The Effect of Carbonization on the Wood Anatomy of *Sclerolobium paniculatum* Vogel

Edy Eime Pereira Baraúna,[a,*] Patricia Hellenn Stallbaun,[a] Thiago Campos Monteiro,[b] Thiago Cardoso Silva,[b] Talita Baldin,[a] Fernando Colen,[a] and Marina Donária Chaves Arantes [c]

Considering the extraordinary diversity of the Brazilian Cerrado and the difficulties related to the inspection of environmental crimes, knowing the wood and charcoal anatomy of widely exploited species is important. Thus, this study aimed to verify the anatomical characteristics of the wood and charcoal of *Sclerolobium paniculatum*. Therefore, anatomical characterizations of the wood and the charcoal produced were performed in order to compare the characteristics of both materials and observe any possible changes in the anatomical properties after carbonization. The results exposed that the qualitative anatomical characteristics of *S. paniculatum* wood can be maintained after the carbonization process. However, quantitatively, the carbonization increased the vessel frequency value and height and width of rays, despite reducing the frequency of rays. The diameter of the vessels was not altered by carbonization. This characterization of the species can then serve as a database for future identification of charcoal produced with this wood. In addition, it can encourage increasing the quality of inspection and consequently reducing the illegal exploitation of the species in natural environments.

Keywords: Charcoal; Anatomical characteristics; Brazilian Cerrado; Wood fiber

*Contact information: a: Universidade Federal de Minas Gerais, Instituto de Ciências Agrárias, Montes Claros, Minas Gerais 39404-547 Brasil; b: Universidade Federal do Paraná, Setor de Ciências Agrárias, Departamento de Engenharia e Tecnologia Florestal, Curitiba, Paraná 80210-170 Brasil; c: Universidade Federal de São João del-Rei, Departamento de Engenharia Florestal, Sete Lagoas, Minas Gerais 35701-970 Brasil; *Corresponding author: ebarauna@ica.ufmg.br*

INTRODUCTION

The production of charcoal always causes a discussion in the community that raises ecological awareness about the origin of its raw material. A problem in many countries is the identification of the origin of charcoal, which can come from planting forests or the exploration and management of native forests (Monteiro *et al*. 2010; Perdigão *et al*. 2020; Ramalho *et al.* 2020; Nisgoski *et al.* 2021). Often, wood from native forests is obtained illegally. In this sense, illegal logging might be hidden or obscured *via* wood carbonization, since this process makes it more difficult to identify the species used for charcoal production. Therefore, it is important to know what anatomical changes occur during wood carbonization.

Qualitative characteristics of wood, in general, remain unchanged during carbonization, while some variations occur in the biometrics of anatomical elements, *e.g.*, the dimensions and frequencies of vessels and rays (Gonçalves and Scheel-Ybert 2016; Ávila *et al*. 2017). Thus, based on the anatomy of the wood, it is possible to distinguish the origin of species after its carbonization (Muñiz *et al*. 2012b). Following this premise, several studies have been carried out on the anatomy of wood and charcoal for some native species of hardwoods in Brazil (Muñiz *et al*. 2013; Nisgoski *et al*. 2014; Stange *et al*. 2018; Perdigão *et al*. 2020; Stüpp *et al*. 2021).

Considering the devastation of native forests in Brazil, primarily in the Cerrado biome, and the scarcity of descriptive studies detailing the charcoal of these species, knowing the anatomy of wood and its charcoal is necessary. This biome has undergone major changes in the last 50 years due to agricultural expansion and considerable changes in its landscape, generating irreversible environmental impacts and damage to this ecosystem (Dutra e Silva and Barbosa 2020). However, this biome is an important energy source, primarily to the state of Tocantins, and its knowledge is important for sustainable forest management of the ecosystems (Carrijo *et al.* 2020).

In this biome, several forest species present silvicultural potential, including *Sclerolobium paniculatum* Vogel (Fabaceae), which is utilized for its rapid growth, high survival rate, shape, and vigor (Castro *et al.* 1990; Terra *et al.* 2019). This species is an excellent carbon fixer, in addition to having medium-density wood with a high calorific value, which helps in selecting it for energy production (Machado Neto *et al*. 2015).

