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WOOD AND CHARCOAL ANATOMY OF FOUR MYRTACEAE SPECIES

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HIGHLIGHTS

Anatomical structure of charcoal from four native species of Myrtaceae family;

Some species from studied genera are in list of endangered;

Correct discrimination of charcoal in commerce control;

After carbonization: decrease in vessel diameter and ray dimensions.

ABSTRACT

Qualitative and quantitative changes in anatomical characteristics of charcoal from *Campomanesia xanthocarpa*, *Eugenia pyriformis*, *Myrcia retorta* and *Plinia peruviana* were described to provide its correct discrimination and information's to contribute to evaluations in illegal logging. The material came from Planalto Catarinense region, southern Brazil. For each species, three discs at diameter at breast height were collected from three randomly selected trees. All the disks were sectioned to obtain samples in different positions of the trunk (bark, intermediate and pith). Samples were wrapped in aluminum foil and carbonized in a muffle furnace, with a final temperature of 450 °C and a heating rate of 1.66 °C·min⁻¹. In species analyzed, growth rings are few distinct, delimited by fiber regions; solitary vessel and axial parenchyma diffuse or diffuse-in-aggregate is predominant. The wood to charcoal conversion caused variation in the following characteristics: vessel diameters decreased varying from 21.1% in *Myrcia retorta* to 33.4% in *Eugenia pyriformis*, while the vessel frequency increased with values from 50.7% to 92.3% related to the same species; height and width of the rays showed reduction, however, *Myrcia retorta* presented ruptures in ray cells and dimensions increased; ray frequency increased from 3.9% in *Eugenia pyriformis* to 54.1% in *Campomanesia xanthocarpa*. Qualitative characteristics of wood from studied species remained in charcoal after carbonization at 450 °C, being possible to discriminate the material based on wood anatomy. In charcoal, vessels dimensions and frequency, after ray characteristics can be applied as first step in this Myrtaceae species distinction at forest control.

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INTRODUCTION

In tropical forests of world, in charcoal production, literature report the use of native species from deforestation regions, and also that there is no selection of cut species. The process impact soil, affects global warming through the production and emission of gases, such as carbon dioxide and methane (Chidumayo and Gumbo, 2013). In Brazil, statistics shows that this scenario is being modified in function of environment legislation and more control in inspection process. In 2016, charcoal manufacture from native forest present a reduction of 31.7% (IBGE, 2016) and the use of planted species is estimated in 84% of total consume of country (IBÁ, 2017). On the other hand, data no included in official statistics shows that charcoal production present a high economic and social importance for much family farmers in southern Brazil and, in this case, native species are applied (Bauer et al., 2015).

In Santa Catarina, Brazil, the Araucaria Forest is composed by 925 species from 439 genera and 116 botanic families. Myrtaceae family is the second in number of species related (Gasper et al., 2013) and some of them are listed as endangered on Brazilian legislation, for example 5 species from genera *Campomanesia*, 20 from *Eugenia*, 10 from *Myrcia* and 8 from *Plinia* (MMA, 2014). A correct identification of species is important in forest control, and as in charcoal qualitative anatomical characteristics remain (Braadbaart and Pole, 2008; Kwon et al., 2009), a database from different species can help in its evaluation.

Changes in cell dimensions after carbonization process are described in literature as a response of anatomical and chemical composition of wood species and also process characteristics (heating rate, final temperature and total time), but qualitative information remains and can be applied in species identification (Nisgoski et al., 2014; Muñiz et al., 2016; Gasson et al., 2017). In general, tangential diameter of vessel presents reduction and its frequency an increase (Gonçalves et al., 2012, 2016) but are not linear and are related to species characteristics as fiber cell wall and parenchyma distribution (Gonçalves and Scheel-Ybert, 2016).

Some studies with charcoal from native species are present in literature, but from Myrtaceae family only charcoal from *Myrcia bella* (Gonçalves et al., 2016) was found. So, considering charcoal production and commerce with native species in southern Brazil, this paper has the objective to evaluate and compare wood and charcoal from four Myrtaceae species, to provide a correct discrimination and contribute to control of illegal logging, by providing information on carbonized wood.

MATERIAL AND METHODS

Three trees from *Campomanesia xanthocarpa* Berg, *Eugenia pyriformis* Cambess, *Myrcia retorta* Cambess, *Plinia peruviana* (Poir.) Govaerts, Myrtaceae family, were randomly selected in a natural Forest in Planalto Catarinense region southern Brazil. Botanical material was registered at Lages Herbarium, in University from Santa Catarina State – LUSC (Table 1).

TABLE 1 Data from studied species.

Species – Register Herbarium	DBH (cm)	Coordinates	Altitude (m)
<i>Campomanesia xanthocarpa</i> Berg			
LUSC 6188	39.5	lat: -27.497031 long: -50.810531 WGS84	680.0
LUSC 6189	34.0	lat: -27.483358 long: -50.808750 WGS84	730.0
LUSC 6190	22.0	lat: -27.483217 long: -50.808783 WGS84	733.0
<i>Eugenia pyriformis</i> Cambess.			
LUSC 6219	18.0	lat: -27.489200 long: -50.975007 WGS84	*
LUSC 6220	15.0	lat: -27.482667 long: -50.811278 WGS84	750.9
LUSC 6221	15.0	lat: -27.482761 long: -50.811514 WGS84	752.7
<i>Myrcia retorta</i> Cambess			
LUSC 6252	27.1	lat: -27.492825 long: -50.812278 WGS84	764.7
LUSC 6253	17.3	lat: -27.492783 long: -50.812303 WGS84	790.6
LUSC 6254	10.6	lat: -27.492894 long: -50.812364 WGS84	758.4
<i>Plinia peruviana</i> (Poir.) Govaerts			
LUSC 6324	25.8	lat: -27.497356 long: -50.810294 WGS84	713.3
LUSC 6325	26.0	lat: -27.493700 long: -50.803347 WGS84	622.5
LUSC 6326	22.7	lat: -27.493750 long: -50.802928 WGS84	708.5

* Without register.

