Floresta e Ambiente 2023; 30(1): e20220031
https://doi.org/10.1590/2179-8087-FLORAM-2022-0031
ISSN 2179-8087 (online)

ORIGINAL ARTICLE – Forest Products Science and Technology

Energy Quality of Wood and Charcoal from the Stem and Root of *Eucalyptus* spp.

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Abstract

This work aimed to evaluate the energy quality of wood and charcoal obtained from the stem and root of the genus *Eucalyptus* spp. From the wood, the physical, chemical and energetic properties were evaluated. For the charcoal produced in ovens of the carbonization furnaces model in the industry and produced in a muffle furnace, the physical, chemical and energetic properties were evaluated. Based on the analysis of technological properties, wood from the root has higher basic density (731.45 kg m^{-3}) and lignin content (26.44%), however, the fixed carbon content and higher calorific value of the root (17.54% and 4547.75 kcal kg^{-1}) were lower than for the stem wood (21.36% and 4730.82 kcal kg^{-1}). It is recommended to use the wood from the root, both for direct burning and for the production of charcoal. The charcoal obtained in the industry, compared to that produced in muffle, presented higher energy quality.

Keywords: Carbon stock, Energy density, Pyrolysis.

1. INTRODUCTION AND OBJECTIVES

Brazil stands out as the largest producer and consumer of charcoal in the world, which is one of the main inputs of the national steel industry (IBÁ, 2020). According to data from the National Energy Balance, charcoal production in 2019 was 6.1 million tons, of which 5.3 million were used in industry, with the pig iron, steel, and ferroalloy industries responsible for consumption, which corresponds to 84.2% of all charcoal produced in the country (EPE, 2020). The consumption of charcoal from planted forests grew by 3.7% in 2019, the planted forest sector maintained a 95% share of charcoal production (IBA, 2020).

In this scenario, *Eucalyptus* wood is known as one of the main sources of raw material for the production of good quality charcoal (Santos et al., 2016). The cultivation of this genus in the country is one of the most advanced due to the evolution of genetic improvement (Lopes et al., 2017). In the state of Tocantins, considered the second largest producer of charcoal in the northern region of the country, wood destined for energy purposes originates mainly from native forests. In 2018, around 6 thousand tons of charcoal were produced by extraction, while only 140 tons were produced by forestry (IBGE, 2018). In the southern region of the state, *Eucalyptus* forests were implanted in order to serve the pulp and paper companies that would be installed in the region. Due to the restructuring of the sector, the forest massif is being destined for the production of charcoal and has been proving to be a good alternative for the replacement of native wood, which gives it features of a renewable and sustainable raw material (Marchesan et al., 2019). In view of the increased consumption of charcoal from planted forests, it is necessary to consider a better use of this resource. According to Costa (2019), in addition to the stem, tree roots are also used for the production of charcoal. However, there are few studies on the energetic features of this material.

Considering this context, the research aimed to evaluate the energy quality of wood from the stem and root of the species *Eucalyptus* spp. and of charcoal produced in carbonization furnaces, comparing them with charcoal obtained through the muffle oven with temperatures and controlled heating rate.

2. MATERIALS AND METHODS

The wood samples of the stem and root used in this research were collected in a forest stand of *Eucalyptus* spp. Aged 10 years and samples of charcoal produced in "carbonization furnaces" were obtained from a charcoal plant located in the municipality of Formoso do Araguaia, in the state of Tocantins (11°47'48" and 49°31'44 "). Ten already fallen trees already felled were selected, from which, collected on average 30 short logs sampled from the base, diameter at breast height, and crown, from these same trees, roots were obtained, respectively. The logs and roots were peeled, washed and standardized, and specimens measuring 2.5 x 2.5 x 5.0 cm (width x thickness x length) were made from them.

2.1. Energetic properties of wood

To determine the moisture content on a dry basis by NBR 7190 (ABNT, 1997), the specimens were placed at room temperature. The basic density of wood was determined by the hydrostatic balance method, based on the ASTM D-2395 standard (ASTM, 2005). The apparent density was determined by the mercury immersion method, according to the methodology proposed by Vital (1984).

The extractive content was obtained according to the standard standardized by TAPPI T 204 cm-97 (1997). The lignin content was determined according to the methodology described by Gomide and Demuner (1986).

