BARBECUE CHARCOAL ANATOMY OF MARKETED BRANDS IN THE METROPOLITAN REGION OF FLORIANÓPOLIS, STATE OF SANTA CATARINA, BRAZIL

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Resumo

Anatomia do carvão vegetal para churrasco das marcas comercializadas na região metropolitana de Florianópolis, Santa Catarina, Brasil. O objetivo deste trabalho foi verificar a ocorrência de adulteração no carvão vegetal comercializado como sendo de acácia negra na região metropolitana de Florianópolis, estado de Santa Catarina, Brasil. A qualidade energética do carvão também foi analisada, visando o uso doméstico. Foram analisadas dez marcas que indicavam que o conteúdo da embalagem se tratava de carvão vegetal de acácia negra (*Acaciamearnsii* De Wild.). Foram analisadas 75 amostras de carvão por marca, que foram quebrados e orientados manualmente. O teste de friabilidade foi realizado com base na facilidade de quebra manual, recebendo notas de 1 (difícil), 2 (medianamente difícil) e 3 (fácil) de quebrar. Os parâmetros anatômicos qualitativos e quantitativos foram descritos conforme orientações da IAWA Committee (1989). As propriedades energéticas analisadas foram: composição química imediata e poder calorífico superior. Os caracteres anatômicos da madeira se mantiveram reconhecíveis após o processo de carbonização permitindo se estabelecer que todas as marcas analisadas tiveram adulteração na composição das espécies contidas nas embalagens. A variabilidade de espécies que compunham cada marca foi elevada, sendo possível formar sete grupos de similaridade, onde as amostras foram agrupadas com base em caracteres anatômicos comuns. A facilidade de quebra manual (friabilidade) teve relação direta com a maior qualidade do carvão vegetal. Todas as marcas de carvão vegetal tiveram baixa qualidade para uso na cocção de alimentos.
Palavras-chave: uso doméstico, anatomia da madeira, propriedades energéticas.

Abstract

The objective of this study was to verify the occurrence of adulteration in marketed charcoal as being of black wattle (*Acacia mearnsii* De Wild.) in the metropolitan region of Florianópolis, state of Santa Catarina, Brazil. The energetic quality of charcoal was also evaluated for domestic use. Ten brands were analysed which indicated that the contents of the package consisted of charcoal of black wattle. A total of 75 charcoal samples per brand were analysed (total of 750 samples), which were broken and manually oriented. The friability testing was performed based on the ease of manual breaking, receiving grades of 1 (difficult), 2 (moderately difficult) and 3 (easy) to break. Qualitative and quantitative anatomical parameters were described according to the International Association of Wood Anatomists Committee. The energetic properties analysed were proximate analyse and gross calorific value. The anatomical characters of the wood remained recognizable after the carbonization process, allowing to establish that all the analysed brands had adulteration in the composition of the species contained in the packages. The variability of the species that composed each brand was raised, in which seven groups of similarity were categorized, the samples were grouped based on common anatomical characters. The ease of friability of charcoal by manual breaking was directly related to the higher quality of the charcoal. All brands of charcoal had low quality for use in cooking food.
Keywords: domestic use, wood anatomy, energy properties.

INTRODUCTION

With regard to the origin of charcoal, 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 improved enforcement has increased the use of wood from planted forests (YAZDANI *et al.*, 2012). Even with the use of reforestation woods for charcoal production, a large part still comes from native forests and illegal logging. Due to this predatory exploitation of forest resources, measures to reduce the use of illegally harvested timber have been proposed, but they have found difficulties regarding the correct identification of carbonized species (MUÑIZ *et al.*, 2012).

In this regard, many charcoal producers and traders, who use wood from native forests or from illegal origin, use the strategy of informing in the packaging that charcoal comes from planted forests, mainly of the genus *Eucalyptus* and black wattle (*Acacia mearnsii* De Wild.). In such cases, the application of registration rules and inspection are hampered by the difficulty of identifying the species, making it necessary to obtain more information about the intrinsic characteristics of the charred wood to allow identification of the species (NISGOSKI *et al.*,2014b) and thus restrain the adulteration of charcoal.

A way of determining the origin of charcoal is to identify the material, determine the species carbonized, the legality of its exploitation and its possible place of origin. For the identification of the charcoal, the anthracology is used, in which the samples of charcoal are compared with samples of wood, or with their anatomical descriptions (KIM AND HANNA, 2006; GONÇALVES *et al.*, 2011; GONÇALVES *et al.*, 2012; NISGOSKI *et al.*, 2012; MUÑIZ *et al.*,2013; NISGOSKI *et al.*,2014a; NISGOSKI *et al.*,2014b), being very important a reference collection for comparison (NISGOSKI *et al.*, 2012). Therefore, the identification of charcoal is important to evaluate the behaviour of anatomical structures after carbonization and also has the objective of increasing the inspection of this product. In this way, the knowledge of the anatomy of charcoal can help in the control of the species in the charcoal supply chain (AFONSO *et al.*, 2015).

