

# Anatomical and energy characteristics of charcoal made from five species

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## ABSTRACT

Charcoal is an important energy raw material and its properties are influenced by the wood's anatomical and chemical composition and the production process. The aim of this study was to evaluate the anatomical characteristics, calorific power and volatiles and ash content of carbonized wood from *Byrsonima spicata*, *Calophyllum brasiliense*, *Cecropia sciadophylla*, *Cochlospermum orinocense* and *Schefflera morototoni*. The calorific power varied from 26,878 to 31,117 kJ kg<sup>-1</sup>; the content of volatile materials ranged from 20.9 to 31.7%; ash content ranged from 0.1 to 3.8%; and carbon content varied from 68.2 to 75.3%. Anatomical structures of charcoal can be used for species identification. The studied species are not indicated for charcoal production because the levels of ash and volatile compounds are higher than those recommended for charcoal produced for household use. In addition, the calorific power and level of carbon content are insufficient for use in the steel industry.

**KEYWORDS:** carbonization, carbonized wood properties, wood structure.

## Características anatômicas e energéticas do carvão de cinco espécies

### RESUMO

O carvão vegetal é um importante insumo energético, sendo suas propriedades influenciadas pela composição anatômica e química da madeira utilizada e pelo processo de produção. Esse trabalho teve como objetivo avaliar as características anatômicas, poder calorífico e o conteúdo de voláteis e cinzas da madeira carbonizada de *Byrsonima spicata*, *Calophyllum brasiliense*, *Cecropia sciadophylla*, *Cochlospermum orinocense* e *Schefflera morototoni*. O poder calorífico variou de 26.878 a 31.117 kJ kg<sup>-1</sup>; o teor de voláteis variou de 20,9 a 31,76%; o teor de cinzas variou de 0,1 a 3,8% e o teor de carbono no carvão ficou entre 68,2 e 75,3%. A estrutura anatômica do carvão pode ser utilizada na identificação de espécies. As espécies estudadas não são indicadas para a produção de carvão, pois o teor de cinzas e materiais voláteis é superior ao indicado para carvão produzido para uso doméstico. Além disso, porque o poder calorífico e o teor de carbono do carvão são insuficientes para uso na indústria siderúrgica.

**PALAVRAS-CHAVE:** carbonização, propriedades do lenho carbonizado, estruturas da madeira.

## INTRODUCTION

Brazil is the world's largest producer and consumer of charcoal, mainly for the production of pig iron, steel and ferroalloys. About 50% of the wood consumed in the world annually is used for energy purposes (Moreira 2011). Because of the current global dependence on fossil fuels, it is necessary to find new energy sources that are less polluting and safer with regard to availability (Santos and Hatakeyama 2012).

Historically in Brazil, wood from native forests was the main raw material used to make charcoal, but today a combination of stricter environmental regulation and increased enforcement has increased the use of wood from planted forests, mainly eucalyptus, to make charcoal for industrial uses (Yazdani *et al.* 2012).

However, in certain regions, wood is still often carbonized from illegally cut trees. In such cases, enforcement of logging rules is hampered due to the difficulty of identifying the species, making it necessary to obtain more information on the intrinsic characteristics of carbonized wood to enable species identification. Previous studies (Lopes Pasquali *et al.* 2002; Kwon *et al.* 2009; Silva *et al.* 2007) have shown the influence of species and carbonization conditions on the properties of charcoal and the possibility of using anatomical characteristics for illegal trade control (Gonçalves *et al.* 2012; Muñiz *et al.* 2012).

In this context, it is important to analyze native species with commercial potential, particularly those growing in the Amazon region. The wood from *Byrsonima spicata*, *Calophyllum brasiliense*, *Cecropia sciadophylla*, *Cochlospermum orinocense* and *Schefflera morototoni* is used to build small structures, to make furniture, wine barrels, boxes, interior finish items, musical instruments and paper, as well as to produce charcoal (Paula and Alves 2007). Therefore, the aim of this study was to provide information on the anatomical characteristics, calorific power and volatiles and ash content of carbonized wood of these five species, to contribute to efforts to differentiate species and control illegal trade, as well as to support possible use of sawmill residues of these woods for making charcoal, to reduce waste.