For each tree, a disc at diameter at breast height (DBH) was selected for evaluations and a wedge with no defects of each one was cut. Material was divided into three samples oriented in anatomical sections (transversal, radial and tangential), with 2 x 2 x 2 cm, named as: near pith, intermediate, and near bark. For wood macroscopic characterization, samples were sanded with 2000 sandpaper.

Wood and charcoal analysis was made in the same samples. After wood evaluation, all samples (moisture content of $12 \pm 1\%$) were wrapped in aluminum foil and carbonized in a muffle furnace, with a final temperature of 450 °C and a heating rate of 1.66 °C·min⁻¹ based on Muñiz et al. (2012a). The carbonized material remained at the final temperature for two hours. Macroscopic description of wood and charcoal was based on images obtained in a Stereomicroscope Discovery V12 (Zeiss) with software Axio Vision Rel. 4.7. Charcoal details were obtained in a Hitachi TM-1000 tabletop scanning electron microscope (SEM) directly from the material, without coating. The description of the anatomical elements of

wood and charcoal samples followed the orientations of the International Association of Wood Anatomists (IAWA, 1989). Number of measurements were adapted on the basis of 30 readings regarding frequency and tangential diameter of the vessels; frequency, height and width of the rays in micrometers.

Data analysis was done in a factorial 2 x 3 considering kind of material (wood and charcoal) and different positions in disk (near bark, intermediate, near pith). Differences in dimensions between wood and charcoal were evaluated by Scott-Knott test at 95% of probability.

RESULTS AND DISCUSSION

Qualitative description

Campomanesia xanthocarpa Berg.

The wood present: Growth rings: few distinct by differences in fiber cell wall. Vessels: diffuse-porous (Figure 1A), elliptic and circular vessels, most solitary,

radial multiples of 2 present, simple perforate plate, intervessel pits alternate. Axial parenchyma: diffuse in aggregate (Figure 1A). Rays: heterogeneous, body ray cells procumbent with rows of square marginal cells; multiseriate predominant, uniseriate present, not storied. Fibers: libriform, non-septate and thick-walled. In charcoal, qualitative characteristic remained. It was possible to observe diffuse-porous, solitary vessel predominant, with more contrast (Figure 1B); few distinction of axial parenchyma (Figure 1C); heterogeneous rays (Figure 1D), uniseriate and multiseriate rays (Figure 1E). Intervessel pits alternated more visible (Figure 1F).

Eugenia pyriformis Cambess

The wood present: Growth rings: present, delimited by fiber regions. Vessels: diffuse-porous, elliptic and circular vessels, most solitary, radial multiples of 2-3 present, simple perforate plate, intervessel pits alternate. Axial parenchyma: in continuous bands (Figure 2A), apotracheal diffuse and diffuse in aggregate. Rays:

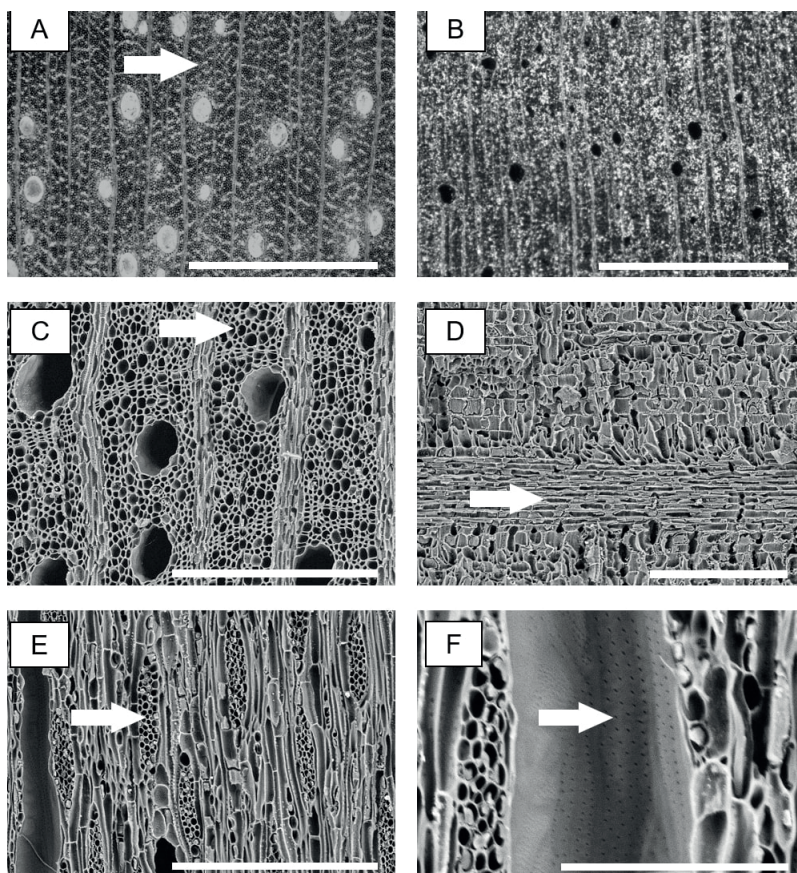


FIGURE 1 *Campomanesia xanthocarpa*. Macroscopic image of transversal section from wood (A), arrow indicating axial parenchyma, and charcoal (B). SEM images of charcoal: transversal section (C), arrow indicating axial parenchyma; radial section (D), arrow indicating rays; tangential section (E) arrow shows multiseriate ray; tangential section (F) arrow in alternate intervessel pits. Scale bars: A, B = 1000 μm ; C, D, E = 300 μm ; F = 100 μm .