Thus, the objective of this study was to verify the occurrence of adulteration in charcoal marketed as being of black wattle. In addition, the energy quality of charcoal was also analysed for domestic use.

MATERIALS AND METHODS

Ten commercial brands (Table 1) were analysed for this study in the metropolitan region of Florianópolis, capital of the State of Santa Catarina, Brazil (Southern region of the country). Three packages (containing an average of 8 kg of charcoal) of each brand were purchased from twenty-two commercial establishments located in the municipalities of: São José (27º 36' 55" S e 48º 37' 39" W), Florianópolis (27º 35' 48" S e 48º 32' 57" W), Palhoça (27º 38' 43" S e 48º 40' 04" W), Governador Celso Ramos (27º 18' 53" S e 48º 33' 33" W), São Pedro de Alcântara (27º 33' 58" S e 48º 48' 19" W), Paulo Lopes (27° 57' 43" S e 48° 41' 02" W), Antônio Carlos (27° 31' 01" S 48° 46' 04" W), Santo Amaro da Imperatriz (27° 41' 16" S 48° 46' 44" W) and Biguaçu (27º 29' 39" S e 48º 39' 20" W) between April 28, 2015 and May 5, 2015.

Table 1- Description of the brands analysed in the study.
Tabela 1 – Descrição das marcas analisadas no estudo

Brand	Company location (city)	Place of purchase of charcoal
A	Palhoça[a]	São José[a]
B	São José[a]	Florianópolis[a]
C	Águas Mornas[a]	Florianópolis[a] São José[a]
D	Biguaçu[a]	Florianópolis[a]
E	Palhoça[a]	Palhoça, Governador Celso Ramos[a] e Florianópolis[a]
F	Palhoça[a]	Palhoça[a], Florianópolis[a]
G	Tubarão[a]	São Pedro de Alcântara[a] Palhoça[a]
I	Brochier[b]	Florianópolis[a]
H	Tabaí[b]	Palhoça[a]
J	Salvador do Sul[b]	Florianópolis[a]

[a] Santa Catarina State, Brazil, [b] Rio Grande do Sul State, Brazil

The brands were selected based on the specifications contained in the packaging and only the brands that indicated that the contents of the packaging were charcoal produced from black wattle wood (*Acacia mearnsii* De Wild.) were analysed.

Twenty-five pieces of charcoal were randomly collected from each package, totalling 75 charcoal samples per brand, which were broken and manually oriented. During the preparation, each sample received a grade regarding the ease of manual breaking (friability) of the charcoal (1 = difficult, 2 = moderately difficult and 3 =

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easy), as an indication of the carbonization quality of the wood. The images of the transverse section, with magnification of 10x, were obtained in a Zeiss stereomicroscope, model Stemi 2000-C, with integrated camera. Dimensions measurements were done with AxioVisionRel.4.8 software.

The anatomical description's protocol, which was used in this study, have considered only some qualitative and quantitative parameters recommended by the International Association of Wood Anatomists Committee - IAWA (1989). Thus, the anatomical analyses were performed only on the transverse section from qualitative and quantitative parameters. The qualitative ones were: porosity, vessels visibility, arrangement and distribution of vessels, visibility of rays and growth layers, presence of tyloses and gum/other deposits, and type of growth ring markers. The quantitative parameters analysed were based on 75 measurements for each vessel number per mm², width in number of cells and number of rays per mm, according to the International Association of Wood Anatomists - IAWA Committee (1989).

The origin of the wood used by the analysed brands for charcoal production was unknown and there was a lack of reference database (Anthracoteca). Therefore, the anatomical description did not seek to identify or describe all species or groups of species that are components of the analysed charcoal. The aim of the methodology used was to cluster the different charcoals according to their anatomical characteristics, which would allow researchers or inspector of enforcement agencies to verify the adulteration of the charcoal used for home use more quickly.

Thus, the study was limited to the use of stereomicroscopes of reflected light using only 10 x magnification, and the use of a camera and software, which ensure the quality of images obtained and measured. Muñiz *et al.* (2012) showed that the general anatomical aspect of distribution and cell types is quite evident, being possible the identification of carbonized material based on the structure of the wood. In some cases, it is not possible the specific identification in field, but for the general characteristics observed, it is possible to determine the group, with the exclusion of some potential species, using only stereomicroscope of reflected light with a magnification of 10 to 25x.

The anatomical description of each sample (brand) was compared with a known sample of black wattle (Fig.1A), thus indicating whether or not the charcoal contained in each package was of this species. When not compatible with the reference species, groups of similarity were arranged, based on the anatomical characters analysed, to determine the probable number of species or group of species present in the adulterated brands.

From each of the analysed brands, a subsample of 500g of charcoal was removed to determine the moisture content, according to EN 14774e3 (EN, 2009), proximate analysis by ASTM D1762-84 (ASTM, 2013) and gross calorific value by DIN 51900 (DIN, 2003). The determination of the energetic properties was performed to analyse the quality of the commercialized charcoal for barbecue and if this quality varied among the commercialized brands.

