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Research Article

Quality of Wood and Charcoal from *Eucalyptus* Clones for Ironmaster Use

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Considering the wide variety of species and clones of *Eucalyptus* cultivated in Brazil, it is necessary to search for new information on wood properties, so that the selection of genetically superior material may be successful. The present study aimed to determine the properties of wood and charcoal from different clones of *Eucalyptus* spp. Six clones at the age of 7.5 years were evaluated and the samples were from a clonal, located in the city of Lassance, Minas Gerais, Brazil. Basic density, chemical composition, and higher heating value were determined. Carbonizations in a laboratory kiln were done and the levels of volatile matter, ash, and fixed carbon, higher heating value, and bulk density of the charcoal produced were determined. Evaluated genetic materials showed differences in their properties. According to research results, several properties of wood should be considered together for the selection of clones for charcoal production. However, basic density and chemical composition of wood, especially high contents of lignin and low contents of extractives, are the properties that had more influence on charcoal yield and its quality. Concerning charcoal production for steelmaking, clone 6 stood out and, conversely, clone 4 showed inferior properties to those of others.

1. Introduction

Area occupied by forest plantations in Brazil reached over 6,500,000 ha, of which 74.8% are *Eucalyptus* plantations, in 2011 [1]. In the same year, Brazilian consumption of logs from plantations of *Eucalyptus* for charcoal production was close to 17,000,000 cubic meters, representing 10.0% of total consumption of logs [1]. These data confirm the importance of *Eucalyptus* in Brazil, which has been the focus of several studies due to concerns about wood quality and homogeneity.

Charcoal quality and its production depend, among other factors, on the quality of wood used, which is defined by a set of chemical, physical, mechanical, and anatomical properties, usually interdependent. Nevertheless, regarding the variations that occur in the wood quality of the above cited genus, it is necessary to study it, for this fact may bring about negative consequences in both the quality and yield of charcoal, which will negatively reflect on the operations of the iron and steel industries blast furnaces [2].

Forestry companies and Brazilian research centers have been motivated to seek solutions to produce homogeneous charcoal, with high yield, high quality, and low cost. Therefore, the technological characteristics of wood should also be considered and not only the economic and forestry aspects, because charcoal yield, quality, and performance are directly influenced by wood properties.

Due to lack of literature on the selection of superior material for the purpose of charcoal production, recently, several studies have been conducted with this aim [3–5]. Therefore, by evaluating the properties of wood and charcoal produced, clones that stand out are directed to selection, vegetative propagation, and commercial plantation. Physical and chemical wood properties are good parameters to assess their quality, and they are also very useful in *Eucalyptus* breeding [6].

Table 1: General information about the different genetic materials of the study.

Clone	Genetic material	Origin (company)	Total height (m)	Mean diameter (cm)	Bar (%)	Annual increment ($m^3 \cdot ha^{-1} \cdot year^{-1}$)
1	*Eucalyptus camaldulensis*	Plantar S.A/Curvelo, MG, Brazil	23,9	15,41	17,0	39,6
2	*Eucalyptus urophylla* Hibrid	Gerdau S.A/Três Marias, MG, Brazil	22,9	14,82	15,0	32,4
3	*Eucalyptus grandis* Hibrid	Suzano/Teixeira de Freitas, BA, Brazil	24,0	16,69	13,0	40,7
4	*Eucalyptus urophylla* Hibrid	Gerdau S.A/Três Marias, MG, Brazil	23,7	15,48	11,0	35,9
5	*Eucalyptus urophylla*	V & M Florestal/João Pinheiro, MG, Brazil	19,9	15,54	9,0	31,5
6	*Eucalyptus camaldulensis*	Gerdau S.A/Três Marias, MG, Brazil	25,0	15,76	15,0	40,3

High density, low levels of ash, and high lignin content are characteristics which may be considered as indices of wood quality for charcoal production [5, 6]. Regarding quality of charcoal, better chemical properties of charcoal such as higher levels of fixed carbon and lower levels of ash and volatiles are associated with high levels of lignin and low levels of holocelluloses and extractives in wood [5].