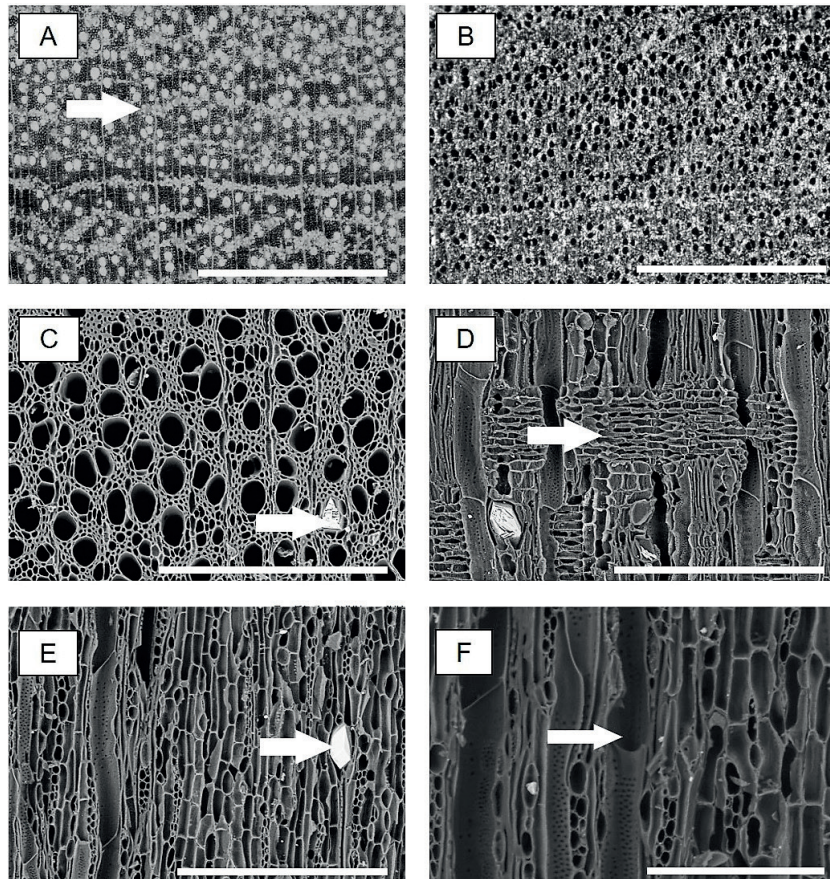


FIGURE 2 *Eugenia pyriformis*. Macroscopic image of transversal section from wood (A), arrow indicating axial parenchyma, and charcoal (B). SEM images of charcoal: transversal section (C), arrow indicating crystal in parenchyma cell; radial section (D) arrow indicating heterogeneous ray; tangential section (E) arrow demonstrates crystal in ray cell; tangential section (F) arrow shows simple perforate plate. Scale bar: A, B = 1000 μm ; C, D, E = 300 μm ; F = 100 μm .

heterogeneous, body ray cells procumbent with rows of upright and/or square marginal cells; uniseriate and multiseriate, not storied. Fibers: libriform, non-septate and thick-walled. In charcoal, its qualitative characteristics are the same: Vessels: diffuse-porous (Figure 2B), solitary predominant, radial multiples of 2-3 present (Figure 2C). Axial parenchyma in bands can be observed with some contrast. Rays: heterogeneous (Figure 2D), uniseriate and multiseriate, crystals present in ray cells (Figure 2E). Simple perforate plate more visible in charcoal (Figure 2F).

Myrcia retorta Cambess

The wood present: Growth rings: few distinct marked by fibers regions. Vessels: diffuse-porous (Figure 3A), rounded, solitary predominant, simple perforate plate, intervessel pits alternate. Axial parenchyma: apotracheal diffuse and diffuse in aggregate, scanty paratracheal. Rays: heterogeneous, body ray cells procumbent with rows of upright and/or square marginal

cells; multiseriate, not storied. Fibers: libriform, non-septate and thin-walled. In charcoal, some changes were verified after carbonization process. In transversal section it was possible to verify cracks in rays, probably in function of thin-walled fibers. Vessel present retraction (Figure 3B,C); few contrast in axial parenchyma; heterogeneous rays (Figure 3D) and multiseriate rays (Figure 3E) are more evident in charcoal. Simple perforate plate is also visible in radial section (Figure 3F).

Plinia peruviana (Poir.) Govaerts

The wood present: Growth rings: few distinct marked by fiber regions. Vessels: diffuse-porous (Figure 4A), rounded, exclusively solitary, simple perforate plate, intervessel pits alternate. Axial parenchyma: apotracheal diffuse and diffuse in aggregate, scanty paratracheal. Rays: heterogeneous, body ray cells procumbent with rows of upright and/or square marginal cells; multiseriate predominant, uniseriate present, not storied. Fibers: with distinct bordered pits, non-septate and thick-walled. In