The AQI analysis was based on ASTM D 1762-84 (ASTM, 2007) and ABNT NBR 8112/83 (ABNT, 1983) standards, in which the percentages of volatile materials (VM), fixed carbon (FC) and ash (A). The higher calorific value of wood was estimated according to Ferreira et al. (2014). The energy density of wood was obtained following the methodology proposed by Jesus et al. (2017). Wood carbon stock per unit volume was calculated according to Protásio et al. (2015).

2.2. Energetic properties of charcoal produced in carbonization furnaces and in muffle furnaces

The charcoal obtained in the charcoal plant was produced in ovens whose model is called carbonization furnaces with a nominal capacity of 13 m^3 of wood and carbonization process with an internal temperature of around 500 to 550 °C and an average charcoal yield of 30%, no gas recovery. After collection, the charcoals were divided into two types of samples: ground in a pestle and sieved, using the particles retained in the 60mesh sieve for the determination of Immediate Chemical Analysis (ICA) and those broken into smaller fractions for the determination of the apparent density at 0% in mercury.

The apparent density of charcoal was determined by the mercury immersion method proposed by Vital (1984). For this test, 10 specimens in non-standard format were used. To obtain the higher calorific value of wood, a methodology determined by Vale et al. (2002). The charcoal produced in a muffle furnace using controlled temperature and heating rate was obtained in three gears with final carbonization temperatures of 400, 500 and 600°C for each material (stem and root) in which 10 bodies were used. specimens for each temperature, totaling 30 specimens per material and 60 in total. The wood was dried at a temperature of 103°C ± 2°C, until reaching constant mass and, after drying, charcoal was produced from controlled pyrolysis (Table 1).

The recovery of the condensable gases was carried out through an adaptation to the muffle furnace that allows the gases to pass through a condenser in order to liquefy them into a compound called pyroligneous liquor. Through the difference between the total gravimetric yield in coal and the total yield in pyroligneous liquor, the total yield in non-condensable gases was obtained. The total charcoal yield is the percentage ratio between the dry mass of charcoal and the dry mass of wood, obtained by weighing on an analytical balance.

Table 1. Temperature and time of carbonization according to carbonization heating speed.

Heating Speed	Temperature (°C)									Heat Index (°C/min)	Total Time
	150	200	250	350	400	450	500	550	600		
1	1h	1h	30min	1h	1h	-	-	-	-	5	4h30
2	1h	1h	30min	1h	30min	30min	1h	-	-	5	5h30
3	1h	1h	30min	1h	30min	30min	30min	30min	1h	5	6h30

2.3. Statistical analysis of data

The experimental design used was completely randomized with a 2x4 factorial arrangement, considering stem and root (2 levels) and three temperature treatments plus charcoal produced in a carbonization furnace (4 levels). The normality test and analysis of variance (ANOVA) were performed. The Tukey test was also used to compare the means at a 5% probability level, with the aid of Sisvar statistical software. To calculate the Pearson ® correlation coefficient, Excel software was used.

3. RESULTS AND DISCUSSION

3.1. Energetic properties of wood

Table 2 shows the mean values of moisture content and wood densities of the stem and root of *Eucalyptus* spp.

Table 2. Means of moisture contente (MC), basic density (Bd), and energy density (Ed) of *Eucalyptus* spp.

Wood variables of *Eucalyptus* spp.	Physical properties of wood		
	MC (%)	Bd (kg m^{-3})	Ed (kg m^{-3})
Stem	11.23 a (2.14)	578.95 b (6.20)	728.71 a (5.50)
Root	11.60 a (2.87)	731.45 a (8.22)	734.02 a (2.90)
Pr>Fc	ns	*	ns

Note: Mean values followed by the same lowercase letter do not differ statistically (Tukey's test - P≥0.05). Values in parentheses correspond to the coefficient of variation (%).

For the moisture content of *Eucalyptus* spp. there were no significant differences, and the trunk and root woods presented mean values of approximately 11%. Such values are within the recommended by COPAM 227, which mentions that the moisture content of the biomass both for direct burning and for the production of charcoal must be less than 40%, this regulation is determined by the state of Minas Gerais, the largest producer and consumer of charcoal (COPAM, 2018). Brand et al. (2013) mentions that the greater the amount of water in the wood, the lower the carbonization rate, increasing the time required for the production of charcoal.

The basic density of wood is directly related to energy production, being a very important variable for the determination of species for direct burning. A wood with high density, consequently, will result in a charcoal of greater density and mechanical resistance (Carneiro et al., 2014). Analyzing Table 2, there was a significant difference between the densities (stem and root), which can be defined as medium and high density respectively. The value obtained in this research for bole density was close to the values found by Carneiro et al. (2014) when working with clones of *Eucalyptus* spp. in which they obtained a density varying between 450 and 560 kg m^{-3}.