Considering the wide variety of species and clones of *Eucalyptus* cultivated in Brazil, it is necessary to search for new information on wood properties, so that the selection of genetically superior material may be successful. Therefore, a better understanding of performance of wood in charcoal production is crucial for selecting clones, optimizing processes, and improving the quality of charcoal.

2. Objectives

The purpose of the study reported herein was to determine some properties of wood and charcoal from six clones of *Eucalyptus* spp.

In order to be more accurate, the objective was to indicate one or more clones of *Eucalyptus* with the greatest potential for production of charcoal to ironmaster use, grating allowance for *Eucalyptus* breeding.

3. Material and Methods

3.1. Material. Six clones of *Eucalyptus* spp. from a clonal test were used (Table 1). The plantings were conducted with spacing 3.8 × 2.4 meters, and the trees were harvested at the age of 7.5 years. The clonal test was from a forestry company, located in Lassance, Minas Gerais, Brazil, whose UTM coordinates are 513262.29 W and 7999059.47 S, Zone 23S, datum SAD 69.

A total of 3 trees, representative of the population, from each clone were used as samples, and the selection was made excluding the trees that had visual defects that can be seen by the naked eye and also those which were at the edges.

The clonal test was conducted in the Brazilian Cerrado, biome which is characterized by pronounced seasonality. The site climate is classified as Köppen Aw, tropical rainy. The average annual temperature is 24°C, and the annual rainfall index is between 750 and 2,000 mm, with an annual average of 1,800 mm, with precipitation concentrated from October to March. These data were provided by the forestry company which monitors the temperature and precipitation throughout the year.

The predominant soil is dystrophic red or red-yellow, porous, permeable, well drained, and, therefore, strongly leached. Most of the texture is sandy and sandy clay, about 25% clay, in the layer of 0–40 cm. After planting, fertilization is made with 100 grams per plant of NPK formulation 06 : 30 : 06 + 0.5% zinc.

3.2. Preparation of Samples. Transversal sections were collected in portions corresponding to the basis (0%), 25, 50, 75% of merchantable height and at top (100%).

Two opposing wedges were obtained from each disc through the medulla and then they were used to determine the basic density of wood.

The remainder of each disc was sectioned, and a part of it was used in the carbonization (composite sample), and another section was destined to other analyses.

In order to determine the higher heating value (HHV) and chemical composition, the wood samples were transformed into sawdust by using a Wiley laboratory mill type, according to standard TAPPI 257 om-52 [7]. For these analyses, the fraction of wood sawdust between 40 and 60 mesh was used [8].

Part of the carbonized samples was designed to determine the bulk density, and the remainder was ground for the content of volatile matter, fixed carbon, ash, and HHV. For these analyses, the fraction of wood sawdust between 40 and 60 mesh was used [8].

3.3. Wood Characterization. The wood basic density was determined by water displacement method, according to ABNT NBR 11941 [9].

The higher heating value (HHV) was determined according to the methodology described by ABNT NBR 8633 [10], using an adiabatic calorimeter IKA300. The HHV represents the maximum amount of energy potentially recoverable from a given biomass source [10], in this case, specifically, the amount of energy in the wood. The determination of the wood HHV is important when it is used for energy purposes, in this case, the production of charcoal.

The content of wood extractives was determined in duplicates, according to TAPPI 204 om-88 [11], using the method of total extractives, substituting ethanol/benzene to ethanol/toluene.

The insoluble lignin was determined in duplicate using Klason method which was modified according to the procedure proposed by Gomide and Demuner [12]. The soluble lignin was determined by spectrophotometry, as proposed by Goldschimid [13].

The lignin content was obtained by total sum of values of the soluble and insoluble lignin.

The holocellulose content was determined by difference, based on free wood extractives.

3.4. Carbonization. The carbonization reactor was cylindrical, with a useful volume of 0.003 m^3, and the carbonizations were performed in an electric kiln, using approximately 0.35 kg of wood.