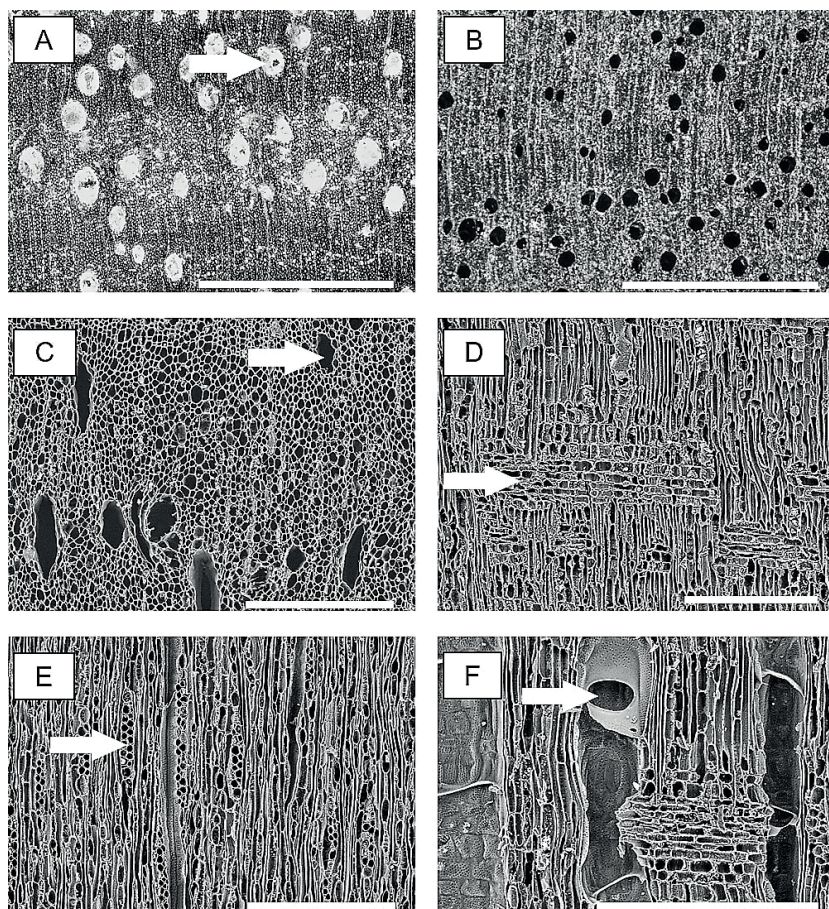


FIGURE 3 *Myrcia retorta*. Macroscopic image of transversal section from wood (A), arrow indicating rounded vessel, and charcoal (B). SEM images of charcoal: transversal section (C) arrow illustrating changes in vessel diameter; radial section (D) arrow showing heterogeneous ray; tangential section (E), arrow in multiserial ray; radial section (F), arrow in simple perforate plate. Scale bar: A, B, = 1000 μm ; C, D, E, F = 300 μm ;

charcoal, qualitative characteristics present the same distribution: vessels in diffuse-porous (Figure 4B), solitary predominant (Figure 4C); few contrast in axial parenchyma; heterogeneous rays (Figure 4D) and multiserial rays (Figure 4E) more visible. Simple perforation plate also visible in tangential section (Figure 4F).

Quantitative characteristics – variation in cell dimensions

Tangential diameter and frequency of vessel

Means of vessel diameter (Table 2) shows a decrease in all positions (near bark, intermediate, near pith) after carbonization process. Only for intermediate position of *Campomanesia xanthocarpa* alterations were not statistically significant. For all studied species and positions, vessel frequency increased after carbonization process (Table 2). Changes in values in different positions were influence by species and material (wood or charcoal).

Evaluating sample position in *Campomanesia xanthocarpa* wood it was verified a significant difference in vessel diameter between region near bark and near pith related to intermediate position, i.e. vessels were bigger in extremities. In charcoal, the same difference was observed, but the comportment was inverse, in intermediate region the reduction in vessel diameter was approximately 5% while in region near bark and near pith alterations were of 29-30%. Vessel diameter for wood and charcoal are similar to reports in literature for wood: in samples collected in Rio Grande do Sul, Santos and Marchiori (2011) related a vessel diameter varying from 17.5 to 141.3 μm , and Soffiatti et al. (2016) verified mean values of approximately 109 μm (52.48-139.79) in trees collected in Paraná state. In wood, region near bark present more vessel frequency in comparison to intermediate region and near pith. In charcoal all positions were distinct, and intermediate region present smallest vessel frequency. Increase in frequency was