Regarding the apparent density, the same trend was also observed, where the root showed an mean value higher than the stem, but not significant. Paneque et al. (2019) found a lower mean apparent density value (581 kg m^{-3}) when working with *Eucalyptus grandis* W. Hill.

Table 3 shows the average mean values of extractives, lignin, and holocellulose contents of *Eucalyptus* spp.

Table 3. Mean values of extractives, lignin and holocellulose contents of *Eucalyptus* spp.

Wood variables of *Eucalyptus* spp.	Chemical properties of wood		
	Total extracts (%)	Total Lignin (%)	Holocellulose (%)
Stem	6.99 b (2.20)	23.65 b (1.18)	69.36 a (0.18)
Root	12.68 a (3.83)	26.44 a (1.06)	60.88 b (0.56)
Pr>Fc	*	*	*

Note: Mean values followed by the same lowercase letter do not differ statistically (Tukey's test - P≥0.05). Values in parentheses correspond to the coefficient of variation (%).

In the chemical analysis, the mean values presented by the root wood of *Eucalyptus* spp. were significantly higher than in the bole (Table 3). The presence of high levels of extractives is not desirable in wood intended for the production of charcoal due to its degradation at low temperatures, however, depending on its chemical nature and on the thermal degradation of the wood extractives, the percentage of extractives may contribute to the increase in PCS and fixed carbon content of charcoal (Pereira et al., 2012).

The levels of lignin observed are close to those reported in other studies with species of the genus *Eucalyptus* and were considered satisfactory for the production of charcoal. Protásio et al. (2013) obtained a content of 28.01 to 35.12%; Hsing et al. (2016) reported an mean content of 21.72% when studying hybrids of *Eucalyptus grandis* and *urophylla.* Charcoal from wood with a high lignin content will have a high yield (Protásio et al., 2012). Santos et al. (2016) stated that higher percentages of lignin in wood provide charcoal with higher fixed carbon content.

The levels of holocellulose observed in this research are below those found by Hsing et al. (2016) who, when working with hybrids of *Eucalyptus* grandis and *urophylla,* found an mean content of 71.15%, and close to that obtained by

Costa et al. (2014) when working with cerrado species with contents ranging from 65 to 73%. When wood is intended for charcoal production, high percentages are not desirable, as the degradation of holocellulose results in a lower yield of charcoal and higher percentages of condensable and non-condensable gases (Santos et al., 2016).

In the analysis of the energetic properties of *Eucalyptus* spp. wood (Table 4) the contents of volatile materials (VM) obtained for the stem and root were 78 and 83%, respectively. This difference of 4.5% may be related to the higher value obtained for the total extracts found in wood from the root.

The fixed carbon content is directly related to the volatile material content, therefore, woods that have a higher volatile material content have a lower fixed carbon content. The values found follow this rule and were higher than those found by Chaves et al. (2013) who worked with *Eucalyptus* spp. clones and whose average fixed carbon content was 15.85%. According to Silva et al. (2015) fuels with higher fixed carbon content and lower content of volatile materials have better energy properties.

The ash contents, both for the stem and for the root, were considered low, which is a common characteristic among *Eucalyptus* species. Chaves et al. (2013) found ash contents varying between 0.29 and 0.45% working with different *Eucalyptus* clones.

The higher calorific value of *Eucalyptus* spp. stem wood was approximately 4%, higher than that found for wood from the root (4547.75 kcal kg^{-1}). This is related to the results obtained for the fixed carbon content. Jesus et al. (2017) when working with different species of *Eucalyptus* found mean values close to that of this work ranging between 4538 and 4669 kcal kg^{-1}.

Regarding energy density, the values were higher than those found by Jesus et al. (2017) when working with different species of *Eucalyptus* in which he obtained mean values between 1400 and 1800 kcal m^{-3}. Energy density is directly related to the basic density of wood.

The fact that the energy density was higher than that reported in the literature can be explained by the medium and high density obtained from the stem and root, respectively.

Table 4. Average content of volatile materials (VM), fixed carbon (FC), ash (A), higher calorific value (HCV), energy density (ED), and carbon stock (CE) of the stem and root of *Eucalyptus* spp.

