Revista Árvore
ISSN: 0100-6762
r.arvore@ufv.br
Universidade Federal de Viçosa
Brasil

Neves Mendes Castro, Ana Flávia; Vinícius Oliveira Castro, Renato; de Cássia Oliveira Carneiro, Angélica; Cavalcante dos Santos, Rosimeire; Macedo Ladeira Carvalho, Ana Marcia; Trugilho, Paulo Fernando; Nogueira Alves de Melo, Isabel Cristina
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Revista Árvore, vol. 40, núm. 3, mayo-junio, 2016, pp. 551-560
Universidade Federal de Viçosa
Viçosa, Brasil

CORRELATIONS BETWEEN AGE, WOOD QUALITY AND CHARCOAL QUALITY OF EUCALYPTUS CLONES[1]

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[1] Received on 21.03.2013 accepted for publication on 16.12.2015.
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ABSTRACT – Brazil is world's greater producer of charcoal, and the Brazilian state Minas Gerais presents the greater production of said product. The wood proprieties influence the charcoal quality, making important to know them, it is known that these proprieties vary according to the age of the tree. With that being said, this research aimed to determine the correlations existing between age, the proprieties of the wood and charcoal proprieties. Three *Eucalyptus* sp. clones from Gerdau S/A were evaluated, at four ages, 3, 4, 5 and 7. From each tree, five discs were removed (0%, 25%, 50%, 75% and 100% corresponding to the commercial height of the trunk). We determined the core/sapwood relationship, basic density, chemical composition of the wood, the calorific value of the wood and of the charcoal, the gravimetric yields, apparent relative density and charcoal chemical analysis, in addition to the analysis of the condensable and non-condensable gases. Correlations between age, proprieties of the wood and charcoal were performed. It was observed a negative correlation between the age of the wood and charcoal ashes content, regardless the clones evaluated. A positive correlation between the basic density of the wood and the apparent density of the coal and a positive correlation between the lignin of wood content and the coal apparent density were observed, as well. The siringil/guaiacil relation, which determines the quantity of each type of lignin existent on the wood, presented a negative correlation with the gravimetric yields in charcoal. Therefore, it is concluded that the age of the tree influenced the proprieties of the wood, regardless the clone; the age of the genetic material did not influence the gravimetric yield in charcoal; the GG 680 clone presented greater potential to produce charcoal, considering only the proprieties of the wood.

Key words: Wood technology; Proprieties of the wood; Carbonization.

CORRELAÇÕES ENTRE IDADE E QUALIDADE DA MADEIRA E QUALIDADE DO CARVÃO VEGETAL DE CLONES DE EUCALIPTO

RESUMO – O Brasil é o maior produtor de carvão vegetal, sendo que Minas Gerais se destaca como o estado com maior produção desse produto. As propriedades da madeira influenciam a qualidade do carvão vegetal, sendo importante conhecê-las, sabendo-se que essas propriedades sofrem variação com a idade da árvore. Sendo assim, este trabalho teve como objetivo determinar as correlações existentes entre idade, as propriedades da madeira e as propriedades do carvão vegetal. Foram avaliados três clones de ***Eucalyptus*** *sp., em quatro idades, aos 3, 4, 5 e 7 anos, sendo provenientes da Gerdau S/A. De cada árvore foram retirados cinco discos (0%, 25%, 50%, 75%, 100% da altura comercial do tronco), e foram determinadas a relação cerne/alburno,*

http://dx.doi.org/10.1590/0100-67622016000300019

densidade básica, composição química da madeira, poder calorífico superior da madeira e do carvão vegetal, rendimentos gravimétricos, densidade relativa aparente e análise química imediata do carvão vegetal, além dos gases condensáveis e não condensáveis. Foram realizadas correlações entre a idade, propriedades da madeira e do carvão vegetal. Observou-se correlação negativa entre a idade da madeira e o teor de cinzas do carvão vegetal, independentemente do clone avaliados; correlação positiva entre a densidade básica da madeira e a densidade aparente do carvão; correlação positiva entre o teor de lignina da madeira e a densidade aparente do carvão. A relação siringil/guaiacil, que determina a quantidade de cada tipo de lignina presente na madeira, apresentou correlação negativa com o rendimento gravimétrico em carvão vegetal. Dessa forma, pode-se concluir que a idade da árvore influenciou as propriedades da madeira, independente do clone; a idade do material genético não influenciou o rendimento gravimétrico em carvão vegetal; o clone GG 680 apresentou o maior potencial para a produção de carvão, considerando-se somente as propriedades da madeira.