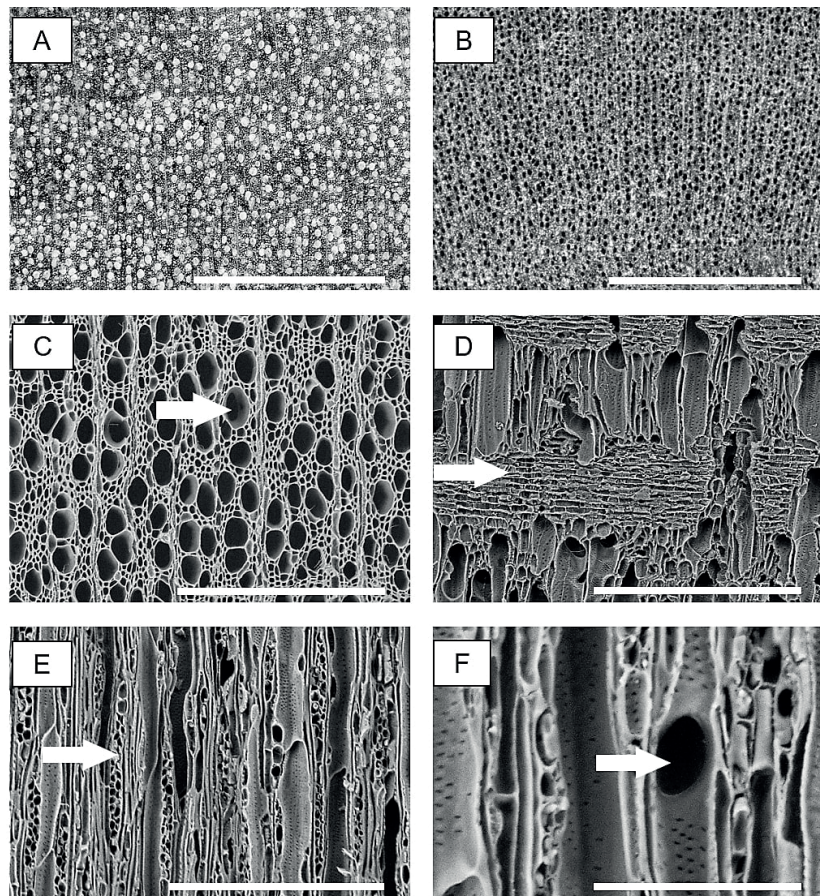


FIGURE 4 *Plinia peruviana*. Macroscopic image of transversal section from wood (A) and charcoal (B). SEM images of charcoal: transversal section (C), arrow indicate solitary vessel; radial section (D), arrow illustrating heterogeneous rays; tangential section (E,F) arrows showing multiseriate rays (E) and simple perforation plate (F). Scale bar: A, B = 1000 μm ; C, D, E = 300 μm ; F = 100 μm .

TABLE 2 Mean tangential diameter and frequency of vessel (standard deviation) of studied species.

Species	Material	Near bark	Intermediate	Near pith
Tangential diameter (μm)				
<i>Campomanesia xanthocarpa</i>	Wood	94.92 Aa (19.74)	81.79 Ab (25.83)	90.09 Aa (24.59)
	Charcoal	67.17 Bb (17.75)	77.32 Aa (23.10)	62.71 Bb (16.37)
<i>Eugenia pyriformis</i> *	Wood	34.72 Aa (5.31)	32.34 Ab (5.25)	30.50 Ac (5.83)
	Charcoal	23.74 Ba (5.30)	22.03 Bb (4.93)	19.34 Bc (4.96)
<i>Myrcia retorta</i> *	Wood	82.72 Aa (20.66)	75.65 Ab (19.24)	75.75 Ab (16.70)
	Charcoal	65.17 Ba (17.62)	57.57 Bb (15.03)	61.98 Ba (16.28)
<i>Plinia peruviana</i> *	Wood	30.34 Ab (5.21)	32.70 Aa (4.92)	28.89 Ab (5.66)
	Charcoal	23.25 Ba (5.20)	21.10 Bb (4.29)	20.44 Bb (3.75)
Vessel frequency ($\text{n}\cdot\text{mm}^{-2}$)				
<i>Campomanesia xanthocarpa</i>	Wood	10.24 Ba (3.73)	8.46 Bb (3.56)	8.76 Bb (2.67)
	Charcoal	16.47 Aa (5.23)	12.53 Ac (4.52)	15.08 Ab (4.31)
<i>Eugenia pyriformis</i>	Wood	124.16 Bb (21.95)	132.89 Bb (18.01)	174.10 Ba (40.04)
	Charcoal	250.87 Ab (55.62)	250.36 Ab (32.57)	326.62 Aa (90.77)
<i>Myrcia retorta</i>	Wood	14.06 Bb (3.37)	13.14 Bb (3.76)	21.97 Ba (8.71)
	Charcoal	23.24 Aa (7.31)	23.14 Aa (7.19)	24.31 Aa (5.02)
<i>Plinia peruviana</i> *	Wood	177.18 Bb (49.77)	162.87 Bc (31.48)	190.82 Ba (34.35)
	Charcoal	329.42 Aa (74.48)	300.34 Ab (60.01)	347.82 Aa (78.40)

For each species, equal letter in means do not present statistical differences by Scott-Knott test at 95% of probability. Capital letter in column refers to material (wood/charcoal) and small letters are related to position on disk (near bark, intermediate, near pith). *Species where interaction between material and position was not significant at 95% of probability.

observed after carbonization process in all positions, varying from 48% in intermediate region, to 72% near pith. Frequency is similar to wood reported by Santos and Marchiori (2011) in material from Rio Grande do Sul, varying from 12-25 vessels·mm⁻².

For *Eugenia pyriformis*, all positions presented decrease in vessel diameter after carbonization process, varying from approximately 32% in region near bark and intermediate, and 37% in region near pith. Also species shows a gradual reduction from bark to pith in vessel diameter of wood and charcoal. In wood of other species from genus *Eugenia*, Santos and Marchiori (2011) reported mean values varying from 25 to 61 µm in samples from Rio Grande do Sul, and Sonsin et al. (2014) related mean values of 56 µm in *Eugenia bimarginata* from Cerrado. For wood and charcoal region near pith present the great number of vessel mm⁻², and also the increase in number after carbonization process was observed in all positions, with values from approximately 88%, in intermediate region and near pith, until 102% near bark. In two species from Cerrado, Sonsin et al. (2014) verified mean frequency of vessel of 70 (*Eugenia bimarginata*) and 124 (*Eugenia rigida*), and Santos and Marchiori (2011) related in species from Atlantic Forest values from 20-143 vessels·mm⁻².