Wood variables of *Eucalyptus* spp.	Energy properties of wood					
	VM (%)	FC (%)	A (%)	HCV (kcal kg-1)	ED (kcal m^{-3})	CE (kg m^{-3})
Stem	78.52 b (1.30)	21.36 a 4.72)	0.11 b (18.70)	4730.82 a (1.00)	3473.10 a (5.90)	156.94 a (8.34)
Root	82.27 a (0.92)	17.54 b (4.27)	0.18 a (18.90)	4547.75 b (0.77)	3313.86 b (2.84)	127.81 b (4.61)
Pr>Fc	*	*	*	*	*	*

Note: Averages followed by the same lowercase letter do not differ statistically (Tukey's test - P≥0.05). Values in parentheses correspond to the coefficient of variation (%).

3.2. Energetic properties of charcoal produced in carbonization furnaces and in muffle furnaces

Table 5 shows the values of charcoal total yield and the yield of condensable and non-condensable gases for Eucalyptus spp. in the final carbonization stages of 400°C, 500°C, and 600°C for the charcoal obtained by the pyrolysis of wood.

The gravimetric yield is strongly influenced by temperature, and in this study, the higher the final carbonization temperature, the lower the mass yield. The gravimetric yield, both of the stem and the root, is within the recommended by the COPAM 217 regulation, which determines for medium-sized projects gravimetric yield from 30% (COPAM, 2018). It is observed that the increase in 200ºC of final temperature of carbonization provided reductions of 18.83 and 19.55%, respectively, in the yield of charcoal from the wood of the trunk and root of the tree. The reduction in charcoal yield is mainly due to the thermal decomposition of hemicellulose and cellulose. At higher temperatures, the thermal decomposition reactions of lignin and solid residues of cellulose and hemicellulose predominated (Rowell et al., 2005). Jesus et al. (2017) also obtained a charcoal yield of over 30%, which is desired by the industry. For the yield in condensable and non-condensable gases, it is noted that the increase in the final temperature of carbonization, caused greater proportions of this material. The results presented in this study were higher than what was reported by Jesus et al. (2017) who obtained a yield of 39.58%. The yield in non-condensable gases found (between 16 and 22%) was close to that reported by Jesus et al. (2017), who obtained average values from 19.70 to 21.92%.

Table 6 shows the mean values of apparent and energetic densities, immediate chemical analysis and carbon stock of the charcoals produced in carbonization furnaces and obtained in muffle furnaces with controlled temperatures and heating rate.

Table 5. Mean total charcoal yield, condensable gas yield, and non-condensable gas yield of *Eucalyptus* spp. for charcoal produced by pyrolysis of wood.

Evaluated material	Yield (%)	400°C	500°C	600°C
Stem	Charcoal yield	37.64	33.38	30.55
	Condensable gas yield	45.78	48.82	46.15
	Non-condensable gas yield	16.59	17.80	23.29
Root	Charcoal yield	40.30	35.16	32.42
	Condensable gas yield	43.16	44.21	44.76
	Non-condensable gas yield	16.54	20.63	22.82

Table 6. Mean values of apparent and energetic densities, chemical analysis and carbon stock of E*ucalyptus* spp.

Charcoal parameters	Charcoal	Evaluated treatments				Pr>Fc Interaction
		Hot oven	Muffle 400°	Muffle 500°	Muffle 600°	
Apparent density (kg cm^{-3})	Stem	405.84 bA (4.47)	433.71 bA (8.32)	428.41 aA (12.04)	426.35 aA (7.43)	*
	Root	516.44 aA (5.52)	500.03 aA (10.24)	440.06 aB (17.94)	416.19 aB (15.06)	
Fixed carbon (%)	Stem	56.56 bD (1.07)	66.49 bC (1.15)	71.55 bB (0.98)	80.08 bA (0.86)	*
	Root	72.09 aD (1.54)	71.04 aC (0.86)	75.87 aB (1.04)	82.55 aA (0.59)	
Volatile materials (%)	Stem	43.10 aA (1.38)	33.09 aB (2.30)	28.03 aC (2.49)	19.48 aD (3.52)	*
	Root	27.42 bB (4.04)	28.43 bA (2.14)	23.62 bC (3.35)	16.90 bD (2.84)	
Higher calorific value (kcal kg^{-1})	Stem	6816.01 bD (0.30)	7146.61 bC (0.36)	7314.8 bB (0.32)	7598.75 bA (0.30)	*
	Root	7332.86 aC (0.50)	7298.02 aD (0.28)	7458.74 aB (0.35)	7680.96 aA (0.21)	
Energy density (kcal m^{-3})	Stem	2766.19 bB (4.45)	3099.54 bAB (8.33)	3133.86 aAB (12.10)	3239.90 aA (7.52)	*
	Root	3786.76 aA (5.42)	3649.11 aAB (10.22)	3281.77 bBC (17.86)	3196.97 bC (15.13)	
Carbon stock (kg m^{-3})	Stem	229.51 bD (4.48)	288.37 bC (8.39)	306.56 bB (12.24)	341.48 aA (7.70)	*
	Root	372.23 aA (5.33)	355.21 aA (10.23)	333.73 aA (17.72)	343.66 aA (15.24)	