Palavras chaves: Tecnologia da madeira; Propriedades da madeira; Carbonização.

1. INTRODUCTION

Since the beginning of the 19th century, Brazil is considered world's greater producer of charcoal, used mostly on the steel industry, on the production of pig iron, ferroalloys and steel (REZENDE; SANTOS, 2010). The Brazilian state Minas Gerais presented the greater production of charcoal, and the steel industry is important for the state's economy, as well.

After the global economic crisis in 2008, the charcoal exports decreased, and the product lost its values on the internal market. In 2010, the national economy recovered, however, some sectors, such as the pig iron industry, remained in crisis (ABRAF, 2011).

Until the end of 2010, there was an elevated index of idle production of pig iron using charcoal, since the annual production was 1/3 of the full capacity and only 56,0% of the furnaces worked (ABRAF, 2011). However, it is expected a recovering of this sector, since the scenery seems to the positive in medium and long term for the forestry sector, due, mostly, the environmental advantages.

The charcoal is used, mostly, as a fuel because it presents proprieties superior to the wood on energy production, since it contains higher calorific values. In the steel industry, the charcoal is largely used to reduce iron ore in order to produce pig iron and other metal alloys. It is purer than the coke (sulfur and ash), resulting in a stronger pig iron, more resistant and malleable for forging (FREDERICO, 2009).

The wood used to produce charcoal must have a greater lignin content associated to a lower holocellulose content and higher density. Genetic material with greater calorific value and extractive content promoted greater coal income, beyond the elevated calorific value (FREDERICO, 2009). Increased density is important for the final quality of the charcoal, but it is necessary to observe alterations on the anatomic aspects of the wood, which are important for the field drying and carbonization process (FREDERICO, 2009). Therefore, it is preferable to use woods with elevated wall fraction, however, it must be considered that if the wall fraction is high, but the wood has a low percentage of fiber, it must not be used for this activity (PAULA, 2005).

The age of the trees also interferes, because several modifications occur on the wood as they age, creating variations on the chemical, physical and anatomic compositions. Usually, the wood presents a quick elevation on the density values and fiber length, from the young age until maturing, where the values remain constant. At the juvenile age, the biomass incorporation rate is crescent, tending to stabilize when the wood reaches the adult age (TRUGILHO et al., 1996).

Therefore, this work aimed to determine the correlations existent between the age, the proprieties of the wood and the charcoal proprieties, in order to determine which proprieties of the wood are more relevant to choose the most appropriate genetic material for the charcoal production.

2.MATERIALAND METHODS

Three *Eucalyptus* sp. clones used for this research (Table 1) were at the ages of 3, 4, 5 and 7, and the clones were from the commercial plantations belonging to the Gerdau S.A., located in Lassance, Minas Gerais,

Table 1 – Identification of the genetic material used.
***Tabela 1** – Identificação do material genético utilizado.*

Clones	Age (years)	Genetic material
GG 100	3	*E. urophylla*
	4	*E. urophylla*
	5	*E. urophylla*
	7	*E. urophylla*
GG 157	3	*E. urophylla*
	4	*E. urophylla*
	5	*E. urophylla*
	7	*E. urophylla*
GG 680	3	*E. urophylla* x *E. grandis*
	4	*E. urophylla* x *E. grandis*
	5	*E. urophylla* x *E. grandis*
	7	*E. urophylla* x *E. grandis*

Brazil. Three average sized trees were selected for each one of the twelve treatments, summing thirty-six trees (samples). The trees were collected in commercial plantations with an average spacing of 3,5 x 2,5m.