In *Myrcia retorta* wood, region near bark present vessels with bigger diameter, different from intermediate and near pith which are equal. In charcoal, diverse comportment was observed, decrease in dimension do not follow values of wood, intermediate region present smallest vessels and a reduction of 24%, region near bark (decrease of 21%) are similar to region near pith (decrease of 18%). Behavior of this species was similar to literature for other species. For wood of *Myrcia bella* from Cerrado, Sonsin et al. (2014) verified mean values of 64 µm and for charcoal, from the same material, Gonçalves et al. (2016) reported a mean value of 56 µm, varying from 39-80 µm. Evaluating differences between position in wood, region near pith present more vessels than intermediate and near bark. In charcoal it was not observed difference in vessel frequency in function of sample position. An increase in vessel frequency was verified after carbonization for all samples, and varied from 11%, in region near pith, to 76% in intermediate region. For *Myrcia bella* wood from Cerrado, Sonsin et al. (2014) related mean frequency of 37 vessels·mm⁻², and in charcoal, Gonçalves et al. (2016) reported a mean value of 44 vessels·mm⁻², varying from 32-60 µm, being similar to observed in this study for other species.

Observing *Plinia peruviana* wood, intermediate region present vessels with larger diameter, while region near bark and pith are similar. After carbonization process all samples showed reduction in vessel diameter, a reduction of 23%, 36% and 29% was verified for regions near bark, intermediate and near pith, respectively. Comparing only charcoal dimensions, region near bark is different from others and present vessels with bigger diameter. Small vessel diameter in genus *Plinia* is also reported for other species, for example, *Plinia rivularis* present values from 32.5-70 µm and *Plinia trunciflora* from 17.5-38.7 (Santos and Marchiori, 2011). All positions of wood are different in number of vessel, and fewer vessels were observed in intermediate region. In charcoal, intermediate region is different from near bark and near pith. In all samples an increase after carbonization process in vessel frequency was verified with little variation between positions: 86% in region near bark, 84% in intermediate region, and 82% near pith. In wood from other species from genus *Plinia*, a frequency of 75-162 was reported in literature (Santos and Marchiori, 2014).

Reduction in vessel diameter after carbonization process is the result of material contraction and must be influenced by species characteristics, and process conditions as heating rate, the difference in regimes and the duration of the process (Nisgoski et al., 2014). In carbonization process, chemical components of cell wall are degraded, and in consequence, the volume occupied by charcoal in a furnace is less than wood volume inside. This fact characterizes contraction of carbonized material and reduction in vessel diameter (Pereira et al., 2016). Higher extractives contents associated with lower crystallinity and lower crystallite size can accelerate the degradation process and reduce wood thermal stability (Poletto et al., 2012). Also fiber cell wall and kind of axial parenchyma can influence dimensional changes in vessel diameter (Muñiz et al. 2012a, 2016; Pereira et al., 2016).

In this study, evaluating mean reduction of vessel diameter by species, it was observed a great decrease in *Eugenia pyriformis* (33.4%), in sequence, *Plinia peruviana* (29.4%), *Campomanesia xanthocarpa* (21.7%) and *Myrcia retorta* (21.1%). Some studies in native species report reduction in vessel diameter after carbonization process, for example, in Cerrado species Gonçalves et al. (2012) related decrease in 70% of evaluated material; in five wood similar to *angelim*, Muñiz et al. (2016) verified changes in all species studied; and in five species from Santa Catarina state, Araucaria Forest, Carvalho et al.

(2017) reported decrease in tangential diameter of vessels in all samples.

Related to variations of vessel frequency by species after carbonization process, it was observed a great increase in *Eugenia pyriformis* (92.3%), in sequence, *Plinia peruviana* (84.0%), *Campomanesia xanthocarpa* (60.3%) and *Myrcia retorta* (50.7%). In all species it was observed increase in frequency and decrease in vessel diameter (Table 2) after carbonization and is the result of cell contraction in function of temperature. Changes in vessel frequency after carbonization process were commented in other studies: Nisgoski et al. (2014) evaluating samples of *Ocotea porosa* in different final temperatures in carbonization process observed no direct relation between decrease in vessel diameter and increase in vessel frequency. Other studies with forest species (Muñiz et al., 2012b; Nisgoski et al., 2012), angelim species (Muñiz et al., 2016) and Anacardiaceae species (Gonçalves and Scheel-Ybert, 2016) also showed the influence of species characteristics in changes in vessel frequency, as thickness of fiber wall and disposition of parenchyma cells.

Ray height and width

In most samples it was observed changes in ray height (Table 3). A reduction was present in *Campomanesia xanthocarpa*, *Eugenia pyriformis* and *Plinia peruviana*, and an increase in ray height occurs in *Myrcia retorta*. Mean value of ray width shows different comportment between position and species and also after carbonization process (Table 3). Differences in species can be related to percentage of multiseriate and uniseriate rays.

In ray height, in *Campomanesia xanthocarpa* wood, it was not observed differences between positions in direction pith to bark. In charcoal, region near bark present ray with the tallest dimensions. Decrease in ray height varied from 11% (near bark) to 18% (intermediate and near pith). Means results in wood are similar to values reported in samples from Atlantic Forest by Santos and Marchiori (2011) which related a mean ray height of 277 μm (140-570), and Soffiatti et al. (2016) who verified mean value of approximately 246.7 μm (51.35-480.86). In wood and charcoal it is possible to notice an increase in ray width from pith to bark. After carbonization, changes occurred in intermediate and region near bark, with decrease in ray width of 6% and 12%, respectively. In region near pith 5% of reduction was verified, with no statistical differences. Mean values of wood are greater than observed in tress from Araucaria Forest in Paraná

state, which varied from 5.7 to 41.8, with mean of 26.3 μm described by Soffiatti et al. (2016).