The heating control was conducted manually in increments of 50°C every 30 minutes, which corresponds to an average heating rate 1.67°C·min^{-1}. The initial temperature was 100°C, and the final temperature was 450°C, and it remained stable for a period of 60 minutes, with a total carbonization of 4.5 hours. These experiment conditions were used according to the following explanations and some references [3, 14–16]. Final temperature of 450°C maximizes gravimetric charcoal and its quality for use in steel mills, especially with respect to fixed carbon content. Heating rate of 1.67°C·min^{-1} provides a charcoal with high mechanical strength, because if a higher heating rate was used, it would cause the disruption of cells due to the rapid exit of water and gas, causing the cracking of charcoal and generation of fines. After the process, charcoal gravimetric yield was determined based on the dry mass of wood.

3.5. Charcoal Characterization. The bulk density was determined by the hydrostatic method, in which the samples were immersed in mercury.

The higher heating value was determined according to the methodology described by ABNT NBR 8633 [10], using an adiabatic calorimeter IKA300.

Energy density was calculated, by multiplying density by HHV.

The content of volatile matter, ash, and fixed carbon on dry basis, was determined according to ABNT 8112 NBR [17] by substituting platinum crucible for porcelain crucible and temperature of ash determination of 750 to 600°C.

3.6. Statistical Analysis. The experiment was conducted according to a randomized design with six treatments (clones) with three replicates (tree-sample), totaling 18 sampling units.

Data normality was verified by Lilliefors test and homogeneity of variance by Hartley, Cochran, and Bartlett. There was no need for data transformation for the assumptions of variance analysis were fulfilled.

Data were subjected to analysis of variance, and, when significant differences were established, treatments were compared through Tukey test at 5% probability.

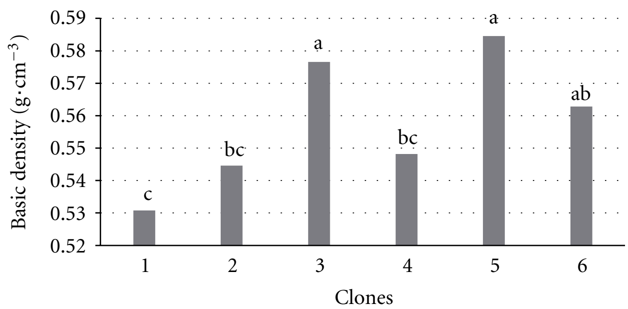

Figure 1: Mean values of wood density of *Eucalyptus* spp. clones, g·cm^{-3}. Standard deviation = 0.02; variation coefficient = 1.6%. Means followed by same letter do not differ at 5% probability by Tukey test.

4. Results and Discussion

4.1. Wood Characterization

4.1.1. Basic Density. The basic density ranged from 0.53 to 0.59 g·cm^{-3} among the evaluated clones (Figure 1). Clones 3 and 5 presented the highest average basic density, 0.58 and 0.59 g·cm^{-3}, respectively, but the density of clones 3 and 5 did not differ from the density of clone 6 (0.56 g·cm^{-3}). Clone 1 had the lowest wood basic density, 0.53 g·cm^{-3}; however, the density of clone 1 did not differ from the density of clones 2 (0.55 g·cm^{-3}) and 4 (0.55 g·cm^{-3}).

The values of basic density are similar to those found in literature: Santos et al. [5] studied three clones of *E. urophylla* × *E. grandis* and a clone of *E. camaldulensis* × *E. grandis* at 7 years old, and the authors found mean values between 0.50 and 0.55 g·cm^{-3}; Oliveira et al. [18], evaluating a *Eucalyptus pellita* clone at 5 years old, found an average of 0.56 g·cm^{-3}.

When considering only the basic wood density, the clones have potential to produce charcoal, because all clones had values higher than the average suggested by Santos et al. [5] and Trugilho et al. [14]. According to these authors, the basic density for the production of charcoal should be superior to 0.50 g·cm^{-3}.