2.1. Material preparation

Five discs corresponding to 0%, 25%, 75% and 100% of the commercial height of the trunk were removed from each sample-tree. Firstly, we measured the percentages of the core and sapwood of each disc, before performing other analysis. Two wedges from opposed sizes were removed from each disc, they were used to determine the basic density of the wood. The rest of the disc was sectioned; a part was used for coal production and the other to determine the chemical composition and the superior calorific value.

For the analysis specified above, composed samples were used. For the basic density of the wood and the core and sapwood percentages the evaluation was performed lengthwise, in other words, the bottomup direction.

2.2. Determining the core and sapwood percentages

To determine the percentages of the core and the sapwood, two perpendicular lines were made in each disc, passing through the cord. The distance was measured from the edges to the core on both extremities of the line and the core measuring. A magnifying glass was used to determine the change from the sapwood to the core, since it is defined by the color modification and obstruction of the pores by tyloses, common on *Eucalyptus* wood. The sapwood percentage was calculated by subtracting the core area from the total area. The core/sapwood relation was calculated by dividing the core area by the sapwood area (EVANGELISTA, 2007).

2.3. Determining the basic density of the wood

Two wedges from opposed sides that pass through the cord, were identified and designed to determine the basic density of the wood. The proceedings used for the analysis are in accordance to the water immersion method, described by Vital (1984). The values were calculated from the arithmetic mean of the density of each wedge.

2.4. Determining the chemical composition of the wood

The wood samples were transformed into sawdust by a laboratory mill of the Wiley type, in accordance to the 257 om-52 norm. The fraction collected was the material that passed through the international sieve n. 16, with 40 mesh, and were stuck in the international sieve n. 24, with 60 mesh (ASTM, 1982). We determined the dry content of the wood, in accordance to the TAPPI 264 om-88 norm (TAPP1, 1998).

The levels of extractives in wood were determined in doubles, as described by the TAPPI 264 om-88 norm, applying the method of extractives, only changing the ethanol / benzene by the ethanol / toluene.

The insoluble lignin levels were determined in doubles by the Klason method, modified in accordance to what was proposed by Gomide and Demuner (1986), derived from the TAPPI T 222 om-88 norm.

The soluble lignin was determined through spectrometry, as described by Goldschimid (1971), by diluting the filtrate obtained in the procedure to determine the insoluble lignin.

The total lignin level was obtained by summing two values of the soluble and insoluble lignin. The holocellulose content was obtained by summing the extractive and total lignin and subtracting 100.

The siringila/guaiacila relation of the lignin was performed in doubles, through the liquid chromatography, after oxidizing the wood sawdust with nitrobenzene, in accordance to the methodological adaptations described by Lin and Dence (1992).

2.5. Carbonization and gravimetric yields

The carbonization was performed using wood samples removed from the discs through the commercial height of the trees (0%, 25%, 50%, 75% and 100%), for each tree, it was obtained a composed sample. The samples were, after that, drought in a greenhouse at 103±2ºC, until reaching the constant mass.

The carbonizations were performed in a laboratory muffle with electric heating; those samples were put in a metallic container. To retrieve the condensable gases, a tubular water-cooled condenser was adapted in the gas exhaust.

The total time for carbonization of wood was five hours, with the average heating rate of 1,56°C/minute, the initial temperature was 30ºC and the final temperature was 450°C, stabilized for 30 minutes. After the carbonizations, were determined, based on the dry mass of the wood, the gravimetric yields, the condensable and non-condensable gases, being the last one obtained by difference.