In *Eugenia pyriformis* wood and charcoal, ray height is similar in region near bark and intermediate portion, being greater than near pith. In all positions a decrease in dimension after carbonization process was observed with some different change, varying from 17% (near bark) to 20% (near pith), being 18% in intermediate region. Different species of *Eugenia* from Rio Grande do Sul, described in literature present ray with height varying from 92-1100 μm , showing a great difference (Santos and Marchiori, 2011). Some differences in positions were verified for wood and charcoal related to ray width. In wood, region near pith presented the smallest ray width and is statistically diverse from other positions. In charcoal, region near bark present the biggest dimension and is different from regions intermediate and near pith. Charcoal showed and decrease in ray width of 30% in region near bark, of 34% in intermediate position, and of 29% in region near pith.

In the species *Myrcia retorta* wood there is no difference between samples position, and in charcoal region near pith shows smallest rays, statistically diverse from region near bark and intermediate. Samples present diverse results from other species, after carbonization process an increase in ray height in all positions was observed, varying from 16% near pith to 34% in intermediate region. These results are related to ruptures in rays that were the result of expansion of cells walls. Ruptures in rays are also reported in *Quercus* sp. (Kim and Hanna, 2006), in some eucalyptus species (Gonçalves et al., 2014) and eucalyptus clones (Pereira et al., 2016). In wood, values are smallest than from *Myrcia hatschbachii* which present mean ray height of approximately 418 μm , varying from 172-899 μm (Soffiatti et al., 2016). In wood, ray width presented some differences in region bark, and for charcoal it was not observed variations in positions from pith to bark. All samples showed an increase in ray width after carbonization process, and changes of more than 50%. In wood, values of studied species are smallest than from *Myrcia hatschbachii* which present mean ray width of approximately 22 μm (Soffiatti et al., 2016).

For *Plinia peruviana* wood samples from region near bark and intermediate present biggest rays. In charcoal a non linear variation was observed, region near pith present smallest rays, it increased to intermediate position and decreased in region near bark. After carbonization process a decrease in ray height was verified in region near bark (17%) and pith (8%), on the other hand, intermediate position resulted in no significant statistically changes, with

TABLE 3 Mean ray height and width (standard deviation) of studied species.

Species	Material	Near bark	Intermediate	Near pith
Ray height (μm)				
<i>Campomanesia xanthocarpa</i> *	Wood	245.54 Aa (54.12)	248.18 Aa (57.06)	243.80 Aa (64.68)
	Charcoal	217.89 Ba (46.67)	204.45 Bb (58.13)	200.74 Bb (42.52)
<i>Eugenia pyriformis</i> *	Wood	168.79 Aa (43.14)	164.99 Aa (44.71)	151.91 Ab (46.36)
	Charcoal	139.98 Ba (37.74)	135.91 Ba (36.45)	121.93 Bb (40.51)
<i>Myrcia retorta</i>	Wood	167.65 Ba (55.53)	159.84 Ba (55.42)	159.83 Ba (52.25)
	Charcoal	206.66 Aa (43.81)	213.97 Aa (46.30)	185.85 Ab (42.45)
<i>Plinia peruviana</i> *	Wood	177.31 Aa (48.10)	174.76 Aa (54.33)	151.51 Ab (37.98)
	Charcoal	148.12 Bb (37.44)	163.79 Aa (45.03)	138.71 Bb (31.11)
Ray width (μm)				
<i>Campomanesia xanthocarpa</i> *	Wood	39.98 Aa (6.48)	33.61 Ab (7.69)	30.59 Ac (6.44)
	Charcoal	35.35 Ba (6.68)	31.45 Bb (6.49)	29.12 Ac (6.42)
<i>Eugenia pyriformis</i> *	Wood	16.16 Aa (3.39)	15.76 Aa (3.26)	14.60 Ab (2.54)
	Charcoal	11.37 Ba (3.08)	10.44 Bb (1.91)	10.39 Bb (2.30)
<i>Myrcia retorta</i> *	Wood	12.21 Ba (2.93)	11.14 Bb (2.52)	11.48 Bb (2.62)
	Charcoal	18.39 Aa (3.54)	17.81 Aa (3.97)	18.20 Aa (3.24)
<i>Plinia peruviana</i> *	Wood	18.62 Aa (4.66)	18.66 Aa (5.11)	16.54 Ab (4.85)
	Charcoal	13.88 Ba (3.40)	12.29 Bb (1.93)	11.16 Bc (2.68)

For each species, equal letter in means do not present statistical differences by Scott-Knott test at 95% of probability. Capital letter in column refers to material (wood/charcoal) and small letters are related to position on disk (near bark, intermediate, near pith). *Species where interaction between material and position was not significant at 95% of probability.

approximately 6% of reduction. The influence of sample position in ray width was observed only in region near pith, in wood. In charcoal, all material was different. After carbonization process, a decrease in all samples occurred. Changes varied from 26% (region near bark) to 34% (intermediate region).

In this study, evaluating mean changes of ray height by species, it was observed an increase of 24.3% in *Myrcia retorta*, and a decrease, in sequence, for *Eugenia pyriformis* (18.3%), *Campomanesia xanthocarpa* (15.7%) and *Plinia peruviana* (10.0%). Other studies with native species also report different comportment, in the same carbonization process of this study, related to thickness of fiber wall (Muñiz et al., 2012a), to characteristics of ray cell composition (homogeneous or heterogeneous) and comments about specific variations intra and inter individuals (Gonçalves et al., 2012).