Basic density can be considered one of the main criteria for selection of species and clones of *Eucalyptus* for charcoal production. Wood with the highest specific gravity should be preferred, because the use of denser woods results in higher production of charcoal for a certain volume of wood placed in the kiln, and the charcoal quality is improved for various purposes, such as the production of pig iron and steel.

According to McKendry [19], the density of the processed product has impact on fuel storage requirements, the sizing of the materials handling system, and on how the material is likely to behave during subsequent thermochemical processing as a fuel/feedstock.

4.1.2. Higher Heating Value (HHV). Analysis of variance showed that HHV was not significantly influenced by clones, at 5% probability. The average HHV studied was

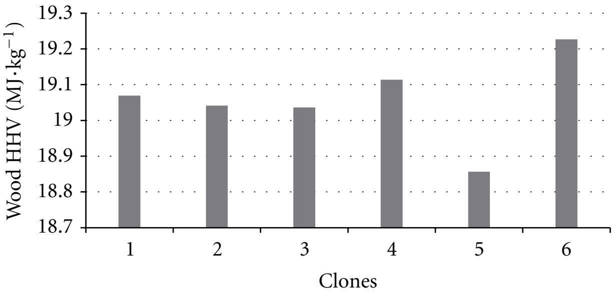

Figure 2: Mean values of wood higher heating value (HHV) of *Eucalyptus* spp., in MJ·kg^{-1}. Standard deviation = 0.19; variation coefficient = 1.0%.

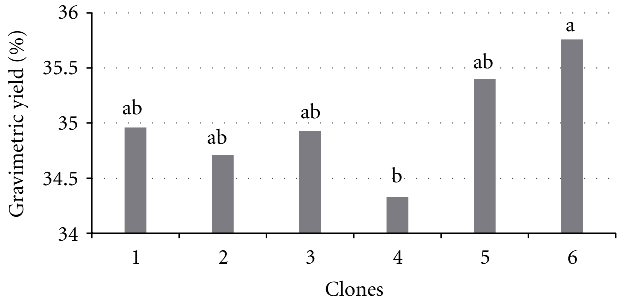

Figure 3: Mean values of charcoal gravimetric yield, in percentage. Standard deviation = 0.66; variation coefficient = 1.3%. Means followed by same letter do not differ at 5% probability by Tukey test.

19.07 MJ·kg^{-1}, with mean values ranging between 18.87 (clone 5) and 19.24 MJ·kg^{-1} (clone 6), as shown in Figure 2.

The HHV of the wood shows little variation within the same genus [5, 16, 18]. Due to the slight variation among the values found for this property in many studies, it is concluded that this is not a characteristic that should be used for selection of *Eucalyptus* clones.

As cited by McKendry [19], the calorific value of a material is an expression of the energy content or heat value released when burned in air. The calorific value is usually measured in terms of the energy content per unit mass. Meanwhile, the higher heating value (HHV) is the total energy content released when the fuel is burned in air; therefore, HHV represents the maximum amount of energy potentially recoverable from a given biomass source.

Wood HHV is influenced by factors such as chemical composition, especially by the lignin and extractives which influence positively and ash which influences negatively [20]. However, this relationship was not observed in this work.

4.1.3. Chemical Composition. Table 2 shows the mean values for the chemical components of the *Eucalyptus* wood.

The sum of the levels of cellulose and hemicelluloses is called holocelluloses [21], and it corresponds to the most significant mass fraction of wood. The holocelluloses' contents for the different clones in this study are in agreement with other studies [5, 16, 18]. Clones 3, 4, 5, and 6 had the highest average levels of holocelluloses, and clone 2 had the lowest mean value.

Concerning charcoal production, species or clones with lower percentages of holocelluloses and higher contents of lignin should be selected due to the low resistance of these components when regarding thermal degradation. As is known, the weight loss of hemicelluloses and cellulose occurred, respectively, at 220–315°C and 315–400°C [22, 23]. Therefore, these components do not contribute significantly to the yield of charcoal, but to noncondensable gases and condensable yield.