2.6. Determining the superior caloric value

The superior calorific value of the wood and charcoal were determined in accordance to the method described by the ABNT NBR 8633 norm (ABNT, 1984), using an adiabatic calorimetric bomb. The wood samples were reduced using a laboratory mill of the Wiley kind, in accordance to the TAPPI 257 om-52 norm (TAPPI, 1998). The fraction collected was the material that passed through the international sieve n. 16, with 40 mesh, and were stuck in the international sieve n. 24, with 60 mesh (ASTM, 1982). The samples were drought in a greenhouse at 103±2ºC, until reaching the constant mass, in order to determine the superior calorific value.

2.7. Coal proprieties

To perform the immediate chemical analysis of the charcoal, the samples were grinded and sieved to a particle size of, approximately, 0,2mm in accordance to the ABNT NBR 8112 norm, with some adaptations, to determine the levels of volatile materials, ashes and fix carbon, with dry base (ABNT, 1986).

The levels of volatile materials was determined by heating the coal at 950°C, in a muffle furnace, the samples were located in crucibles, which were closed and taken to the muffle door for two minutes, for acclimation, and, posteriorly, to the interior of the furnace during nine minutes, summing eleven minutes.

The ashes content was determined after the complete combustion of coal, through the material heated in a muffle furnace at 605ºC, during 6 hours. The ashes mass in relation to the dry coal corresponds to the ashes content.

The carbon content was calculated by summing the levels of volatile material and ashes, and subtracting 100.

The gravimetric yield for fixed carbon was obtained by multiplying the gravimetric yield for charcoal by the fixed carbon content.

2.8. Apparent relative density

The apparent relative density was determined in accordance to the method proposed by Vital (1984), using a hydrostatic balance to determine the relocated volume. The coal samples were weighted and, posteriorly, immersed in water to determine the relocated volume.

2.9. Statistical analysis

The data obtained were submitted to the Lilliefors and Cochran tests, to verify the normality and homogeneity of the variances, respectively. Then, the variance analysis proceeded by applying the F test, the measuring was compared by the Tukey test. For the variables that did not attend the normality presumptions, the non-parametric Kruskall-Wallis test was used. The significance level of 5% was considered.

To determine the correlations existent between the proprieties of the wood and age with the charcoal proprieties, the Pearson correlation coefficient was applied. The significance level of 5% was considered, as well.

The statistical analysis were performed using the STATISTICA 8,0 program (STATSOFT INC, 2008).

3. RESULTS

On Table 2, we present the average values obtained for the wood variables in function of the age of the clones. The variables evaluated were the core/sapwood relation, basic density of the wood, superior calorific value, extractive levels, lignin level, siringil/guaiacil relation and holocellulose level.

The average values obtained for the charcoal variables in function of the age and genetic material are described on Table 3. The variables evaluated were the gravimetric yield in charcoal, superior calorific value, apparent relative density, volatile levels, ashes content and fixed carbon content.

On Table 4, we present the results for the correlations between the proprieties of the wood and the proprieties of coal for the GG 100, GG 157 and GG 680 clones, and other clones, as well.

Table 2 – Average values observed for the wood variables in function of the age and genetic material.
***Tabela 2** – Valores médios observados para as variáveis da madeira em função da idade e do material genético.*

Clone	Age (years)	C/SW	BDW ($g.cm^{-3}$)	SCVW ($Kcal.Kg^{-1}$)	EXT (%)	LIGT (%)	S/G	HOLO (%)
GG 100	3	0,41Aa	0,452Bb	4.542Cb	2,37Bb	32,23ABa	2,65Ab	65,41Aab
	4	0,56Aa	0,458Bb	4.654ABab	4,08Aa	31,46ABa	2,57Ab	64,46ABa
	5	0,55Aa	0,461Bb	4.719Aa	3,90Aa	30,82Ba	2,53Aab	65,28Aa
	7	0,62Aa	0,522Ab	4.617Ba	4,68Aa	32,86Aa	2,30Bb	62,46Bb
GG 157	3	0,50Aa	0,448Bb	4.620Ba	2,91Bab	31,20Aa	3,18Aa	65,89Aba
	4	0,52Aa	0,466Bb	4.718Aa	3,04ABb	30,73Aa	3,17Aa	66,24Aa
	5	0,52Aa	0,531Ab	4.687Aa	3,94Aa	32,11Aa	2,68Ba	63,95Ba
	7	0,69Aa	0,543Aab	4.615Ba	3,33ABb	31,69Aa	2,82Ba	64,97Aba
GG 680	3	0,32Ba	0,486Ca	4.586Aa	4,02Aa	32,04ABa	2,52Ab	63,93ABb
	4	0,41ABa	0,504Ca	4.621Ab	3,50Aab	31,63ABa	2,52Ab	64,87Aa
	5	0,63ABa	0,528Ba	4.480Bb	3,44Ab	31,32Ba	2,40Bb	65,24Aa
	7	0,74Aa	0,565Aa	4.482Bb	4,31Aa	33,82Aa	2,40Bb	61,88Bb

