/cm^3					BD, g/cm^3	WD, g/cm^3
	0%	25%	50%	75%	100%		
T. fagifolia	0.628	0.596	0.625	0.619	0.617	0.617^{B}	0.615^{D}
C. langsdorffii	0.637^{ab}	0.586^{ab}	0.571^{ab}	0.556^{b}	0.532^{b}	0.576^{BC}	0.582^{F}
H. byrsonimifolia	0.618	0.598	0.582	0.579	0.565	0.588^{BC}	0.591^{E}
T. formosa	0.674^{a}	0.633^{ab}	0.616^{bc}	0.596^{bc}	0.583^{c}	0.620^{B}	0.623^{C}
M. opacum	0.748^{a}	0.706^{ab}	0.706^{ab}	0.687^{ab}	0.645^{b}	0.699^{A}	0.706^{A}
C. americana	0.545	0.486	0.489	0.499	0.473	0.499^{D}	0.499^{I}
C. leprosum	0.542	0.540	0.536	0.552	0.556	0.545^{CD}	0.543^{H}
J. brasiliensis	0.620^{a}	0.562^{b}	0.551^{b}	0.539^{b}	0.543^{b}	0.563^{C}	0.563^{G}
M. pubescens	0.730^{a}	0.697^{ab}	0.691^{ab}	0.663^{ab}	0.642^{b}	0.685^{A}	0.693^{B}

Note: BD – basic density, and WD – weighted basic density. Mean values followed by different letters differ from each other by the Tukey Test ($p>0.05$), in which lower-case letters compare values in lines and upper-case letters compare values in columns

similar behavior was observed for the weighted basic density, and the values of 0.706 and 0.499 g/cm^3 were determined, respectively.

Statistical difference was determined between species. The residuals showed normality according to the Shapiro-Wilk test. The basic density values showed low variability, with a coefficient of variation (*CV*%) of 6.29 and 0.45% for basic and weighted density, respectively.

In the evaluation of the basic density in the different longitudinal positions, five species showed statistical differences in density along the stem, showing higher density in the tree base region. The *Terminalia fagifolia*, *Heteropterys byrsonimifolia*, *Curatella americana*, and *Combretum leprosum* species did not demonstrate significant differences for the longitudinal variation of the basic density (Table 2). All species generally showed a decrease in basic density in the base-top direction, except for *Combretum leprosum*.

Table 2 presents the basic longitudinal and mean density per species and the Tukey Test result, in which mean values followed by different letters differ from each other by α=0.05.

The average basic density among Cerrado species, considering only the radial sampling of the base discs, was 0.645 g/cm^3. The highest average basic density (0.659 g/cm^3) was observed in the external region the, and the lowest (0.624 g/cm^3) in the central region. *Machaerium opacum* wood showed the highest average basic density of the base disc. In contrast, *American Curatella* showed the lowest value, similarly to the evaluation of the average basic density of the species (Table 3). No studied species showed statistically significant differences between the three radial positions.

The physical properties of studied wood species did not show significant differences in the different regions between the pith and the stem bark, except for the anisotropy coefficient (Table. 4), in which *Heteropterys byrsonimifolia* and *Machaerium opacum* were statistically different.

The average value for the radial retraction of wood among the species was 4.70%, with *Magonia pubescens* showing the highest average and *American Curatella* the lowest. The total average for wood tangential retraction was 7.90%. The greatest tangential retraction among the species was observed for *Magonia pubescens* and the lowest for *Machaerium opacum*.