Clones 1, 2, and 6 stood out on the lignin content which is the main component of wood when the purpose is the production of charcoal. The lignin contents observed in the studied clones were satisfactory for charcoal production and consistent with other studies, in which *Eucalyptus* clones were studied for the same purpose. Santos et al. [5] and Arantes et al. [24] reported the mean values of total lignin 32.0 and 29.8%, respectively.

The chemical composition of wood influences the yield and the quality of charcoal. For example, clones 1, 2, and 6 showed high levels of lignin, and they also had higher yields of charcoal and high fixed carbon content. This fact is related to the higher resistance to thermal degradation of lignin, when compared to holocelluloses, mainly due to the increasing number of C–C and C=C present in its structure and also because lignin has a high percentage of elemental carbon and low oxygen, when compared with other chemical components of wood.

Clone 2 had the highest percentage of extractives, 4.97%, not differing significantly from clones 1, 4, and 5. For clone 6, the lowest extractive content was recorded, 3.10%, differing significantly from the other clones. The content of extractives observed in this study is in accordance with the work of Santos et al. [5], who found levels ranging from 5.0% extractives for four clones of *Eucalyptus* spp., 7 years old.

For charcoal production, extractives content should be as low as possible, for most of these compounds are degraded at temperatures inferior to the final ones found in the process of carbonization whose average is 450°C, not contributing to charcoal gravimetric yield and its properties [25]. This is because the majority of the extractives present in the *Eucalyptus* that are commercially used and whose age is around 7 are, in most cases, fatty acids and steroids which have low thermal stability. On the other hand, the phenolic extractives present in old woods have an important influence on the increase of calorific value of wood and charcoal due to their high carbon content [26], which is not the case for wood evaluated in this study. Therefore, wood with low levels of extractives should be preferred, such as clone 6.

Although significant differences in ash content were observed among the clones, the values obtained can be considered low, and the maximum value found is equal to 0.18%. A low ash content is also observed by Soares [27], when evaluating an *E. grandis* × *E. urophylla* clone, 7 years old. According to Tsoumis [28], the mineral content of *Eucalyptus* corresponds in general less than 1.0%.

Table 2: Average values of holocellulose, lignin, extractives, and ash of *Eucalyptus* spp. wood, in percentage.

Clones	Holocellulose*	Lignin*	Extractives	Ash
1	65.25ab	30.29ab	4.30ab	0.16ab
2	63.46b	31.42a	4.97a	0.14ab
3	65.90a	29.82bc	4.15b	0.12ab
4	66.42a	28.78c	4.70ab	0.10b
5	65.44a	29.68bc	4.77ab	0.11ab
6	66.36a	30.37ab	3.10c	0.18a
Standard deviation	1.18	0.93	0.67	0.04
Variation coefficient (%)	1.8	1.7	15.5	19.3

* Wood-free extractives. Means in column followed by same letter do not differ at 5% probability by Tukey test.

Presence of high concentrations of inorganic components in wood is not interesting, because they are not degraded during carbonization and they remain in charcoal as an undesirable residue. It contributes to the reduction of charcoal HHV, besides its presence not being desirable to the production of some types of ferroalloys, for they become brittle, less malleable, and favorable to fissure.

4.2. Charcoal Characterization

4.2.1. Gravimetric Yield. Charcoal yield obtained from the evaluated clones is considered satisfactory, and the high yields show potential of clones to participation of hybridization and selection charcoal production programs.

The higher value was found for clone 6 and the lower for clone 4, while their yields are not significantly different from clones 1, 2, 3, and 5 (Figure 3).

Neves et al. [16] found in charcoal production efficiency around 30.3 e 32.5%, which is inferior to values observed in this study. Botrel et al. [3] found average yield between 33.2 and 37.0% for 9 hybrid clones of *Eucalyptus* spp., at 6.5 years old, agreeing with the charcoal yields observed in this work.