## MATERIALS AND METHODS

The wood samples of the species *Byrsonima spicata* (Cav.) DC. (Malpighiaceae), *Calophyllum brasiliense* Cambess. (Calophyllaceae), *Cecropia sciadophylla* Mart. (Urticaceae), *Cochlospermum orinocense* (H.B.K.) Steud. (Cochlospermaceae), *Schefflera morototoni* (Aubl.) Decne. & Planch. (Araliaceae) came from the municipality of Nova Maringá, Mato Grosso state (13°1'2"S, 57°4'8"W). The trees were cut in a natural forest, and disks were extracted from the diameter at breast height (DBH), with thickness of about

8 cm. Eight samples were obtained of each species, with dimensions of 2 x 2 x 5 cm, oriented in the three anatomical planes. Each sample was wrapped in aluminum foil and carbonized in a muffle furnace (Q318S, Quimis, São Paulo, Brazil), with a final temperature of 450 °C and a heating rate of 1.66 °C min<sup>-1</sup>. The carbonized material remained at the final temperature for two hours.

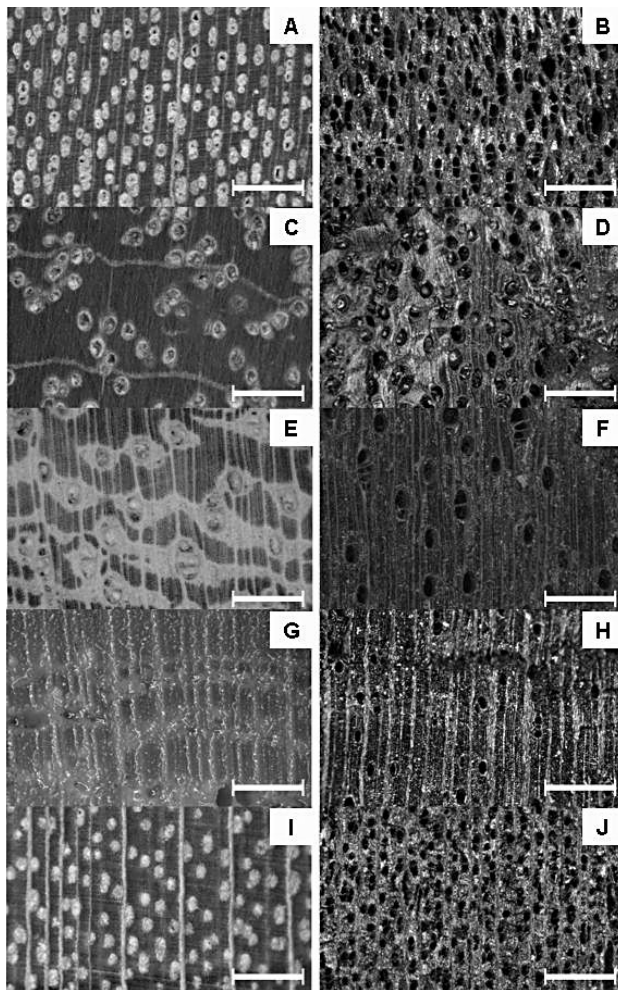
The description of the anatomical elements of the charcoal samples followed the orientations of the International Association of Wood Anatomists (IAWA 1989), on the basis of 25 readings regarding frequency and tangential diameter of the vessels and height and width of the rays in micrometers. The images of the general distribution of the cells in the transversal plane were obtained with a stereomicroscope with digital camera (Zeiss Discovery V12, Carl Zeiss, Göttingen, Germany). For detailed analysis, the samples were manually broken and fixed with a conductive carbon double-sided tape into traditional scanning electron microscopy stubs. The images were obtained directly from the carbonized material, without coating, with a tabletop microscope (TM-1000, Hitachi, Tokyo, Japan). The cell dimensions of the wood and charcoal were compared by the Tukey test at probability of 5% (Oliveira 2008).

A randomly selected portion of each charcoal sample was ground and sifted and the fraction retained between 40-60 mesh sieves was used for immediate chemical analysis, according to the NBR 8112 standard from the Brazilian Association of Technical Standards (ABNT 1983). The sample material was also used to measure the calorific power in an abiotic calorimetric pump (IKA 5000, Staufen, Germany), following the recommendations of NBR 8633 (ABNT 1984).