Despite being mostly found in natural environments, planting of *S. paniculatum* is encouraged in degraded areas, given its potential for environmental recovery. Besides, its wood can be managed after this period since it has energy characteristics similar to those of *Eucalyptus* (Souza *et al.* 2004). However, large-scale plantations are not yet a reality for forest production of this species in Brazil. In this sense, considering the extraordinary diversity of the Brazilian Cerrado and the difficulties related to the inspection of environmental crimes, knowing the wood and charcoal anatomy of widely exploited species is important. Thus, this study aimed to verify the anatomical characteristics of the wood and charcoal of *S. paniculatum*.

EXPERIMENTAL

Wood Collection and Preparation

To perform the study, nine *Sclerolobium paniculatum* Vogel trees were collected from the municipalities of Dueré (11°20'46”S and 49°16'14”W) and Cariri do Tocantins (11°53'25”S and 49°09'25”W), in the state of Tocantins, Brazil. The areas are classified by the Köppen system as tropical climate with a dry season (Aw) and are phytogeographically inserted in a Cerrado environment (Gonçalves *et al.* 2016).

As a criterion, the trees were selected according to their diameter at breast height (DBH), ranging from 20 to 25 cm, and their phytosanitary aspect. For each tree, a thick disc of 10 cm was obtained at the height of DBH, which was separated into two opposite wedges. From these wedges, 2 cm x 2 cm x 2 cm pieces were made, which were taken from the transition region between heartwood and sapwood. These pieces were free from defects. Altogether, for each tree, two representative samples of each evaluated wedge were obtained, being one allocated for anatomical analysis of the wood and the other submitted to the carbonization process.

Carbonization Process

The pieces of wood allocated for the carbonization process were taken to an acclimatized room to stabilize humidity to 12%. Then, the samples were wrapped in aluminum foil and carbonized in a muffle, with a final temperature of 450 °C (2 h at the final temperature) and a heating rate of 1.66 °C·min^{-1}, totaling 8 h of carbonization, according to the methodology described by Muniz *et al.* (2012) and Stüpp *et al*. (2021).

Anatomical Analyses

The anatomical characterization of *S. paniculatum* wood was performed following the IAWA Committee description standard outlined in Wheeler *et al*. (1989). Thirty measurements were performed for the diameter and frequency of the vessels, as well as for the frequency, height, and width of the rays (in μm).

For the wood fiber individualization, the method described by Franklin (1945) and modified by Berlyn *et al*. (1976) was used. Small longitudinal wood samples were placed in a mixture of hydrogen peroxide and acetic acid (in a 1 to 1 ratio) and left in a kiln at a temperature of 60 °C for 24 to 48 h. Then, the dissociated material was washed in running water and stained with hydroalcoholic safranin. In order to observe the dissociated cellular elements, microscope slides were made, on which 30 measurements were performed for each of the parameters, *i.e.*, fiber length, fiber diameter, lumen diameter, wall thickness, and fiber wall fraction. The fiber cell wall thickness was mathematically determined by the difference between the fiber and lumen diameter. The wall fraction was estimated according to Eq. 1,

$$FWF = \frac{2(WT)}{FW} \times 100 \quad (1)$$

where FWF is the fiber wall fraction (%), WT is the wall thickness (μm), and FW is the fiber width (μm) (Melo *et al*. 2016; Monteiro *et al*. 2017).

The anatomical characterization of charcoal was performed by taking measurements of the diameter and frequency of the vessels. The observations and measurements of the anatomical characteristics were performed with a Zeiss microscope with reflected light. The charcoal samples were manually broken according to the three fundamental planes of the wood. The measurements of the constituent elements were performed with Axio Vision Rel. software (version 4.7, Carl Zeiss AG, Jena, Germany) using the description outlined in Wheeler *et al.* (1989).

Statistical Analyses

Statistical analysis was performed according to the types of material analyzed, *i.e.*, wood or charcoal. In a completely randomized experiment, the statistical differences between the anatomy of the wood and the charcoal were evaluated by the F test, at a 95% probability level, using the Sisvar software (Ferreira 2019).

RESULTS AND DISCUSSION

Sclerolobium paniculatum wood is characterized by presenting growth layers irregularly demarcated by fibrous zones, vessels with diffuse porosity, predominant solitary vessels, fibers with simple pits, and axial parenchyma being sparse paratracheal vasicentric with two to five cells per series (Fig. 1A). After carbonization, it was observed that the exposure of the wood to high temperatures caused cracks between rays (Fig. 1B). Despite this, it was possible to identify the maintenance of the cell arrangement when viewing the transversal sections of the species, revealing the conservation of some anatomical elements after the adopted carbonization regime.