The evaluation of the yields in the carbonization process is extremely important if the studied material is destined to charcoal production [3]. It is worth emphasizing that the yield of charcoal produced in large scale tends to be lower due to a set of features regarding parameters for carbonization such as final temperature, heating rate, dimensions of the pieces of wood, and moisture that affect the process. In this study, these variables were preestablished and maintained in all carbonizations, which is hard to be fully controlled when charcoal is produced in a large scale.

The wood's chemical properties expressively influenced the charcoal yield. The best performance in charcoal production was the clones whose wood had a set of chemical properties as high lignin content and low total extractive content. Clone 4 presented the lowest lignin content and one of the highest extractive content, and, in addition, it also presented the lowest production of charcoal. However, clone 6, which presented the lowest production of charcoal and one of the highest on lignin, also presented the greatest production of charcoal. The other clones present average production efficiency.

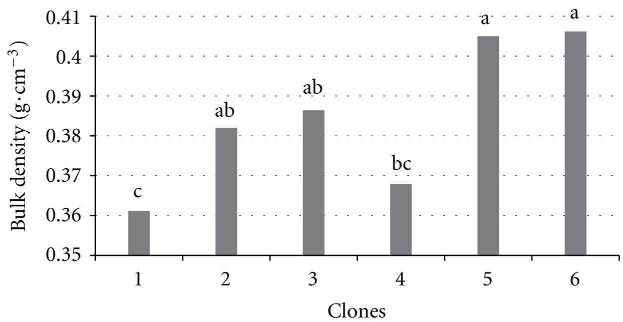

Figure 4: Mean values of charcoal bulk density of *Eucalyptus* spp., in g·cm^{-3}. Standard deviation = 0.02; variation coefficient = 3.6%. Means followed by same letter do not differ at 5% probability by Tukey test.

The highest wood density for clones 3, 5, and 6, which had the highest charcoal yield, was verified. On the other hand, the relationship was not observed for clones with lower densities, such as clone 1. This fact indicates that although the density is an important index of the wood quality, it cannot be used alone as a parameter for selection of genetic material to produce charcoal.

4.2.2. Bulk Density. The variation of the charcoal bulk density was 0.36 to 0.41 g·cm^{-3} (Figure 4). Clones 5 and 6 had the highest density, an average of 0.41 g·cm^{-3}, followed by clone 2 (0.38 g·cm^{-3}) and 3 (0.39 g·cm^{-3}), and the lowest densities were observed for clone 1 (0.36 g·cm^{-3}) and 4 (0.37 g·cm^{-3}).

Similar results were found by Botrel et al. [3], who detected mean values between 0.28 and 0.40 g·cm^{-3} and Trugilho et al. [15] who obtained a mean value of 0.45 g·cm^{-3}.

The differences found for the density of the different clones may be given to basic density. In general, the higher the specific gravity of wood is, the greater the bulk density of charcoal is [5].

According to Santos [29] it is desirable that the bulk density of charcoal should not be inferior to 0.40 g·cm^{-3}. Therefore, charcoal of clones 2, 3, 5, and 6 showed, statistically, satisfactory average. However, other properties of the

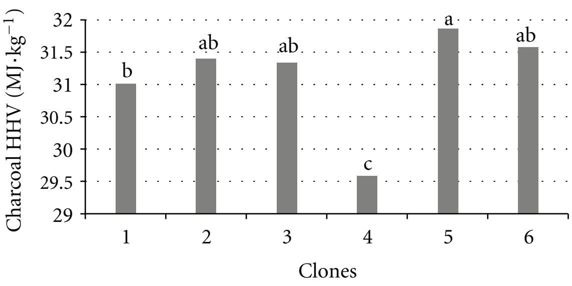

Figure 5: Mean values of charcoal higher heating value (HHV) of *Eucalyptus* spp., in MJ·kg^{-1}. Standard deviation = 0.80; variation coefficient = 2.6%. Means followed by same letter do not differ at 5% probability by Tukey test.