## RESULTS

The porosity and vessel arrangement of the species was more distinct after carbonization. Irregular contraction of vessels and rupture of rays were observed in *Byrsonima* and *Schefflera*. Axial parenchyma bands in *Calophyllum brasiliense* and aliform parenchyma in *Cecropia sciadophylla* were not observed in carbonized wood. In *Cochlospermum orinocense*, the vessels were more visible in charcoal (Figure 1). The summary of the anatomical characteristics is as follows:

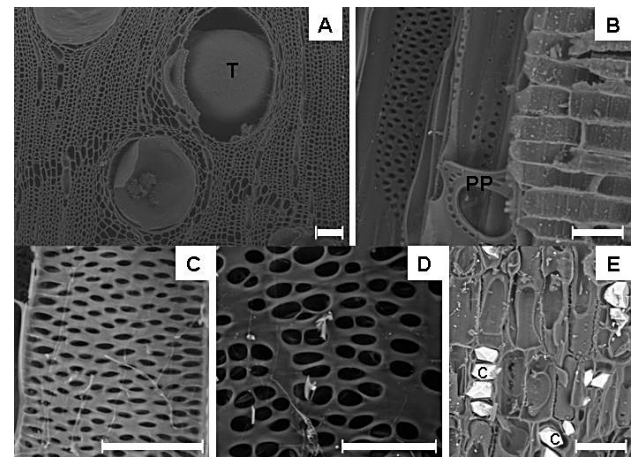
Growth rings distinct in *Schefflera morototoni* demarcated by difference in fiber walls, and indistinct in other studied species. Wood diffuse-porous; vessels solitary and in radial multiples of 2-4 present in *Byrsonima spicata*; vessels solitary and in radial multiples of 2-5 observed in *Cecropia sciadophylla*; vessels solitary, predominant, and occasional in radial multiples of 2-3 present in *Calophyllum brasiliense*, *Cochlospermum orinocense* and *Schefflera morototoni*. Tyloses occasional present in *Calophyllum* (Figure 2A) and *Cecropia*; simple perforate plates (Figure 2B) and alternate intervessel



**Figure 1.** *Byrsonima spicata* wood (A) and charcoal (B); *Calophyllum brasiliense* wood (C) and charcoal (D); *Cecropia sciadophylla* wood (E) and charcoal (F); *Cochlospermum orinocense* wood (G) and charcoal (H); *Schefflera morototoni* wood (I) and charcoal (J). Scale bar = 1 mm.

pits (Figure 2C-D) observed in all species. Vessel-ray pitting and vessel-parenchyma pitting are similar to intervessel pits; coarse vessel-ray pits observed in *Schefflera*.

Axial parenchyma is scanty paratracheal (*Byrsonima*, *Schefflera*), in bands (*Calophyllum*), vasicentric, aliform, confluent and in narrow marginal bands (*Cecropia*), vasicentric and in bands (*Cochlospermum*). Heterogeneous rays observed in all species; Ray width is variable, uniseriate (*Calophyllum*), with 1-3 seriate (*Byrsonima*), 1-4 seriate (*Cecropia*), 1-6 seriate (*Cochlospermum*), 3-4 seriate (*Schefflera*), irregularly storied in *Schefflera*. Prismatic crystals are present in marginal ray cells in *Byrsonima* (Figure 2E). Thick to very thick fiber walls were observed in *Byrsonima* and *Calophyllum*, thin fiber wall present in *Cecropia*, *Cochlospermum* and *Schefflera*, septate fiber present in *Schefflera*.



**Figure 2.** Transversal section of *Calophyllum brasiliense* charcoal (A); Radial section of *Schefflera morototoni* charcoal (B); Intervessel pits in *Cochlospermum orinocense* charcoal (C) and *Cecropia sciadophylla* charcoal (D); Crystals in *Byrsonima spicata* charcoal (E). T = tyloses; PP = perforation plate; c = crystal. Scale bar = 50  $\mu$ m

The dimensional changes in the anatomical structures between wood and charcoal did not present a uniform pattern (Table 1). The tangential diameter of the vessels decreased significantly in *Schefflera* (28%), *Cecropia* (29%) and *Byrsonima* (39%). The frequency of vessel increased in *Byrsonima*, *Calophyllum* and *Schefflera*. The ray width was the parameter that varied the least in terms of statistical significance, declining 22% in *Calophyllum* and 31% in *Cochlospermum*.