The anatomy of pits in the vessels of the studied wood may be associated with the dry conditions of the Cerrado, since this biome is characterized by strong seasonal rainfall with cold and dry winter, as well as compact and dry soil for the first few meters down (Ferri 1979; Rizzini 1997; Franco 2002; Oliveira and Marquis 2002; Machado *et al.* 2007). These environmental factors can affect the microstructure of the wood, changing its anatomical properties. Thus, some identification parameters may be of low significance in the identification of charcoals (Gonçalves *et al.* 2011).

Vasicentric axial parenchyma, biseriate and uniseriate, and homocellular rays are characteristic of the genus *Sclerolobium* (SUDAM 1981; Mainieri *et al.* 1983; Mainieri and Chimelo 1989), which were also observed in this study (Fig. 1C). After the transformation into charcoal, some anatomical structures remained, and some cracks appeared following the paratracheal parenchyma line, causing an expansion in the tangential direction (Fig. 1D). This phenomenon also occurred in some rays (in the radial direction).

The rays were characterized as being exclusively uniseriate (99%) and homogeneously formed by procumbent cells (as shown in Fig. 1E). The same characteristics were found by Pires and Marcati (2005) in a study with two other varieties of the species, *i.e.*, *S. paniculatum* var. *subvelutinum* and *S. paniculatum* var. *rubiginosum*. Therefore, it is worth noting that this can be an important characteristic for identifying the wood of this species.

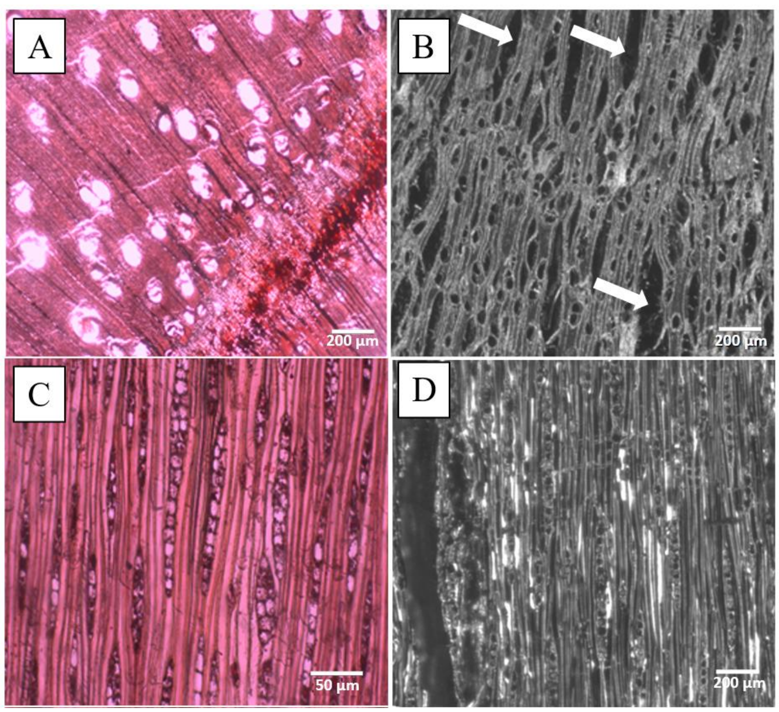

Fig. 1. Images of the anatomical characterization of *Sclerolobium paniculatum* in the transversal section: (A) wood and (B) charcoal, where the arrows indicate splits in rays; in the longitudinal tangential section: (C) wood and (D) charcoal

The height and width of the rays underwent significant changes during the carbonization process, registering an increase in their values (Table 1). In addition, the carbonization process reduced the frequency of rays, and the charcoal presented a higher vessel frequency.

Table 1. Anatomical Characteristics of the Wood and Charcoal of *S. paniculatum*

Statistics		Minimum	Average	Maximum	Standard Deviation
Frequency of vessels (mm²)	Wood	1.00	2.76 b	4.00	0.95
	Charcoal	7.00	10.13 a	14.00	1.83
Diameter of vessels (µm)	Wood	30.06	96.27 a	155.79	31.55
	Charcoal	33.48	89.99 a	180.43	31.70
Frequency of rays (linear mm)	Wood	7.00	10.30 a	15.00	2.18
	Charcoal	3.00	5.53 b	8.00	1.43
Height of rays (µm)	Wood	110.00	185.45 b	310.00	51.72
	Charcoal	120.34	223.66 a	253.45	35.65
Width of rays (µm)	Wood	20.00	15.76 b	45.00	7.23
	Charcoal	10.88	31.66 a	21.92	2.70

Note: Averages followed by the same letter do not differ statistically from each other, according to the Tukey test at the 95% probability level.