For friability and energetic properties, ANOVA and the Tukey test were applied at 5% of probability. For the anatomical parameters, the minimum, medium and maximum values, standard deviation and coefficient of variation were determined.

RESULTS

Level of adulteration in the composition of commercialized charcoal species

Fig. 1B shows a similar sample to the standard black wattle sample used to verify the adulteration of the charcoal contained in the packages identified as black wattle. The black wattle (*Acacia mearnsii* De Wild.) that should be contained in the packages of the analysed brands has indistinct or absent growth rings, diffuse-porous, 5 to 20 vessels per mm², gums or other deposits present in the vessels of the heartwood, vasicentric axial parenchyma, which may occur sparse and confluent paratracheal, multiseriate rays commonly 4 to 10 cells wide, and 4 to 12 rays/mm, and prismatic crystals present (INSIDEWOOD, 2016) (Fig. 1A).

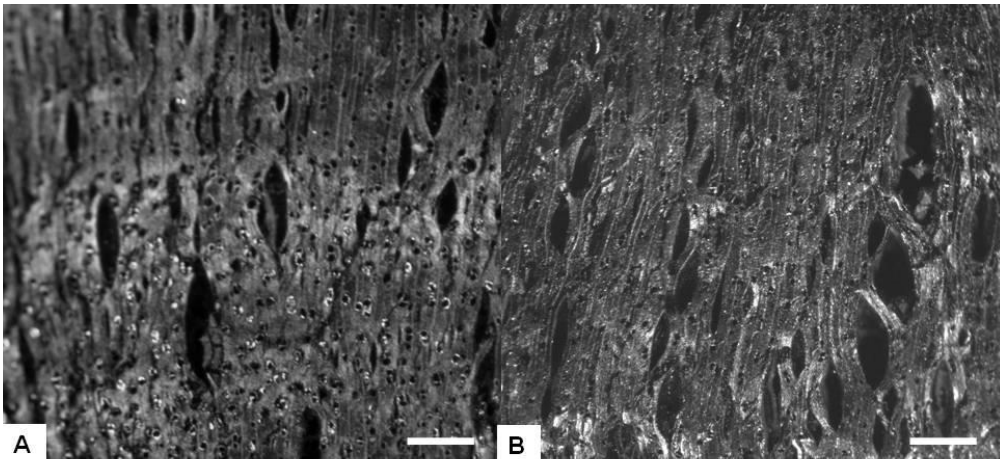

Figure 1 - Sample of black wattle used as reference to evaluate the analysed charcoal brands (A) and Sample considered as similar to standard sample of comparison - Brand G, specimen G124 (B). Scale bar = 1000 µm.
Figura 1 – Amostra de carvão de acacia negra usada como referência para avaliar as marcas de carvão (A) e amostra considerada como similar à amostra considerada padrão para comparação – marca G, amostra G124 (B). Barra da escala = 1000 µm.

However, in all analysed brands it was possible to verify adulteration in the composition of the species present in the packages, being the variability of species that composed each brand quite high (Table 2 and 3 and Fig.2).

According to the analysis of the images (Fig. 1 and Fig. 2), seven groups of similarity were categorized to allow the arrangement of the samples based on common anatomical characters (Table 2). It is important to emphasize that these groups contain one or more species, and the groups were formed only to allow the arrangement of similar samples with each other, in order to verify the range of variation of wood species present in each charcoal brand. However, there was no attempt to identify the component species of each group of similarity.

Table 2- Similarity groups based on the anatomical characters observed in the samples of each brand of charcoal analysed.
Tabela 2 – Grupos de similaridade baseados nos caracteres anatômicos observados nas amostras de cada marca de carvão analisada.

Similarity groups	**Anatomical characteristics**
Group 1	Solitary and multiple pores. Diffuse-pores, with tyloses or contents. Narrow rays (1 to 4 cells wide) (Fig. 2A)
Group 2	Solitary and multiple pores. Diffuse-pores, without tyloses or contents. Narrow rays (1 to 4 cells wide) (Fig. 2B)
Group 3	Solitary and radial multiple pores with 3, 4,5,6, 7 or more cells. Diffuse-pores, with or without tyloses or contents. Narrow rays (1 to 4 cells wide), with eventual presence of radial canals (Fig. 2C)
Group 4	Solitary pores, diagonal arrange, with or without tyloses. Narrow rays (Fig. 2D)
Group 5	Solitary, multiple, clusters and diffuse pores, with and without tyloses and very wide rays (Fig. 2E)
Group 6	Small and numerous pores, solitary, with or without tyloses. Narrow rays (Fig. 2F)
Group 7	Gimnosperm wood aspect, seeming to be representative of the genus *Pinus* (Fig 2G)

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Table 3 - Participation of each brand within the similarity groups of species and similarity with the standard black wattle sample.

Tabela 3 – Participação de cada marca dentro dos grupos de similaridade de espécies e similaridade com a amostra padrão de acacia negra.