Note: Mean values followed by the same uppercase letter in the column and lowercase letters in the row do not differ statistically according to Tukey's test (5%). *significant at 5% (01 = <p<0.05). The values between parentheses correspond to the variation coefficient (%).

Regarding the apparent density, it can be observed that with the increase of the final temperature of carbonization there was a decrease in the density. Marchesan et al. (2020) also observed a decrease in the apparent density of charcoal with the increase in the final temperature of carbonization and stated that this fact is related to the degradation of the chemical constituents of the wood (loss of mass), in addition to the reduction in the dimensions of the wood. charcoal, causing an impact on the apparent density. It is observed that the charcoal from the root wood presented higher average values of apparent density, which may have occurred because it had higher basic and apparent density. The average values found in this research were slightly lower than those reported by Marchesan et al. (2020) for Corymbia citriodora, which obtained an apparent density of 472 and 446 kg m^{-3} at a carbonization rate of 500 and 550°C, respectively.

The values obtained for volatile materials are mostly not high for volatile material. Only the samples submitted to pyrolysis at 600°C were considered adequate, having presented an average content of approximately 18%. As the final carbonization temperature increases, the volatile material content decreases. This same relationship was found by Oliveira et al. (2010) when testing different carbonization marches. Brand (2010) stated that low levels of volatiles lead to high levels of fixed carbon.

Fixed carbon contents were also not considered appropriate because they are mostly low. It was observed that again, only the samples submitted to pyrolysis at 600°C were considered adequate for this parameter, having presented an average content of approximately 81%. Fixed carbon is the main component in charcoal, so the higher its value, the greater its caloric power. As the final carbonization temperature increased, the fixed carbon content increased. The same trend was observed by Silva et al. (2018).

The calorific value also increased with the increase of the final carbonization temperature and, with the exception of the charcoal from the carbonization furnace, all other samples were within the recommended quality standards. Marchesan et al. (2020), when studying the energy quality of three species of *Eucalyptus* and *Corymbia citriodora*, found an average value ranging from 7235.97 to 7469.98 kcal kg^{-1} at a final temperature of 500°C. According to Jesus et al. (2017), the increase in higher calorific value with the increase in final temperature is related to the addition of fixed carbon and oxygen output. Energy density is directly related to the energy contained in a given volume of wood. In this research, the mean values observed were higher in the samples from the root. The same trend observed for the apparent density occurred for the energy density in which, as the final temperature of the carbonization stages was increased, the density decreased.

The greater the basic density of wood, the greater the apparent density, therefore, the greater the energy density and fixed carbon stock (Costa et al, 2014). The results presented in this study corroborate the assertion of these authors. The carbon stock varied significantly between the stem and root samples. The charcoal produced in a carbonization furnace had a higher carbon stock than that produced in the laboratory and it was observed that with the increase of the final carbonization temperature, the fixed carbon stock decreased.

Table 7 shows the ash contents, both for charcoal produced in a carbonization furnaces and for charcoal produced in muffle furnaces. Note that there was no interaction between the factors, but there was a significant difference at the level of 5% probability between the wood of the stem and root and between the charcoal produced in the industry and the others produced in the laboratory.

Table 7. Means of ash content of charcoals from industry and produced in the laboratory with *Eucalyptus* spp. wood.

Charcoal	Ashes (%)	Pr>Fc
Stem	0.41	*
Root	0.50	
Treatments	**Ashes (%)**	**Pr>Fc**
Industry	0.38 b	*
400°C	0.48 a	
500°C	0.47 a	
600°C	0.50 a	
Interaction	**Ashes (%)**	**Pr>Fc**
Stem x Root	-	ns

Note: Mean values followed by the same lowercase letter do not differ statistically (Tukey's test - P≥0.05).