When evaluating two tropical forest species of angiosperms belonging to the *Fabaceae* family, Muñiz *et al*. (2012a) discovered an increase in radius width in *Cedrelinga catenaeformis* and a decrease in radius width in *Enterolobium schomburgkii*. As such, Muñiz *et al*. (2012a) and Nigoski *et al*. (2014) stated that the behavior in relation to the width of the rays does not follow a pattern, which indicated that, in this case, the species is the relevant factor, observing that the width of the rays can be increased in some wood species, consequently decreasing the frequency. The same conclusion was reported by Gonçalves *et al*. (2012) and Gonçalves and Scheel-Ybert (2016) when verifying an increase in the height of the rays for the group of analyzed species from the Cerrado biome of São Paulo.

The descriptive statistics of the averages obtained *via* the quantitative anatomical characterization of the fibers are shown in Table 2. The fiber length presented average values of approximately 765 µm while the fiber wall thickness exhibited average values of approximately 6.5 µm. They were classified as thin to thick walls, according to the classification of the IAWA Committee (Wheeler *et al*. 1989).

Table 2. Anatomical Characterization of Fibers of *S. paniculatum* Wood

Statistics	Length (µm)	Fiber Diameter (µm)	Lumen Diameter (µm)	Wall Thickness (µm)	Wall Fraction (%)
Minimum	500	7	13	4	57
Average	765	12	17.5	6.5	70
Maximum	1030	17	22	9	82
Coefficient of variation (%)	19.82	22.31	14.61	18.12	18.51

The thickness of the fiber wall, the frequency and diameter of the vessels, the amount of parenchymal tissue, in addition to other factors, *e.g.*, environmental variables, can affect the density of the wood, and consequently its energy properties (Kollmann and Côté Jr. 1968; Panshin and De Zeeuw 1980; Zobel and Buijtenen 1989; Oliveira *et al.* 2021). Thus, these anatomical characteristics make *S. paniculatum* wood present a medium density, *i.e.*, approximately 700 kg·cm^{-3} (Machado Neto *et al*. 2015).

The wall fraction presented an average value of 70%. Woods characterized by the presence of fibers with a high wall fraction value have the potential for production of charcoal, presenting a greater mass to support the thermal decomposition of wood, favoring the yield and quality of charcoal (Paula 2005). Thus, these characteristics increase the demand for *S. paniculatum* wood for the production of energy *via* direct combustion or the production of charcoal.

As seen in other studies, qualitatively, the anatomical structures did not change, and important characteristics for species identification can be observed in the transversal face, even in charcoal (Muñiz *et al*. 2012a; Muñiz *et al*. 2013). Thus, this characterization of *S. paniculatum* can serve as a database for future identification of charcoal produced with its wood. In addition, it can encourage increasing the quality of inspection and consequently reducing the illegal exploitation of the species in natural environments.

CONCLUSIONS

1. The qualitative anatomical characteristics of *Sclerolobium paniculatum* wood are maintained after the carbonization process.
2. Quantitatively, the carbonization of *S. paniculatum* increased the frequency of the vessels and the height and width of the rays, despite reducing the frequency of the rays. The diameter of the vessels was not altered *via* carbonization.
3. This characterization of *S. paniculatum* can serve as a database for future identification of charcoal produced with its wood. In addition, it can encourage increasing the quality of inspection and consequently reducing the illegal exploitation of the species in natural environments.

ACKNOWLEDGMENTS

The authors thank the *Research Development Foundation – FUNDEP (Project 27506)* from *Universidade Federal de Minas Gerais* and the *Universidade Federal do Paraná* for the financial support. This study was performed with the support of the Coordination for the Improvement of Higher Education Personnel - (CAPES) - Brazil - Financing Code 001.