Carbon was estimated for each individual using the pantropical equation of Chave et al. (2014). The carbon variable was strongly related to the DBH

Table 3 Carbon stocks in above-ground wood and litter in analyzed regions

Species	Radial position, BD g/cm^3		
	Central	Intermediate	External
T. fagifolia	0.598	0.718	0.748
C. langsdorffii	0.595	0.696	0.835
H. byrsonimifolia	0.604	0.617	0.624
T. formosa	0.626	0.651	0.632
M. opacum	0.712	0.784	0.790
C. americana	0.529	0.540	0.525
C. leprosum	0.608	0.618	0.528
J. brasiliensis	0.600	0.565	0.579
M. pubescens	0.745	0.685	0.666

Note: BD is basic density

Table 4 Average values of axis retraction and anisotropy coefficient of wood of Cerrado stricto sensu species in different radial positions

Species	RR, %			RT, %			AC, %		
	C	I	E	C	I	E	C	I	E
T. fagifolia	3.89	3.68	4.31	7.16	7.51	7.13	2.33	2.66	1.87
C. langsdorffii	4.35	4.75	4.60	8.05	7.58	6.95	1.99	1.79	1.83
H. byrsonimifolia	4.89	5.47	5.69	8.65	9.51	8.29	0.70 b	2.66 a	1.20 b
T. formosa	5.40	6.14	5.46	11.38	9.99	10.55	2.56	2.02	2.12
M. opacum	4.82	3.59	3.73	5.19	6.00	4.35	0.98 b	1.78 a	1.01 b
C. americana	3.16	3.99	4.38	6.68	5.59	6.73	2.92	2.14	1.82
C. leprosum	4.84	5.11	4.60	8.83	7.97	7.00	2.58	1.10	1.53
J. brasiliensis	4.51	4.53	3.13	6.89	6.48	5.09	1.67	1.54	1.19
M. pubescens	6.02	5.97	5.96	11.76	11.98	10.10	2.04	2.57	1.76

Note: RR – radial retraction {central (C), intermediate (I), and external (E)}; RT – tangential retraction; AC – anisotropy coefficient. Letters for the parameters that showed significant difference at the level of 5%. Letters comparing the variation of the different positions within the species (lines). Average values followed by different letters differ from each other by Tukey Test ($p<0.05$)

variable (Pearson correlation: 0.84, *p*-value: 2.2 e^{-16}) and to the basic wood density (Pearson correlation: 0.72). Fig. 3 shows the carbon immobilization of wood in the respective species. It is observed that the *Magonia pubescens* species showed the highest average (0.401 t/m^3) of carbon immobilization in wood. The species generally show a concentration of 0.322 t/m^3 carbon in the wood. Carbon immobilization for different species showed no significant differences.

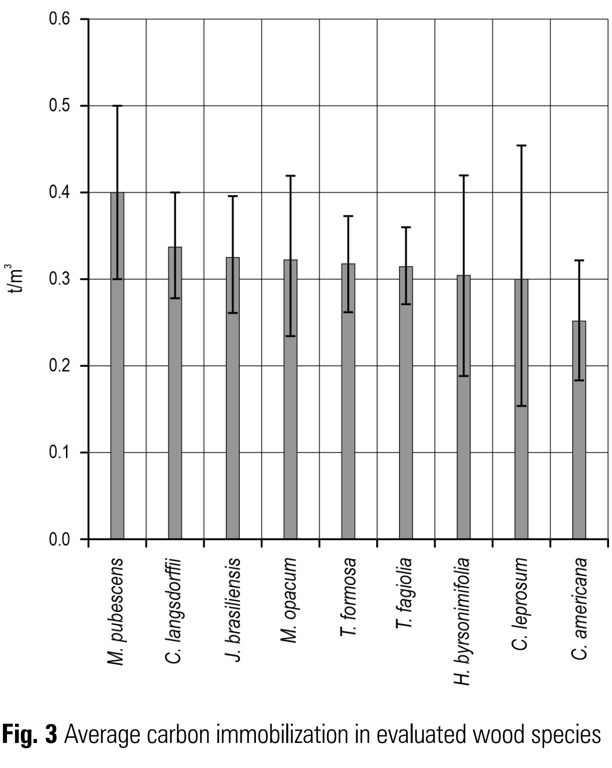

Fig. 3 Average carbon immobilization in evaluated wood species

4. Discussion

The wood of Cerrado species in the state of Minas Gerais was generally determined to be of lower wood density than those found in other regions of the country. In the study of the density of Cerradão tree species, Silva et al. (2015) found the average basic wood density of 0.650 g/cm^3. In this research, *Machaerium opacum* (0.699 g/cm^3) and *Magonia pubescens* (0.685 g/cm^3) species showed high wood densities for this biome (Table 2), and similar values were found by Silva et al. (2018) when studying the same species. These values can be used as indicators for other uses of these species, which are mainly used for energy production.