For example, a reduction in ray height after carbonization process was observed in *Stryphnodendron polyphyllum* and *Tapirira guianensis* (Gonçalves et al., 2012), *Enterolobium schomburgkii* (Muñiz et al., 2012a), *Ficus citrifolia*, *Hieronyma laxiflora*, *Sapium glandulatum* (Nisgoski et al., 2015) and *Diplotropis purpurea* (Muñiz et al., 2016). On the other hand, an increase in ray height, is related in *Cedrelinga catenaeformis* (Muñiz et al., 2012a), in *Ocotea porosa* (Nisgoski et al., 2014), and no statistical changes were verified in *Hymenolobium petraeum*, *Parkia pendula*, *Vatairea guianensis* and *Vatairea paraensis* (Muñiz et al., 2016).

In this study, evaluating mean changes of ray width by species, it was observed an increase of 56.3% in *Myrcia retorta*, and a similar decrease for *Eugenia pyriformis* and *Plinia peruviana* (30.7%), and few reductions in *Campomanesia xanthocarpa* (7.6%). Decrease in ray width was also reported in *Enterolobium schomburgkii* (Muñiz et al., 2012a). The same behavior was related by Gonçalves et al. (2012) in *Stryphnodendron polyphyllum*, *Croton grandiflora* and *Vochysia tucanorum*. On the other hand, an increase in ray width was also observed in *Cedrelinga catenaeformis* (Muñiz et al., 2012a) and can be related to chemical changes in substances stored at parenchyma cells which can expand and result in gas components.

Variations in ray width by species can explain different comportment. It was commented by Kim and Hanna (2006), evaluating *Quercus variabilis*, that in uniseriate ray its morphological characteristics remained and cell presented small separations, instead of multiseriate rays showed disintegration in cell wall and honeycombed wood was verified with increase in carbonization temperature.

Ray frequency

After carbonization different behavior was observed and influence of position and species was verified (Table 4). Variations in position of *Campomanesia xanthocarpa* wood was only present between region near pith and other positions. In charcoal, all positions showed difference in ray frequency. After carbonization

process an increase in ray frequency was observed for all positions, varying from approximately 52%, in region near pith and near bark, to 58% in intermediate region. In wood, Santos and Marchiori (2011) verified a mean ray frequency of 13 mm⁻¹, varying from 10-15 evaluating wood from Rio Grande do Sul.

In *Eugenia pyriformis* wood, region near bark present less vessels by millimeter being different from other positions. In charcoal it was observed more rays in region near pith, being diverse from other samples. Changes in ray frequency after carbonization occurred only in position near bark, with an increase of 6%.

For *Myrcia retorta* positions from pith to bark present no influence in ray frequency in wood and charcoal. Some increase in frequency was observed for region near bark (10%) and intermediate region (7%). Gonçalves et al. (2016) reported in charcoal frequency of 17, varying from 13-21 rays by millimeter in *Myrcia bella*, in wood Sonsin et al. (2014) verified a mean value of 13 mm⁻¹.

Influence of position in samples from *Plinia peruviana* was only observed in intermediate region of wood material, which resulted in less frequency and is different from others. In charcoal production, an increase in ray frequency was verified for all positions, varying from approximately 29% in region near pith to 57% in intermediate region.

In this study, evaluating changes in ray frequency by species, it was observed an increase of 54.1% in *Campomanesia xanthocarpa*, 41.3% in *Plinia peruviana*, 5.9% in *Myrcia retorta* and 3.9% in *Eugenia pyriformis*. These variations are the results of different contraction and homogenization of cell wall. Ávila et al. (2017) comments that these variations can be explained by mass loss and wood contraction in function of carbonization process, but also intraspecific and ecological trends can be involved.

CONCLUSION

The wood to charcoal conversion caused variation in the following characteristics: decrease in vessel diameter; increase in vessel frequency; decrease in ray height and width in *Campomanesia xanthocarpa*, *Eugenia pyriformis* and *Plinia peruviana* and opposite behavior in *Myrcia retorta*; increase in vessel frequency in all species. The species *Myrcia retorta* presented ruptures in ray cells.

Qualitative characteristics of wood from studied species remained in charcoal after carbonization at 450 °C, being possible to discriminate the material based on wood anatomy. In charcoal, vessels dimensions and frequency, after ray characteristics can be applied as first step in this Myrtaceae species distinction at forest control.

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TABLE 4 Ray frequency (n·mm⁻¹) (standard deviation) of studied species.

Species	Material	Near bark	Intermediate	Near pith
<i>Campomanesia xanthocarpa</i> *	Wood	6.97 Bb (1.93)	7.29 Bb (2.30)	8.17 Ba (2.51)
	Charcoal	10.59 Ac (1.84)	11.54 Ab (1.91)	12.42 Aa (2.36)
<i>Eugenia pyriformis</i> *	Wood	9.78 Bb (2.21)	10.71 Aa (2.34)	10.91 Aa (2.24)
	Charcoal	10.40 Ab (1.89)	10.76 Ab (2.70)	11.42 Aa (2.02)
<i>Myrcia retorta</i> *	Wood	14.89 Ba (2.29)	15.10 Ba (3.19)	15.63 Aa (3.48)
	Charcoal	16.31 Aa (2.86)	16.12 Aa (2.70)	15.87 Aa (2.78)
<i>Plinia peruviana</i>	Wood	10.83 Ba (2.61)	9.60 Bb (2.59)	11.21 Ba (2.34)
	Charcoal	14.92 Aa (2.18)	15.04 Aa (1.63)	14.51 Aa (3.35)

For each species, equal letter in means do not present statistical differences by Scott-Knott test at 95% of probability. Capital letter in column refers to material (wood/charcoal) and small letters are related to position on disk (near bark, intermediate, near pith). *Species where interaction between material and position was not significant at 95% of probability.

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