The ash contents were within the recommended value of less than 1.5%. Soares et al. (2015) in a study with *Eucalyptus* hybrids with different ages, found ash contents of 0.87%, above the values of this study. Jesus et al. (2017) evaluated species of the genus *Eucalyptus* and obtained mean values in a range of 0.68% to 2.82%. A direct relationship was observed in which ash content increased as the final carbonization temperature increased. High ash contents are not desirable for the use of charcoal in steel industries, as they can fuse into the boiler walls, causing insulation of the heating system (Vale et al., 2017).

Pearson's correlation coefficient (r) varies from -1 to 1 and expresses the degree of relationship between two variables. The correlation of the apparent density of charcoal in relation to energy density and carbon stock was positive and high (Table 8). Therefore, denser materials tend to have more available energy.

Table 8. Analysis of Pearson's correlation between the variables studied.

Correlations from Pearson	$Ad_{charcoal}$	FC	VM	A	HCV	Ed	CS	EC	CL	HC	Bd_{wood}
$Ad_{charcoal}$	1										
FC	-	1									
VM	-	**-1.00**	1								
A	-	-	**-0.725**	1							
HCV	-	**1.00**	**-1.000**	-	1						
Ed	**0.973**	0.270	-0.270	-	0.270	1					
CS	**0.817**	**0.607**	**-0.607**	-	**0.607**	**0.928**	1				
EC	-	-	-	-	0.438	0.466	-	1			
CL	0.379	0.433	-0.436	-	0.433	0.463	**0.543**	-	1		
HC	-0.376	-0.439	0.442	-	-0.439	-0.461	**-0.543**	-	-	1	
Bd_{wood}	0.354	0.351	-0.354	-	0.351	0.421	0.478	**0.843**	**0.824**	**-0.829**	1

Note: Ad is the apparent density of charcoal (kg cm^{-3}); FC is the fixed carbon content (%); VM is the content of volatile materials (%); A is the ash content (%); HCV is the higher calorific value (kcal kg^{-1}); Ed is the energy density (kcal m^{-3}); CS is the carbon stock (kg m^{-3}); EC is the extractive content (%); CL is the lignin content (%); HC is the holocellulose content (%); Bd is the basic density of wood (kg m^{-3}).

A highly positive correlation was also observed between the fixed carbon content in relation to the calorific value and carbon stock, the opposite being also observed in relation to the content of the volatile materials. Assis et al. (2012) also observed that the contents of fixed carbon are positively related to the values of calorific value.

There is also a negative and high correlation between volatile material contents with ash contents, calorific value and carbon stock. Nones et al. (2015) also obtained the same correlation when working with *Eucalyptus benthamii.* Silva et al. (2015) stated in their work that biomass with a higher content of volatile materials and lower ash content has a lower higher calorific value.

Fixed carbon stock was positively correlated with higher calorific value and energy density, that is, the greater the carbon stock, the greater the energy density and calorific value of charcoal. Carbon stock was also positively correlated with lignin content and negatively with holocellulose. According to Brito (1977), the higher the lignin content, the lower the holocellulose content. Therefore, charcoal with a high lignin content will have a low holocellulose content and a high fixed carbon content, which will consequently generate a carbon stock.

Finally, there was a highly positive correlation between wood basic density and extractives and lignin contents and a highly negative correlation with holocellulose. According to Santos (2008), woods with large amounts of extractives tend to be denser. Vale et al (2010) stated that the increase in the lignin content implies a decrease in the holocellulose content. Therefore, in view of the high significance between the lignin content and the basic density, there is an inverse relationship between the holocellulose content and the basic density.

4. CONCLUSIONS

Both the stem and root wood of *Eucalyptus* spp. have potential for the production of good quality charcoal since they presented results within the recommended by the literature. Observing all the parameters studied, it can be concluded that the root has higher quality and potential for energy generation, both in direct burning (wood) and for the production of charcoal.

The charcoal produced from the shaft in a carbonization furnace showed low values for fixed carbon contents, directly affecting the higher calorific value. The charcoal obtained through the pyrolysis of wood in a muffle furnace presented the best averages and was considered better than the charcoal produced in carbonization furnace.

The carbonization process with a temperature of 600°C showed higher levels of fixed carbon and calorific value, but the charcoal yield was lower, therefore, temperatures between 400 and 500°C are recommended for production to be more efficient.

SUBMISSION STATUS

Received: 12 Apr. 2022

Accepted: 13 Jan. 2023

Associate editor: Fernando Gomes

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