Brand	Similarity to Black wattle (%)		G1	G2	G3	G4	G5	G6	G7
	Yes	No							
A	0.00	100.00	10.00	46.00		10.00			34.00
B	32.00	68.00	38.67	57.33	2.67	1.33			
C	10.67	89.33	24.00	53.33	14.67	4.00	2.67	1.33	
D	23.88	76.12	13.33	61.33		25.33			
E	13.33	86.67	5.33	54.67	32.00	5.33		2.67	
F	28.00	72.00	22.67	62.67	1.33	8.00		5.33	
G	28.00	72.00	18.00	80.00		2.00			
H	24.00	76.00	10.67	86.67	2.67				
I	29.33	70.67	8.00	85.33	1.33			5.33	
J	42.00	58.00	6.00	94.00					

The measurements made in the anatomical structure of the charcoal of the analysed brands also indicated a high variation in the composition of the charcoal species, as can be observed by the values of standard deviation and coefficient of variation in the analysed brands (Table 4).

Table 4 -Mean and standard deviation in vessels frequency and rays frequency in charcoal.

Tabela 4 – Médias de desvio padrão na frequência dos vasos e frequência dos raios no carvão vegetal.

Brand	Vessels/mm^2					Rays/mm				
	Min	Mean	Max	SD[a]	CV[b] (%)	Min	Mean	Max	SD	CV (%)
A	8	16	45	7.83	48.35	8	14	26	4.01	28.84
B	5	16	31	5.31	32.24	4	7	12	1.49	20.59
C	5	18	77	11.05	59.83	2	8	16	3.19	37.98
D	7	17	34	6.58	38.38	4	9	17	2.95	31.33
E	3	16	50	9.03	55.86	5	12	33	6.71	55.26
F	8	20	50	9.77	49.62	4	8	17	2.61	32.07
G	8	17	32	5.50	32.83	5	8	12	1.69	22.35
H	9	20	34	6.12	31.10	5	8	18	2.16	25.68
I	7	17	33	5.04	29.63	6	9	14	1.83	21.41
J	10	18	30	6.23	35.41	5	7	10	1.44	19.30