REFERENCES CITED

Ávila, A., Giongo, C., and Scheel-Ybert, R. (2017). "Anatomia do lenho carbonizado de 10 espécies nativas da planície costeira do Rio Grande do Sul – Subsídio a pesquisas arqueobotânicas e paleoecológicas [Charcoal anatomy of 10 native species of Rio Grande do Sul coastal plain (Brazil) – A support for archaeological and paleoecological research]," *Cadernos do Lepaarq* 14(27), 480-511. DOI: 10.15210/lepaarq.v14i27.9661

Berlyn, G. P., Miksche, J. P., and Sass, J. E. (1976). *Botanical Microtechnique and Cytochemistry*, Iowa State University Press, Ames, IA.

Carrijo, J. V. N., Miguel, E. P., Vale, A. T. D., Matricardi, E. A. T., Monteiro, T. C., Rezende, A. V., and Inkotte, J. (2020). "Artificial intelligence associated with satellite data in predicting energy potential in the Brazilian savanna woodland area," *IForest* 13(1), 48-55. DOI: 10.3832/ifor3209-012

Castro, A. W. V. d., Yared, J. A. G., Alves, R. N. B., Silva, L. S., and Meirelles, S. L. M. B (1990). "Comportamento silvicultural de *Sclerolobiums paniculatum* (taxi branco) no cerrado Amapaense [Silvicultural behavior of *Sclerolobiums paniculatum* (taxi branco) in the cerrado of Amapá]," *Comunicado Técnico - Embrapa* (7), 1-4.

Dutra e Silva, S. D. and Barbosa, A. S. (2020). "Paisagens e fronteiras do Cerrado: Ciência, biodiversidade e expansão agrícola nos chapadões centrais do Brasil [Landscapes and borders of the Cerrado: Science, biodiversity and agricultural expansion in the central highlands of Brazil]," *Estudos Ibero-Americanos* 46(1), 1-18. DOI: 10.15448/1980-864X.2020.1.34028

Ferreira, D. F. (2019). "Sisvar: A computer analysis system to fixed effects split plot type designs," *Revista Brasileira de Biometria* 37(4), 529-535. DOI: 10.28951/rbb.v37i4.450

Ferri, M. G. (1979). "Transpiração nos Principais Ecossistemas Brasileiros e em Espécies Cultivadas no Brasil [Transpiration in the Main Brazilian Ecosystems and in Cultivated Species in Brazil]," in: *Fisiologia Vegetal*, M. G. Ferri (ed.) EDUSP, São Paulo, Brazil, pp. 25-73.

Franco, A. C. (2002). "Ecophysiology of woody plants," in: *The Cerrados of Brazil*, P. S. Oliveria and R. J. Marquis (ed.), Columbia Univ. Press, New York, NY, pp. 178-197.

Franklin, G. L. (1945). "Preparation of thin sections of synthetic resins and wood-resin composites, and a new macerating method for wood," *Nature* 155, 51. DOI: 10.1038/155051a0

Gonçalves, D. S., Souza, P. A. d., Oliveira, A. L. d., and Martins, T. S. (2016). "Diagnóstico ambiental e proposta de plano de recuperação da APP, fazenda Santa Juliana, Cariri do Tocantins – To [Environmental diagnosis and proposed APP recovery plan farm Santa Juliana, Cariri do Tocantins - To]," *Nucleus* 13(1), 167-182. DOI: 10.3738/1982.2278.1562

Gonçalves, T. A. P., and Scheel-Ybert, R. (2016). "Charcoal anatomy of Brazilian species. I. *Anacardiaceae*," *Anais da Academia Brasileira de Ciências* 88(3), 1711-1725. DOI: 10.1590/0001-3765201620150433

Gonçalves, T. A. P., Marcati, C. R., and Scheel-Ybert, R. (2011). "Wood and charcoal anatomy in species of the Brazilian cerrado: Effect of carbonization on wood structure," *Sagvntvm Extra* 11, 51-52.

Gonçalves, T. A. P., Marcati, C. R., and Scheel-Ybert, R. (2012). "The effect of carbonization on wood structure of *Dalbergia violacea*, *Stryphnodendron polyphyllum*, *Tapirira guianensis*, *Vochysia tucanorum*, and *Pouteria torta* from the Brazilian cerrado," *IAWA Journal* 33(1), 73-90. DOI: 10.1163/22941932-90000081

Kollmann, F. F. P., and Côté Jr., W. A. (1968). *Principles of Wood Science and Technology: Solid Wood*, Springer-Verlag, Berlin, Germany.