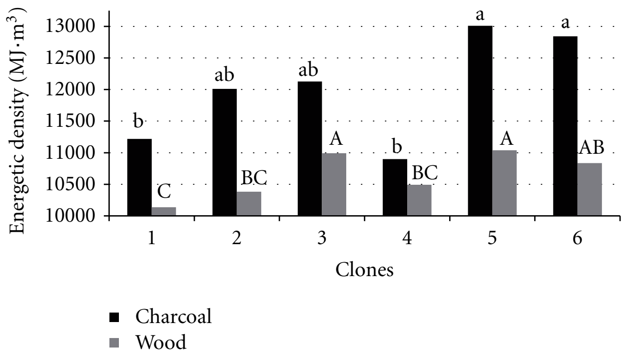

Figure 6: Energetic density of charcoal and wood, in MJ·m^{-3}. Standard deviation = 865.66 (charcoal), 374.42 (wood); variation coefficient = 7.21% (charcoal), 3.52% (wood). Means followed by same letter do not differ at 5% probability by Tukey test.

charcoal should be maintained at acceptable levels, especially the content of fixed carbon.

The higher the charcoal density is, the greater is the use of blast furnace volume and the longer is the residence time of metallic charge in the equipment, and, in addition, the greater is the load carrying capacity in terms of carbon by volume. Thus, the density of charcoal is maximized, and, consequently, there is an increase in the quantity of energy per unit volume of fuel which results in an increase of the mechanical resistance of charcoal for the industrial blast furnaces as well [16].

4.2.3. Higher Heating Value (HHV). Charcoal HHV average was among 29.60 and 31,89 MJ·kg^{-1} (Figure 5). Charcoal from clone 5 showed the greatest HHV, which was statistically similar to clones 2, 3, and 6, whose HHV were, respectively, 31.41, 31.02, and 31.60 MJ·kg^{-1}. These clones showed no statistical differences from clone 1 (31.04 MJ·kg^{-1}). Clone 4 showed the worst performance for this property. The results are in agreement with the literature of Neves et al. [16] who found HHV values among 31.92 to 32.23 MJ·kg^{-1}.

It could be concluded that the total lignin content positively influenced the HHV of charcoal, given that this relation was also observed by Santos et al. [5]. Soon, wood with more lignin content provides the production of charcoal with higher heating value.

This is due to the preservation of lignin structure that is rich in carbon, an element that is more energetic because it is more difficult to break its connections C–C and C=C, when compared to oxygen, which is present in higher proportions in cellulose and hemicelluloses.

The charcoal HHV is directly related to its fixed carbon content that increases with the wood degradation. However, this association was not observed in this study, except for clone 6, which showed the highest values for HHV and fixed carbon content.

Figure 6 shows the increase in energetic density of charcoal, as compared with wood.

There were increases of 10.7, 15.7, 10.3, 3.9, 17.8, and 18.5% on energetic density for clones 1, 2, 3, 4, 5, and 6, respectively.

Charcoal HHV is higher than wood HHV because most of the components that have less stable bonds in the wood are broken down during carbonization. However, the compounds that have heat-resilient bonds remain preserved, as the aromatic rings present in the lignin.

It should be noted that the HHV of charcoal showed an average increase of 61.30%, when it is compared with HHV of wood (Figures 2 and 5). This is the main reason for the increase in energetic density of charcoal as compared to the wood, because this is a multiplication between density and HHV. Thus, as portion of the wood is degraded during carbonization; the charcoal density is less than the wood, but charcoal HHV is significantly greater, resulting in a higher energetic density of charcoal.

Table 3: Mean values of charcoal fixed carbon, volatile matter, and ash contents, in percentage.

Clones	Fixed carbon	Volatile matter	Ash
1	72.93c	26.72a	0.35b
2	74.91ab	24.76bc	0.33b
3	73.86abc	25.79abc	0.35b
4	73.86abc	25.74abc	0.41b
5	73.56bc	26.08ab	0.36b
6	75.13a	24.23c	0.64a
Standard deviation	0.13	0.98	0.92
Variation coefficient (%)	18.5	2.2	0.8

Means in column followed by same letter do not differ at 5% probability by Tukey test.