[a]SD - Standard deviation[b] CV – Coefficient of variation

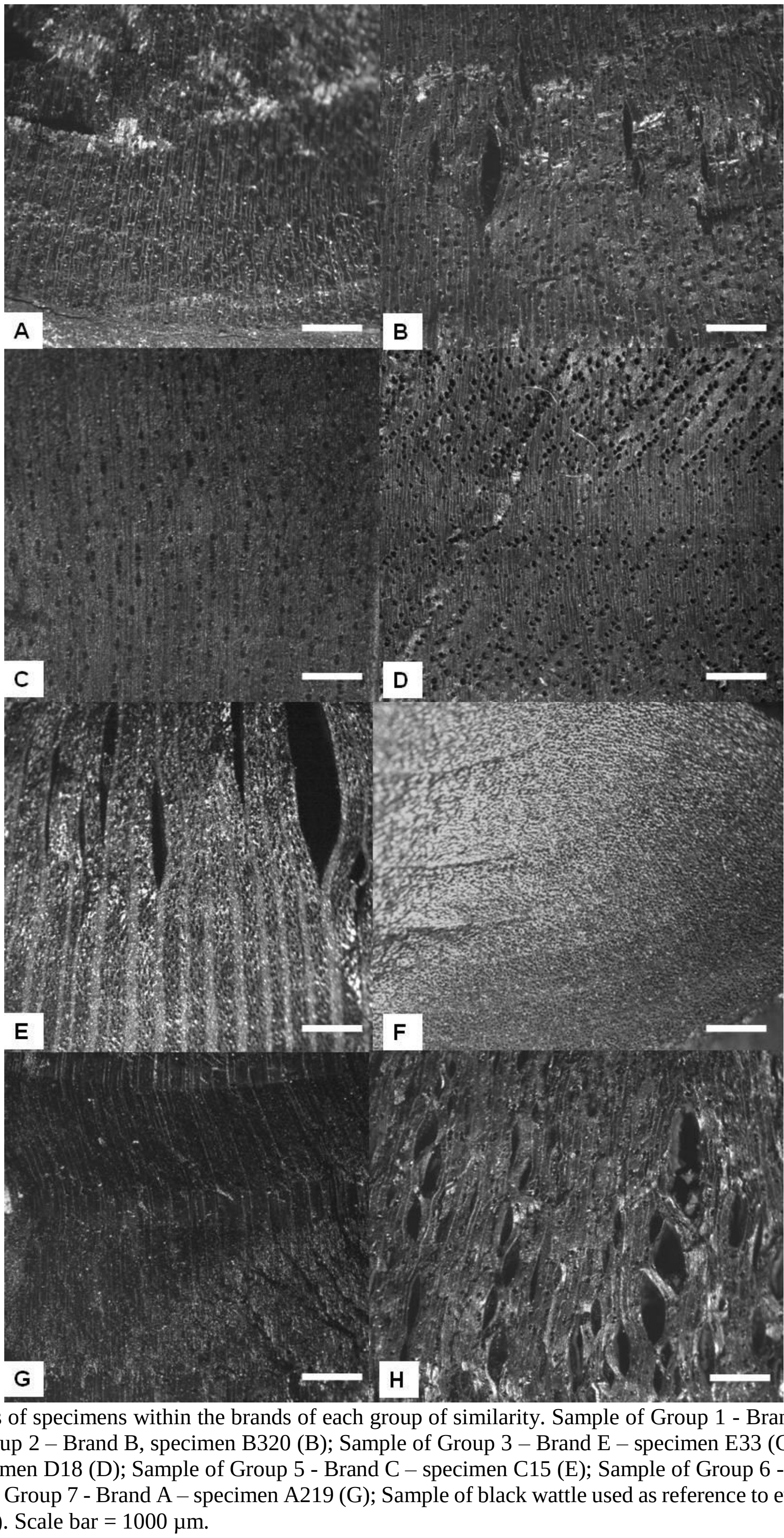

Figure 2 -Examples of specimens within the brands of each group of similarity. Sample of Group 1 - Brand H, specimen H18 (A); Sample of Group 2 – Brand B, specimen B320 (B); Sample of Group 3 – Brand E – specimen E33 (C); Sample of Group 4 - Brand D – specimen D18 (D); Sample of Group 5 - Brand C – specimen C15 (E); Sample of Group 6 - Brand I – specimen I318 (F); Sample of Group 7 - Brand A – specimen A219 (G); Sample of black wattle used as reference to evaluate the analysed charcoal brands (H). Scale bar = 1000 µm.

Figura 2 – Exemplos de amostras de cada marca em cada grupo de similaridade. Amostra do Grupo 1 – marca H, amostra H18 (A); Amostra do Grupo 2 – marca B, amostra B320 (B); Amostra do Grupo 3 – marca E – amostra E33 (C); Amostra do Grupo 4 – marca D – amostra D18 (D); Amostra do Grupo 5 – marca C – amostra C15 (E); Amostra do Grupo 6 – marca I – amostra I318 (F); Amostra do Grupo 7 – marca A – amostra A219 (G); Amostra de carvão de acacia negra usada como referência para avaliar as marcas de carvão (H). Barra da escala = 1000 µm.

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Friability of charcoal by manual breaking

When considering the categories of resistance to manual breaking, in the category difficult to break, the brand A had the lowest percentage of hard to break pieces and was statistically different than the brand J which had the highest percentage of hard to break pieces of charcoal. Both brands were statistically similar to all others. The same happened with the easy to break pieces of charcoal, highlighting the brand A with the highest percentage of easy breaking, statistically different from brand J, and both equal to all others. The proportion of moderately difficult pieces of charcoal to break was statistically similar for all the brands analysed (Table 5).

Table 5- Resistance to manual breaking of the analysed brands.
Tabela 5 – Resistência à quebra manual das marcas analisadas.

Brand	Categories of resistance to manual breaking					
	Difficult to break (%)[a]		Moderately difficult to break (%)[a]		Easy to break (%)[a]	
A	10.67	b	32.00	a	57.33	a
H	28.00	ab	41.33	a	30.67	ab
G	23.84	ab	48.15	a	28.01	ab
C	24.00	ab	48.00	a	28.00	ab
F	28.00	ab	49.33	a	22.67	ab
D	37.33	ab	41.33	a	21.33	ab
B	20.00	ab	60.00	a	20.00	ab
E	40.00	ab	44.00	a	16.00	ab
I	37.33	ab	48.00	a	14.67	ab
J	47.91	a	40.05	a	12.04	b
Mean[b]	**29.71**	**B**	**45.22**	**A**	**25.07**	**B**
CV (%)	**41.75**		**30.38**		**61.16**	

[a]Means IN COLUMN followed by the same letter do not differ statistically between them at 5% of probability by the Tukey test.
[b]For the mean of each category, values followed by the same letter IN LINE do not differ statistically between them at 5% of probability by the Tukey test.

Quality of charcoal marketed for domestic use

The energetic properties of the charcoal also varied among the analysed brands (Table 6).

Table 6- Physical and energetic charcoal properties of 10 brands of charcoal for domestic use.
Tabela 6 – Propriedades físicas e energéticas das 10 marcas de carvão vegetal para uso doméstico.