Machado, S. R., Rodella, R. A., Angyalossy, V., and Marcati C. R. (2007). "Structural variations in root and stem wood of *Styrax* (Styracaceae) from Brazilian forest and cerrado," *IAWA Journal* 28(2), 174-188. DOI: 10.1163/22941932-90001632

Machado Neto, A. d. P., Brandão, C. F. L. e. S., Duarte, B., Almir, J., Marangon, L. C., and Feliciano, A. L. P. (2015). "Densidade e poder calorífico como base para prevenção de incêndios florestais sob linhas de transmissão [Density and calorific

power as a basis for forest fires prevention under transmission lines]," *Nativa* 3(1), 10-15. DOI: 10.14583/2318-7670.v03n01a02.
Mainieri, C., and Chimelo, J. P. (1989). *Fichas de Características das Madeiras Brasileiras* [Characteristic Forms of Brazilian Woods], Instituto de Pesquisas Tecnológicas do Estado de São Paulo, PROMOCET, São Paulo, Brazil.
Mainieri, C., Chimelo, J. P., and Angyalossy-Alfonso, V. (1983). *Manual de Identificação das Principais Madeiras Comerciais Brasileiras* [Identification Manual of the Main Brazilian Commercial Woods], Instituto de Pesquisas Tecnológicas do Estado de São Paulo, São Paulo, Brazil.
Melo, L. E. d. L., Silva, J. R. M. d., Napoli. A., Lima, J. T., Trugilho, P. F., and Nascimento, D. F. R. (2016). "Influence of genetic material and radial position on the anatomical structure and basic density of wood from *Eucalyptus* spp. and *Corymbia citriodora*," *Scientia Forestalis* 44(111), 611-621. DOI: 10.18671/scifor.v44n111.07
Monteiro, T. C., Lima, J. T., Hein, P. R. G., Silva, J. R. M. d., Trugilho, P. F., and Andrade, H. B. (2017). "Effect of wood anatomical elements in log drying of *Eucalyptus* and *Corymbia*," *Scientia Forestalis* 45(115), 493-505. DOI: 10.18671/scifor.v45n115.07
Monteiro, T. C., Silva, R. V., Lima, J. T., Hein, P. R. G., and Napoli, A. (2010). "Use of near infrared spectroscopy to distinguish carbonization processes and charcoal sources," *Cerne* 16(3), 381-390. DOI: 10.1590/S0104-77602010000300014
Muñiz, G. I. B. d., França, R. F., Fiorese, A. E., and Nisgoski, S. (2013). "Análisis de la estructura anatómica de la madera y del carbón de dos especies de *Sapotaceae* [Analysis of the anatomical structure of wood and charcoal of two *Sapotaceae* species]," *Maderas – Cienc. Tecnol.* 15(3), 311-320. DOI: 10.4067/S0718-221X2013005000024
Muñiz, G. I. B. d., Nisgoski, S., França, R. F., and Schardosin, F. Z. (2012a) "Anatomia comparativa da madeira e do carvão de *Cedrelinga catenaeformis* Ducke e *Enterolobium schomburgkii* Benth. para fins de identificação [Comparative anatomy of wood and charcoal of *Cedrelinga catenaeformis* Ducke and *Enterolobium schomburgkii* Benth. for identification purposes]," *Scientia Forestalis* 38(94), 291-297.
Muñiz, G. I. B. d., Nisgoski, S., Shardosin, F. Z., and França, R. F. (2012b). "Anatomia do carvão de espécies florestais [Charcoal anatomy of forest species]," *Cerne* 18(3), 471-477. DOI: 10.1590/S0104-77602012000300015
Nisgoski, S., Gonçalves, T. A. P., Sonsin-Oliveira, J., Ballarin, A. W., Muñiz, G. I. B. (2021). "Near-infrared spectroscopy for discrimination of charcoal from *Eucalyptus* and native cerrado species - Contribution to a database for forestry supervision," *Forest Science* 67(4), 419-432. DOI: 10.1093/forsci/fxab015
Nisgoski, S., Magalhães, W. L. E., Batista, F. R. R., França, R. F., and Muñiz, G. I. B. d. (2014). "Anatomical and energy characteristics of charcoal made from five species," *Acta Amazonica* 44(3), 367-372. DOI: 10.1590/1809-4392201304572
Oliveira, G. M. V., Mello, J. M. d., Mello, C. R. d., Scolforo, J. R. S., Miguel, E. P., and Monteiro, T. C. (2021). "Behavior of wood basic density according to environmental variables," *Journal Forestry Research* 1(3), 1-9. DOI: 10.1007/s11676-021-01372-2
Oliveira, P. S., and Marquis, R. J. (2002). *The Cerrados of Brazil*, Columbia University Press, New York City, NY.
Panshin, A. J., and Zeeuw, C. d. (1980). *Textbook of Wood Technology*, McGraw-Hill Book Company, New York, NY.
Paula, J. E. (2005). "Caracterização anatômica da madeira de espécies nativas do cerrado,