4.2.4. Fixed Carbon, Volatile Matter, and Ash Contents. Table 3 shows the mean values of charcoal fixed carbon, volatile matter, and ash contents.

Fixed carbon content reached maximum value of 75.13% for clone 6, and minimum value of 72.93% for clone 1. Santos [29] reported that the charcoal should have fixed carbon content between 75 and 80% concerning steel, because higher fixed carbon levels contribute to the increase in the productivity of blast furnaces for the same consumption of charcoal.

Levels of volatile matter are inversely proportional to the fixed carbon content, being highest for clone 1 (26.72%)

and lowest for clone 6 (24.23%). According to Santos [29], charcoal should present volatile matter contents of 20–25% for steel use, given that higher concentration of volatile matter means lower levels of fixed carbon which reduce the efficiency of charcoal in the blast furnace. However, according to the author, this feature determines the stability of flame and combustion velocity. Volatile matters promote an increase permeability of the blast furnace burden and a decrease reactivity of charcoal.

Fixed carbon and volatile matter contents were slightly different from those desirable for the steel industry, cited by Santos [29].This fact can be explained by the low degradation of the material which caused a high efficiency in charcoal production and therefore high content of volatile matters and low content of fixed carbon.

It is observed that the charcoal ash content of clone 6 was significantly higher than the others. Nevertheless, these values are below the maximum desirable to steel, as recommended by Santos [29] who states that the ash content must be less than 1%. The presence of ash in charcoal should be little for it reduces its HHV. In addition, ash causes wear in the blast furnace and can also affect the quality of pig iron, due to the phenomenon of segregation.

Botrel et al. [3] obtained 25.50% of volatile matter, 74.25% of fixed carbon, and 0.25% of ash. Neves et al. [16] found average levels of 18.92, 80.29, and 0.80% of volatiles, fixed carbon, and ash, respectively. Considering the wood of the present work as well the evaluated genetic materials by [3, 16] they were carbonized under the same conditions; the differences observed in the immediate chemical composition may be attributed to wood chemical composition.

In particular, it can be observed that there is a positive relation between the fixed carbon content of charcoal and the lignin content due to its thermal stability properties and the high content of carbon in its composition, which in turn contribute to the increase of the fixed carbon of charcoal.

As for the content of wood extractives, it could be observed that there is an inverse relation concerning the content of fixed carbon. This fact can also be explained by the thermal stability properties of the extractives present in wood. It is important to point out that the extractives are predominantly lipophilic, and they are degraded during the carbonization process. Therefore, the greater the content of extractives is, the smaller the percentage of fixed carbon in the final product is.

5. Conclusions

(i) The evaluated genetic materials showed differences in their wood properties which affect charcoal production.

(ii) According to research results, several properties of wood should be considered together for the selection of clones for charcoal production. However, basic density and chemical composition of wood, especially high contents of lignin and low contents of extractives, are the properties that had more influence on charcoal yield and its quality.

(iii) For this study, wood HHV is not a characteristic that should be used for selection of *Eucalyptus* clones. This is because no significant differences were observed for such property among the evaluated clones as well as previous studies of the same genus. Furthermore, wood HHV did not present any relationship with the properties of charcoal.

(iv) Even though clones 1/6 and 2/4/5 belong to the same species, *Eucalyptus camaldulensis* and *Eucalyptus urophylla*, respectively, differences could be observed within the same species such as the properties of wood and charcoal. Therefore, it can be concluded that there is a necessity of selection and also *Eucalyptus* breeding concerning wood and charcoal.

(v) Although all clones have presented satisfactory properties for charcoal production and also for ironmaster use, when considering the set of properties, clone 6 (*Eucalyptus camaldulensis*) stood up, and, in contrast, clone 4 (*Eucalyptus urophylla* Hybrid) showed inferior properties. Among the clones, charcoal of clone 6 stood out, for it showed high density, high HHV, and fixed carbon content.

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