Brand[a]	MC[b] (%)		VC[c] (%)		FCC[d] (%)		AC[e] (%)		GCV[f] (MJ/kg)	
A	7.9	a	25.47	b	71.68	a	2.84	a	31.02	bc
B	7.4	b	26.14	b	72.62	a	1.24	b	31.27	b
C	7.3	b	25.69	b	72.52	a	1.78	b	30.54	bc
D	7.4	b	31.27	a	68.03	b	0.69	b	30.33	c
E	7.7	a	28.98	a	69.48	b	1.54	b	29.35	d
F	7.4	b	29.35	a	69.33	b	1.32	b	30.77	bc
G	7.0	b	25.71	b	72.84	a	1.45	b	32.18	a
H	7.2	b	31.84	a	66.69	b	1.47	b	30.14	cd
I	7.8	a	28.30	a	70.03	b	1.67	b	30.56	bc
J	7.5	b	32.12	a	66.22	b	1.66	b	30.45	bc
Mean	**7.45**		**14.17**		**70.24**		**1.61**		**30.66**	
CV (%)	**5.62**		**28.14**		**5.76**		**56.72**		**0.99**	

[a]Means IN COLUMN followed by the same letter do not differ statistically between them at 5% of probability by the Tukey test.
[b]MC = moisture content (%)
[c]VC = volatile content (%)
[d] FCC = fixed carbon content (%)
[e]AC = ash content (%)
[f]GCV = gross calorific value (MJ/kg).

DISCUSSION

Level of adulteration in the composition of commercialized charcoal species

Although the anatomical structure of the charcoal is closely related to the anatomy of the wood, some modifications were observed by several authors such as: the reduction of the tangential diameter of the vessels (GONÇALVES *et al.*, 2011; GONÇALVES *et al.*,2012; NISGOSKI *et al.*, 2012; GONÇALVES *et al.*, 2014;MUÑIZ *et al.*, 2013); increase the number of vessels per mm² (NISGOSKI *et al.*, 2012; MUÑIZ *et al.*, 2012; MUÑIZ *et al.*, 2013); increase the frequency of vessels (GONÇALVES *et al.*,2012; GONÇALVES *et al.*, 2014); shrinkage in the width of the rays (GONÇALVES *et al.*, 2011; MUÑIZ *et al.*, 2013) and height of the rays (MUÑIZ *et al.*, 2013); increase the frequency of rays (GONÇALVES *et al.*, 2011; GONÇALVES *et al.*,2012; GONÇALVES *et al.*, 2014); cracks that accompanied the parenchyma line, also occurring in some rays (NISGOSKI *et al.*, 2012); uniseriate rays contract more than multi-seriates (NISGOSKI *et al.*, 2012); disintegration of the membrane and edge of the pits and perforation plates (HOADLEY, 1990; NISGOSKI *et al.*, 2012).

In this research, brand A had none of the samples similar to black wattle. The samples were compared to images of *Pinus* charcoal from the work of Muñiz *et al.* (2012) and based on this comparison it was possible to verify that 34% of the samples had the appearance of gymnosperm wood (Table 3). Since the use of species of *Pinus* genus for multiple uses is common in the study area, it is possible that charcoal was produced with species of this genus.

Muñiz *et al.* (2012) studied ten forest species and verified that there is a strong distinction between gymnosperms, in which growth rings are evident, and angiosperms, which show some cracks in the rays and parenchyma lines, and that most species maintained the anatomical structures, where the comparison with a reference collection is extremely important.

While the J and B brands had the highest percentage of samples similar to the species described on the package, the C, E and F brands had the largest variations of component species, having samples belonging to 5 or 6 similarity groups, and also had the highest coefficients of variation for vessels/mm² and rays/mm (Table 4).

Regarding the anatomical structure of the charcoal, Muñiz *et al.* (2012) observed the influence of the species on the behaviour of the vascular elements, in which in some species, the vessels contracted significantly, and in others they burst, increasing in size by carbonization in the process described above. Gonçalves *et al.* (2011); Gonçalves *et al.* (2012); Nisgoski *et al.* (2012); Muñiz *et al.* (2012); Muñiz *et al.*(2013) and Gonçalves *et al.* (2014) also reported the significant variation in vessel diameter and vessel frequency for other carbonized woods, indicating the influence of the species on the alterations of the anatomical structure in the charcoal.

Considering that the composition of the charcoal should be only black wattle and that this species has 5 to 20 vessels per mm² and 4 to 12 rays/mm, the observed values also confirmed the variability of species present in the brands. The minimum and maximum values, as well as the coefficient of variation within the samples reinforce the possibility of the existence of a mixture of species in the composition of the charcoal brands. Several authors obtained much lower values of standard deviation for the same structures measured within the same species. Afonso *et al.* (2015) found standard deviations varying from 1.1 to 4.8 for vessels/mm² and 1.1 to 3.2 for rays per mm; Nisgoski *et al.* (2015) found 1.5 to 5.77 and 0.99 to 1.97; Nisgoski *et al.* (2014b) calculated values from 1.4 to 3.3 and 1.1 to 1.8 and Nisgoski *et al.* (2014a) found 1.71 to 2.87 and 0.96 to 1.38 of standard deviation, respectively for vessels/mm² and rays per mm. In addition to that, Nisgoski *et al.* (2012) observed 2.01 to 7.61 for vessels/mm² for different carbonized wood species.

The vitrification of some samples of charcoal also hampered the process of comparison and identification. The vitrification of charcoals corresponds to a variable fusion of anatomical constituents within the wood, leading to homogenisation of the structure that makes identification impossible when the process reaches its final stage. The vitrified charcoals become very dense and refractive, with “sub-conchoidal” fractures. The fusion may be associated with radial cracks. Vitrification often affects small pieces of wood such as twigs. Nevertheless, more generally, this alteration of the anatomical structure by fusion may result from specific conditions of combustion, and can reveal the state of the wood before combustion (MARGUERIE AND HUNOT, 2007).