Carneiro et al. (2017) reported that wood physical properties are fundamental characteristics in evaluating tree species for producing bioenergy and charcoal. Studying the wood quality of five species occurring in the Cerrado for charcoal production, Costa et al. (2016) found an average density of 0.504 g/cm^3, which is lower than the average density found in this study.

The variation in the basic wood density of the different Cerrado species can be influenced by several environmental factors, such as the quality of the site (physical-chemical attributes of the soil, temperature, water regime), and the population density, as already mentioned by Lima et al. (2011) and Vidaurre et al. (2011). In addition, wood density can vary between genera, species of the same genus, trees within the same species, and between different parts of the trees in the longitudinal and radial direction (Rios et al. 2018).

The maximum density value in the longitudinal variation was at the base (Table 2), possibly due to the existence of rigid supporting tissues. All species showed a reduction in wood density in the base/top direction, as observed in the studies by Oliveira et al. (2005). They reported that the evaluated trees had the same variation pattern along the stem, in which there was a decrease in density at the top of the tree stem. However, this behavior was not observed for *Combretum leprosum*, which showed different behavior with top density values higher than the base density values, with these density values being statistically equal. It is worth noting that the basic wood density is considered one of the most important parameters to evaluate its quality due to the ease of determination and relation to its other characteristics. Thus, the fact that *Combretum leprosum* wood shows low variation in density within the stem suggests the supply of more homogeneous raw material for the timber industry and consequently better conditions for its processing. In addition, the industrialization of low-density wood consequently generates lighter products. This large-scale production favors cost reduction, such as reduced freight costs. Woods with these characteristics can be destined for products which require less variability in physical-mechanical properties (Oliveira et al. 2005), such as frames.

Panshin and Zeeuw (1980) presented a synthesis of the longitudinal variation patterns of the basic wood density as:

⇒ density uniformly decreases in the base-top direction

⇒ density decreases to the middle of the stem and, from this point, grows to the top

⇒ density decreases uneven from the base to the top.

These authors also state that density can vary between species of the same genus, trees of the same species, and even between parts of the same tree.

The evaluated samples showed different variation patterns of the wood physical properties in the axial and radial direction The literature reports radial variation of wood properties in several hardwood species and shows that the amplitude of these variations results from genetic and environmental factors, and the interaction between them, as reported by Zobel and Jett (1995). The variation of wood density in the radial direction was not uniform, with different behavior in the stem (Table 3). In this sense, the analysis of the interaction between the species and the radial region of the stem only showed significant differences for the coefficient of wood anisotropy (Table 4), with species behaving differently in the pith to bark direction.

It is important to stress that the final use of wood depends on the basic density. The separation of wooden pieces into density classes can help in the production of large-scale wooden objects. The higher-density parts can be used for purposes requiring greater mechanical strength such as wooden structures, floors, and furniture. On the other hand, less-density parts can be used for household items and frames such as *Combretum leprosum*. Depending on the production scale of timber objects and their export potential, using low-density timber is important for producing a light load and consequently generating lower freight costs.

The wood density in hardwoods generally increases in the direction from the pith to the bark. This pattern was determined in most of the evaluated Cerrado species (*Terminalia fagifolia, Copaifera langsdorffii, Heteropterys byrsonimifolia, Tocoyena formosa,* and *Machaerium opacum*. The reverse behavior occurred with the *Curatella americana, Combretum leprosum, Magonia pubescens,* and *Jacaranda brasiliensis* species (Table 3)).

The increasing values of density in the direction from the pith to the bark are similar to those presented by Cruz et al. (2003), who reported this trend for seven Eucalyptus clones, and by Monteiro et al. (2010), who verified an increase in the basic density for four Eucalyptus species under the influence of traction wood.