visando sua utilização na produção de energia [Anatomical characterization of wood from native cerrado spp., aiming at use in energy production]," *Cerne* 11(1), 90-100.

Perdigão, C. R. V., Júnior, M. M. B., Gonçalves, T. A. P., Araujo, C. d. S., Mori, F. A., Barbosa, A. C. M. C., Souza, F. I. B. d., Motta, J. P., and Melo, F. E. L. (2020). "Forestry control in the Brazilian Amazon I: Wood and charcoal anatomy of three endangered species," *IAWA Journal* 41(4), 1-20. DOI: 10.1163/22941932-bja10016

Pires, I. P., and Marcati, C. R. (2005). "Anatomia e uso da madeira de duas variedades de *Sclerolobium paniculatum* Vog. do sul do Maranhão, Brasil [Wood anatomy and use of two varieties of *Sclerolobium paniculatum* Vog. in the south of Maranhao State, Brazil]," *Acta Botanica Brasilica* 19(4), 669-678. DOI: 10.1590/S0102-33062005000400002

Ramalho, F. M. G., Carvalho, G. S., Hein, P. R. G., Napoli, A., Wojcieszak, R., and Guilherme, L. R. G. (2020). "Artificial neural networks to distinguish charcoal from *Eucalyptus* and native forests based on their mineral components," *Energy Fuels* 34(8), 9599-9608. DOI: 10.1021/acs.energyfuels.0c01034

Rizzini, C. T. (1997). *Tratado de Fitogeografia do Brasil: Aspectos Ecológicos, Socio-lógicos e Florísticos* [Treaty of Phytogeography of Brazil: Ecological, Sociological and Floristic Aspects], Âmbito Cultural Edições Ltda, Rio de Janeiro, Brazil.

Souza, C. R., Lima, R. M. B., Azevedo, C. P., and Rossi, L. M. B. R. (2004). Taxi-branco (*Sclerolobium paniculatum* Vogel). Embrapa Amazônia Ocidental, Manaus, Amazonas, Brazil.

Stange, R., Vieira, H. C., Rios, P. D., and Nisgoski, S. (2018). "Wood and charcoal anatomy of four *Myrtaceae* species," *Cerne* 24(3), 190-200. DOI: 10.1590/01047760201824032552

Stüpp, Â. M., Vieira, H. C., Rios, P. D., Muñiz, G. I. B. d., and Nisgoski, S. (2021). "Effect of carbonization on wood anatomy of three *Fabaceae* species from an Araucaria forest stand in southern Brazil," *Bosque* 42(1), 33-42. DOI: 10.4067/s0717-92002021000100033

SUDAM (1981). *Madeiras da Reserva Florestal de Curuá-una Estado do Pará: Caracterização Anatômica, Propriedades Gerais e Aplicações* [Woods from the Forest Reserve of Curuá-una State of Pará: Anatomical Characterization, General Properties and Applications], Superintendência do Desenvolvimento da Amazônia, Ministério do Interior, Belém, Brazil.

Terra, R. D. R., Vieira, R. S., Baraúna, E. E. P. (2019). "Prediction of properties of *Sclerolobium paniculatum* and *Qualea grandiflora* charcoal," *Floresta e Ambiente* 26(1), 1-6. DOI: 10.1590/2179-8087.007216

Wheeler, E. A., Baas, P., and Gasson, P. E. (1989). "IAWA list of microscopic features for hardwood identification," *IAWA Journal* 10(3), 219-332. DOI: 10.1002/fedr.1990101110

Zobel, B. J., and Buijtenen, J. P. v. (1989). *Wood Variation: Its Causes and Control*, Springer-Verlag, Berlin, Germany.

Article submitted: August 4, 2021; Peer review completed: September 11, 2021; Revised version received and accepted: September 29, 2021; Published: October 6, 2021.
DOI: 10.15376/biores.16.4.7846-7854