Friability of charcoal by manual breaking

According to Braadbaart and Poole (2008), for both low and high heating rates, in the carbonization performed at temperatures up to 300° C, the characteristics of the wood do not vary much, the colour becomes darker, but the texture and properties are essentially those of wood and not of charcoal. Between 310 and 370° C, the physical properties of wood change and the wood begins to have the typical charcoal aspect. This alteration is accompanied by a more pronounced change in colour (dark brown to black), possibility of breaking the sample by hand (increase the friability) and loss of mass (becoming relatively light). Likewise, charred samples at 450ºC, easily fracture by hand, without becoming excessively friable or producing dust.

The analyzed charcoal is produced in furnaces, the process control occur by changing the color of the smoke, and closing the chimneys and air intakes of the furnaces as the smoke becomes translucent, until complete closing of the furnace, followed by cooling. The carbonization control depends on the experience of the process conductors, lasting around 7 to 8 days. Therefore, the conduction of the process is empirical and observations made in furnaces in the study region indicate that the maximum temperatures reached are around 450º C. Thus, brands that demonstrated a greater proportion of manual breaking difficulty may indicate that the wood was not fully charred and this may contribute to the reduction of the quality of charcoal for domestic use.

Quality of charcoal marketed for domestic use

In relation to the moisture content, the B, C, D, F, G, H, and J brands formed a group with lower moisture content, being statistically different from the A, E, and I brands with higher moisture content forming similar groups with each other.

For the proximate analysis, the A, B, C, and G brands had the lowest values of volatile content, being statistically equal to each other, and different from the group formed by the D, E, F, H, I, and J brands with the highest volatile content. For the fixed carbon, the D, E, F, H, I, and J brands were statistically similar to each other, with lower fixed carbon content, and different from the group formed by the A, B, C, and G brands with higher fixed carbon content. For the ash content, the A brand had the highest ash content and was statistically different from all other samples.

The proximate analysis confirms the results obtained for the friability of the charcoal, in which the A brand with the highest percentage of samples easy to break also showed the lowest volatile content, high fixed carbon content, indicating that the carbonization was well conducted and the charcoal produced had better quality, together with the B, C and G brands. The J brand, which had the highest percentage of hard to break samples, also had the highest volatile content and the lowest fixed carbon content, confirming that friability may be an indicative of the proximate chemical composition and quality of charcoal for domestic use.

For calorific value the brand G had the highest value and was statistically different from the other brands, and the lowest value was observed for brand E, also different from all other brands analyzed. The A, C, F, I and J brands were similar to each other. As for calorific value, Brand *et al.* (2015) observed a higher variance among brands of charcoal commercialized for barbecue than what was observed in this paper. The same authors also obtained lower values for the calorific value of charcoal.

In Brazil, only the state of São Paulo (Southeast region of the country) has created a legislation that regulates the quality that charcoal must have for domestic use, establishing the minimum or maximum parameters for the properties of moisture content, volatile content, fixed carbon and ash content of charcoal. Therefore, in scientific studies that have been studying the quality of charcoal for domestic use, this legislation was used to determine the quality of this product (BRAND *et al.*, 2015).

The Resolution nº 40 SAA/2015 (SÃO PAULO, 2015) determines that the fixed carbon content (FCC) must be greater than 73% and ash content (AC) should be less than 1,5%. None charcoal brand meets the required standards for fixed carbon content. For ash content the B, D, F, G and H brands meet the values determined by the Premium Seal. The results obtained here for quality are equivalent to those obtained by Brand *et al*. (2015). These authors evaluated the quality of charcoal for domestic use in the south mountain region of Santa Catarina and found a low quality for this product.

CONCLUSIONS

- All the analysed brands had adulteration in the composition of the species contained in the packages.
- The variability of the species that composed each brand was high, in which seven groups of similarity were categorized, the samples were grouped based on common anatomical characters.
- The friability of charcoal by manual breaking was an indication of the proximate chemical composition and charcoal quality for domestic use.
- All brands of charcoal had low quality for use in cooking food.

REFERENCES

AFONSO, C.M.I.; GONÇALVES, T.A.P.; MUÑIZ, G.I.B.; MATOS, J.L.M.; NISGOSKI, S. Mozambique's charcoals: anatomy of nine native species. **Bosque,** v. 36, n. 1, p. 105-112,2015.

AMERICAN SOCIETY FOR TESTING AND MATERIALS. ASTM, D 1762-84: Standard Test Method for Chemical Analysis of Wood Charcoal. 2013.

BRAADBAART, F.; POOLE, I. Morphological, chemical and physical changes during charcoalification of wood and its relevance to archaeological contexts. **J ArchaeolSci**, v.35, n. 9, p. 2434-2445, 2008.