Radial variation may be related to tree growth, in which a higher rate of change is observed in the first growth rings (pith region), with the posterior rings showing similar characteristics to adult wood. Juvenile wood is characterized by lower density due to a small proportion of latewood, unlike mature wood whose cell walls are very thickened, which contributes a lot to greater density. According to Panshin and Zeeuw (1980), this increase in density is due to the thicker walls in the compression wood, which generates an increase of material in the cell wall compared to normal wood. The same authors describe four behaviors for the radial variation of the basic wood density in hardwoods, with the same being found in this work.

The models decrease from the pith to the bark direction (*Magonia pubescens*); decrease to the intermediate portion, followed by an increase until the bark (*Jacaranda braziliensis*); increase from the pith to the bark (*Terminalia fagifolia, Copaifera langsdorffii, Heteropterys byrsonimifolia*, and *Machaerium opacum*); and increase from the pith to the intermediate portion, followed by a decrease to the bark (*Tocoyena formosa, Curatella americana*, and *Combretum leprosum*).

The retraction characteristics of wood showed great differences between the species and may be affected by the environmental factors, the way of drying, and the inherent behavior of the wood itself

(Oliveira et al. 2010). Values obtained through linear retraction can result from the positioning and cellular composition of the fibers, which show greater variation in the tangential direction, followed by the radial and longitudinal direction (Ištok et al. 2017, Jokanović et al. 2022b). Longitudinal retraction was disregarded in this study since its values are low and close to the caliper reading error. Larger retractions can be observed in the transverse direction, with high contractions in the tangential direction, followed by the radial direction (Oliveira et al. 2010, Dias et al. 2018). The difference between radial and tangential retraction can be explained (for example) by the restrictive influence of rays in the radial direction (Kollmann and Cotê 1968) or the greater inclination of microfibrils on the radial axis, among other anatomical and chemical effects of wood. In this sense, high retraction values were observed in the tangential direction compared to the radial axis for the different woods of Cerrado species.

The anisotropy coefficient (AC) of *Heteropterys byrsonimifolia* and *Machaerium opacum* wood showed a significant difference in the different radial positions between the pith and stem bark (Table 4). The AC values of the different Cerrado wood species varied between 0.70 and 2.92. Durlo and Marchiori (1992) classify wood quality into three classes according to the anisotropy coefficient, so most species were classified as normal or low quality.

According to the classification by Klitzke (2007), only the wood of *Machaerium opacum* and *Jacaranda brasiliensis* species is stable and of excellent quality (AC<1.5), while the wood of *Copaifera langsdorffii, Heteropterys byrsonimifolia,* and *Combretum leprosum* is of normal quality (AC between 1.5 and 2), and the wood of *Terminalia fagifolia*, *Tocoyena formosa*, *Curatella americana*, and *Magonia pubescens* is of medium quality (AC between 2 to 2.5). However, some species with high commercial wood value are classified as medium to low quality (Dias et al. 2018), demonstrating the need for further studies on the properties of wood, and on the potential for the industrialization of Cerrado species.

Basic wood density is considered one of the main quality assessment indexes, being directly correlated with biomass stored per cubic meter (Carneiro et al. 2014). Therefore, the higher the biomass value, the higher the carbon stock, which promotes a mitigation of greenhouse gases and assists in the sustainability of the system.

The *Machaerium opacum* and *Jacaranda brasiliensis* species showed great capacity of exploitation, with good physical properties and being classified as stable woods of excellent quality. Oliveira and Silva (2003) recommend species with lower anisotropy coefficients for dimensional stability. In addition, these species showed good potential for carbon immobilization of 0.327 and 0.329 t/m^3, respectively. They play a major role in the carbon cycle, regulating atmospheric concentration of carbon dioxide, directly influencing global warming.

All species generally showed a good ability to immobilize carbon, especially compared to other studies. In studying carbon balance in the production of reforestation wood in the North of Minas Gerais, Souza et al. (2019) evaluated areas cultivated with clonal eucalyptus at the age of seven, considering a basic density of 0.45 t/m^3, and found a carbon stock of 51.05 t/ha and a total volume of 245 m^3/ha, corresponding to approximately 0.208 t/m^3 of carbon. These levels are lower than those found in this study.