*Byrsonima spicata* and *Calophyllum brasiliense* were the species with the greatest number of dimensional variations in the characteristics analyzed between the wood and charcoal, with respective reductions of 36% and 17% in the frequency of rays and increases of 40% and 25% in the frequency of vessels. In *Calophyllum brasiliense*, only the tangential diameter of the vessels did not present a significant difference, in contrast to *Cecropia sciadophylla*, for which this was the only characteristic that diminished, due to the contraction of the wood during the carbonization process. Opposite behavior was observed in *Cochlospermum orinocense*, with a significant decline in the width and height of the rays, and *Schefflera morototoni*, in which there was no difference in ray dimensions.

Charcoal properties (Table 2) varied among species, calorific power from 26,878 to 31,117 kJ kg<sup>-1</sup>; volatile materials content from 20.9 to 31.7%; ash content from 0.1 to 3.8%; and fixed carbon from 68.2 to 75.3%. *Calophyllum brasiliense* was the species with lowest content of ash and fixed carbon and highest volatiles content. *Schefflera morototoni* was the species with highest calorific power and content of fixed carbon.



**Table 1.** Summary of changes in anatomical characteristics between wood (W) and charcoal (C). Data are given as mean and (standard deviation).

Species	Vessel diameter ( $\mu\text{m}$ )		Vessels $\text{mm}^{-2}$		Ray height ( $\mu\text{m}$ )		Ray width ( $\mu\text{m}$ )		Rays $\text{mm}^{-1}$	
	W	C	W	C	W	C	W	C	W	C
<i>Byrsonima spicata</i>	154.0a (16.8)	94.4b (31.0)	13.2a (2.3)	18.1b (2.0)	771.6a (277.4)	460.9b (197.6)	38.0a (14.0)	35.9a (13.9)	10.9a (1.7)	7.4b (1.1)
<i>Calophyllum brasiliense</i>	195.2a (33.9)	199.2a (56.7)	5.5a (1.4)	6.8b (2.3)	187.8a (51.3)	136.5b (49.1)	15.5a (2.8)	12.4b (2.9)	6.4a (1.5)	5.3b (1.8)
<i>Cecropia sciadophylla</i>	258.1a (48.6)	182.7b (52.9)	2.6a (1.1)	2.9a (1.4)	569.9a (249.9)	496.4a (138.4)	57.9a (13.4)	35.3a (6.2)	3.9a (0.8)	4.2a (1.5)
<i>Cochlospermum orinocense</i>	130.0a (26.9)	114.7a (29.0)	2.3a (1.2)	3.0a (1.6)	923.6a (275.0)	550.8b (326.2)	99.2a (23.1)	67.8b (36.9)	5.1a (0.8)	4.6a (1.5)
<i>Schefflera morototoni</i>	147.2a (23.0)	104.8b (22.0)	11.0a (2.2)	14.0b (3.3)	576.8a (155.5)	691.6a (302.3)	76.0a (9.1)	72.2a (20.8)	2.6a (0.6)	3.6b (1.1)

\*Means followed by the same letter in each specie characteristic, do not differ from wood and charcoal by the Tukey test at probability of 5%.

## DISCUSSION

In *Calophyllum brasiliense* and *Cecropia sciadophylla*, the opposite structure changes can be explained by the difference in the quantity and distribution of the axial parenchyma cells, wall thickness of the fibers and width of the rays, since *Calophyllum* presents narrow parenchyma bands, medium to thick fiber walls and uniseriate rays, unlike *Cecropia*, which has vasicentric parenchyma, thin wall fibers and from 2 to 4 multiple rays. Observing the wood anatomical structures, *Schefflera morototoni* has septate fibers and irregular ray stratification, characteristics absent in *Cochlospermum orinocense*, besides few parenchyma cells, resulting in statistically significant dimensional variations in opposite characteristics.

The influence of the fiber wall thickness, axial parenchyma cell quantity and distribution and ray width has also been noted by Prior and Gasson (1993), Kim and Hanna (2006), Kwon *et al.* (2009), among others, in reports of variations in function of the carbonization process of various species. An increase in the tangential diameter after carbonization at 400 °C of *Acacia tortilis*, *Ziziphus mucronata* and *Sclerocarya caffra* (Prior and Gasson 1993), and reduction in tangential diameter of the vessels in species from the cerrado (savannah) region of São Paulo (Gonçalves *et al.* 2012), were related to species and production process. A significant increase in the frequency of vessels in *Cedrelinga catenaeformis* and *Enterolobium schomburgkii*; a significant reduction of the vessel diameter in *Enterolobium*; a significant reduction in the ray width of *Cedrelinga*; and a significant increase in ray width of *Enterolobium* can be explained by the quantity of axial parenchyma cells and thickness of the fiber walls (Muñoz *et al.* 2012).