BRAND, M.A.; RODRIGUES, A.A.; OLIVEIRA, A. De; MACHADO, M.S.; ZEN, L.R. Quality of charcoal for domestic consumption marketed in the Southern Highlands Region of Santa Catarina. **Árvore**, v. 39, n. 6, p. 1165-1173, 2015.

DEUTSCHES INSTITUT FÜR NORMUNG. DIN 51900: 2 Determining the gross calorific value of solid and liquid fuels using the isoperibol or static-jacket calorimeter, and calculation of net calorific value, Berlin, 2003.

EUROPEAN COMMITTEE FOR STANDARDIZATION. CEN. EN 14774e3, Determination of moisture content e Part 3: oven dry method, Moisture in general analysis sample, Brussels, 2009.

GONÇALVES, T.A.P.; MARCATI, C.R.; SCHEEL-YBERT, R. Wood and charcoal anatomy in species of the Brazilian cerrado: effect of carbonization on wood structure. **SAGVNTVM**, v. Extra 11, p. 51-52, 2011.

GONÇALVES, T.A.P.; MARCATI, C.R.; SCHEEL-YBERT, R. The effect of carbonization on wood structure of *Dalbergiaviolaceae, Stryphnodendron polyphyllum*, *Tapirira guianensis*, *Vochysia tucanorum*, and *Pouteria torta* from the Brasilian cerrado. **IAWA Journal,** v.33, n. 1, p. 73-90, 2012.

GONÇALVES, T.A.P.; BALLARIN, A.W.; NISGOSKI, S.; MUÑIZ, G.I.B. A contribution to the identification of charcoal origin in Brazil: I-anatomical characterization of *Corymbia* and *Eucalyptus*. **Maderas, Ciencia y Tecnología**, v. 16, n. 3, p. 323-336,2014.

HOADLEY,R.B.1990. **Identifying wood: accurate results with simple tools.** USA: Taunton Press.

IAWA COMMITTEE.IAWA List of microscopic features for hardwood identification. **IAWA Bulletin,** v.10, n. 3, p. 219-332, 1989.

INSIDEWOOD.**Modern Wood Taxonomyby Genus.** Available from:<http://insidewood.lib.ncsu.edu/description?7.>Accessed in: 20/05/2016.

KIM, N.H.; HANNA, R.B. Morphological characteristics of *Quercus variabilis* charcoal prepared at different temperatures. **Wood SciTechnol,** v.40, n. 5, p. 392-401, 2006.

MARGUERIE, D.; HUNOT, J.Y. Charcoal analysis and dendrology: data from archaeological sites in north-western France. **Journal of Archaeological Science**, v. 34, n. 9, p. 1417-1433, 2007.

MUÑIZ, G.I.B.; CARNEIRO, M.E.; NISGOSKI, S.; RAMIREZ, M.G.L.; MAGALHÃES, W.L.E. SEM and NIR characterization of four forest species charcoal. **Wood Sci Technol**, v.47, n. 4, p. 815-823, 2013.

MUÑIZ, G.I.B.; NISGOSKI, S.; SHARDOSIN, F.Z.; FRANÇA, R.F. Charcoal anatomy of forest species. **Cerne**, v. 18, n. 3, p. 471-477,2012.

NISGOSKI, S.; MUÑIZ, G.I.B.; BATISTA, F.R.R.; MÖLLEKEN, R.E. Influence of carbonization temperature on the anatomical characteristics of *Ocotea porosa* (Nees *et* Mart. ex Nees) L. Barroso. **Wood SciTechnol**, v. 48,n. 2, p. 301-309,2014a.

NISGOSKI, S.; MAGALHÃES, W.L.E.; BATISTA, F.R.R.; FRANÇA, R.F.; MUÑIZ, G.I.B.Anatomical and energy characteristics of charcoal made from five species. **Acta Amazonica**, v. 44, n. 3, p. 367-372, 2014b.

NISGOSKI, S.; MUÑIZ, G.I.B.; FRANÇA, R.F.; BATISTA, F.R.R. *Copaifera* cf. *langsdorfii* Desf. And *Dipteryx odorata* (Aubl.) Wild. charcoal anatomy. **Braz. J. Wood Sci.**, v.3, n. 2, p.66-79,2012.

NISGOSKI, S.; MUÑIZ, G.I.B.; MORRONE, S.R.; SCHARDOSIN, F.Z.; FRANÇA, R.F. NIR and anatomy of wood and charcoal from Moraceae and Euphorbiaceae species. **Braz. J. Wood Sci.**, v. 6, n. 3, p.183-190, 2015.

SÃO PAULO (Estado) Secretariat of Agriculture and Supply of São Paulo. Resolução n°40 SAA, de 14 de dezembro de 2015. São Paulo,2015. (in Portuguese)

YAZDANI, M.G.; HAMIZAN, M.; SHUKUR, M.N. Investigation of the fuel value and the environmental impact of selected wood samples gathered from Brunei Darussalam.**Renewable and Sustainable Energy Reviews,** v.16, p.4965-4969, 2012.