Schneider et al. (2005) considered the basic density of 0.60 g/cm^3 in determining the biomass and carbon stock in Acacia Negra stands and estimated a carbon stock of 97.14 t/ha and a volume of 238.8 m^3/ha for the stand with higher productive capacity (best site index), corresponding to approximately 0.406 t/m^3 of carbon, thus presenting higher carbon stocks than those from the species evaluated in this work.

The characteristics of the evaluated species show the immobilization potential of carbon tons in objects such as household items, furniture, and wooden structures. These woods used in structures can store tens of tons of carbon, as found by Hung et al. (2009) in timber structures in Taiwanese parks. The authors presented the potential for carbon immobilization between 30 and 61 tons of CO_2, varying according to the structure used.

On the other hand, a problem with the use of Cerrado trees is the often-tortuous form. Bukauskas et al. (2019) presented several construction systems with different shapes and dimensions of logs, reinforcing the potential of these logs for these purposes. In addition, the market for defective and small logs has grown in recent years due to the work of architects and interior designers in manufacturing different products such as tables, floors, and household items.

It is worth noting that the Brazilian Cerrado is considered the largest neotropical savannah. Therefore, it has a fundamental role in the global carbon cycle and can act as a great assimilator and accumulator of carbon, mainly due to carbon stock in the soil, roots (Ozório et al. 2019, Brito et al. 2018, Cordeiro et al. 2018), and above ground (Oliveira et al. 2019). Increasing environmental degradation in this biome has generated an increase in the amount of CO_2 in the atmosphere, and the roots of these trees also have carbon immobilization potential when used in manufacturing objects and furniture. The scarcity of studies related to quantifying the total biomass in the Cerrado compromises the understanding of the CO_2 conversion process in the biome. In this context, it should be highlighted that the *Magonia pubescens* species showed the highest amount of immobilized carbon in the stem per cubic meter (Fig. 3) and high basic density values (Table 2).

On the other hand, the other species with lower densities can be used in manufacturing objects such as household items, which require little mechanical resistance and consequently lower density. These objects are usually produced on a large scale, sometimes with container exports, and can store tons of carbon. Thus, based on their potential physical properties, the different Cerrado woods presented herein can be considered for manufacturing timber products with higher added value. Finally, using these woods in these timber objects has the potential for immobilizing tons of carbon and consequently helping to mitigate global warming.

5. Conclusions

The longitudinal variation of the density decreased from the base to the top in all Cerrado species. This variability pattern provides relevant information that can contribute to decisions about its applicability.

The woods of the native Cerrado species generally showed the same pattern concerning dimensional stability. The wood of the internal regions near the pith, and intermediate and external regions near the bark did not show significant differences in the basic density, radial and tangential retractions, or in the anisotropy coefficient. The exception was *Heteropterys byrsonimifolia* and *Machaerium opacum*, which showed a lower anisotropy coefficient in the central position.

The anisotropy coefficient of five species was classified as normal to excellent quality, with potential for use in the mechanical wood processing industry. On the other hand, the dimensional stability of the wood from *Terminalia fagifolia*, *Tocoyena formosa*, *Curatella americana*, and *Magonia pubescens* species is of low quality. The wood of *Machaerium opacum* and *Jacaranda brasiliensis* species showed good physical characteristics with homogeneous basic density along the stem, both in the radial and longitudinal directions, and good dimensional stability, with good timber potential.

Another relevant finding in this research is related to the amount of carbon that can be immobilized in the timber products of the evaluated species, with emphasis on *Magonia pubescens*. Some species have more potential for carbon immobilization per cubic meter of wood than traditionally used species in the timber sector. This information reinforces the importance of using forests of the Cerrado biome sustainably, and selecting species with the potential to be reforested and used in the recovery of degraded areas. In turn, these woods can be used sustainably for manufacturing products.

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