Dimensional variations are related to tangential contraction in volume (Vale *et al.* 2010). Although the carbonization temperature did not substantially modify the basic structure,

there was a reduction of the wall thickness of the axial parenchyma cells and contraction of the mechanical tissues (Lopez Pasquali *et al.* 2002). According to the authors cited above, the fact that the basic original structure is maintained in the solid residues can be attributed mainly to the residual lignin, which is the structural component of wood that degrades the slowest.

The characteristics of the carbonized wood of the species studied here are comparable with the descriptions of non-carbonized wood of these species, without identification of age and origin, found in Richter and Dallwitz (2000), Alves and Angyalossy-Alfonso (2002) and León and Williams (2006). Based on this information, the anatomical structure of the wood samples after carbonization can be used to enable identifying the species.

The charcoal contents of volatiles and ash obtained in the studied species are greater than those of the different eucalyptus species and clones normally used to make charcoal for the steel industry (Oliveira *et al.* 2010; Santos *et al.* 2011; Neves *et al.* 2011) and similar to those of some native species (Silva *et al.* 2007; Protásio *et al.* 2011). The levels of fixed carbon and calorific power are lower than those of eucalyptus species and clones (Oliveira *et al.* 2010; Neves *et al.* 2011; Santos *et al.* 2011) and similar to those of other species from cerrado regions and the Amazon Forest (Vale *et al.* 2001; Silva *et al.* 2007; Protásio *et al.* 2011).

According to Vale *et al.* (2001), the higher the content of fixed carbon and the lower the levels of volatiles and ash, the greater the calorific power of the wood or charcoal will be. For *Schefflera macrocarpa*, the authors found 77.4% fixed carbon; 21.5% volatile material; 1.05% ash; and 7,741 kcal kg<sup>-1</sup> of upper calorific power. They also observed a weak correlation between basic wood density and charcoal quality of the 12 cerrado species studied, so they did not recommend using

**Table 2.** Charcoal properties.

Species	Moisture (%)	Calorific Power (kJ kg <sup>-1</sup> )	Volatiles Compounds (%)	Ash (%)	Carbon (%)
<i>Byrsonima spicata</i>	4.4	27,705	27.9	1.3	70.8
<i>Calophyllum brasiliense</i>	3.1	28,657	31.7	0.1	68.2
<i>Cecropia sciadophylla</i>	4.2	29,212	20.9	3.8	75.3
<i>Cochlospermum orinocense</i>	4.6	26,878	24.2	3.4	72.5
<i>Schefflera morototoni</i>	4.5	31,117	22.6	2.0	75.3

basic density to estimate those variables. A study of the quality of charcoal made from two cerrado species against that made from *Eucalyptus grandis* concluded that the cerrado species carbonized individually were better for production of charcoal than eucalyptus, and that the two cerrado species had similar quality (Vale *et al.* 1996).

Studies have demonstrated that charcoal for making pig iron and steel should have fixed carbon content above 75%, since this content is directly responsible for the specific consumption of the reducer (carbon) and consequently for the production of pig iron. The ash content should be as low as possible, since high levels can cause accumulation of impurities inside solidified metal, causing variations in the physical, chemical and mechanical properties of pig iron (Neves *et al.* 2011).

According to the current regulations issued by the São Paulo state government, which require volatiles content lower than 23.5% for charcoal for household use, only charcoal from the species *Cecropia* and *Schefflera* is acceptable. On the basis of the ash content threshold (lower than 1.5%), *Calophyllum* and *Byrsonima* can be used. In relation to the fixed carbon level, none of the species would be acceptable for either household use (Rosa *et al.* 2012) or for iron and steel making (Neves *et al.* 2011).

## CONCLUSION

Anatomical structures of charcoal can be applied for species identification. The different dimensional changes between the species are the result of the variation of the fiber wall thickness and the arrangement of the axial parenchyma cells. The studied species are not indicated for charcoal production because the level of ash and volatiles are higher than those allowed for charcoal for household use and the calorific power and level of fixed carbon are insufficient for use in the steel industry.

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