Where: (C/SW) core/sapwood relation; (BDW) basic density of the wood in $g.cm^{-3}$; (SCVW) superior calorific value of the wood in $Kcal.Kg^{-1}$; (EXT) extractive content of the wood in percentage; (LIGT) total lignin content of the wood in percentage; (S/G) wood siringil/guaiacil relation; (HOLO) holocellulose content of the wood in percentage. Averages followed by the same uppercase letter among the ages and lowercase among the clones, do not differ at 5% of significance, by the Tukey test.

Table 3 – Average values for the charcoal variables in function of the age and genetic material.
***Tabela 3** – Valores médios obtidos para as variáveis do carvão vegetal em função da idade e do material genético.*

Clone	Age (years)	GYC (%)	SCVW ($Kcal.Kg^{-1}$)	CAD ($g.cm^{-3}$)	Volatile (%)	Ashes (%)	CFCC (%)
GG 100	3	32,98Ab	7.409Aa	0,301Ab	21,34Ba	1,24Aa	77,43Aa
	4	33,10Aa	7.478Aa	0,310Aab	21,57ABb	0,89Ba	77,55Aa
	5	33,18Ab	7.446Aa	0,262Bb	23,21ABa	0,96Ba	75,83Aa
	7	33,53Ab	7.332Aa	0,330Aab	23,77Aa	0,48Ca	75,75Aa
GG 157	3	32,61Ab	7.279Ab	0,320ABab	22,05Ba	1,44Aa	76,52Ab
	4	34,29Aa	7.314Ab	0,291Bb	22,42Bab	0,96Ba	76,63Aa
	5	34,49Aa	7.343Ab	0,341Aa	24,35ABa	0,55Ba	75,10Aa
	7	34,81Aa	7.383Aa	0,322ABb	25,40Aa	0,35Cab	74,25Bb
GG 680	3	34,31Aa	7.331Ab	0,337Aa	23,13Aa	0,51ABb	76,36Ab
	4	33,91Aa	7.363Aab	0,327Aa	23,89Aa	0,65Ab	75,46Ab
	5	34,65Aa	7.306Ab	0,345Aa	24,97Aa	0,32BCc	74,71Aa
	7	34,96Aa	7.282Aa	0,355Aa	24,05Aa	0,17Cb	75,77Aa

Where: (GYC) gravimetric yield for charcoal in percentage; (SCVW) superior calorific value of the charcoal in $Kcal.Kg^{-1}$; (CAD) charcoal apparent density in $g.cm^{-3}$; (Volatile) coal volatile levels in percentage; (Ashes) ashes content of coal in percentage; (CFCC) coal fixed carbon content in percentage. Averages followed by the same uppercase letter among the ages and lowercase among the clones, do not differ at 5% of significance, by the Tukey test.

Table 4 – Correlations between the proprieties of the wood (lines) and charcoal (columns).
***Tabela 4** – Correlações entre as propriedades da madeira (linhas) e do carvão vegetal (colunas).*

Clone GG100	GYC (%)	SCVW ($Kcal.Kg^{-1}$)	CAD ($g.cm^{-3}$)	Volatile (%)	Ashes (%)	CFCC (%) (%)
Age (years)	0,37	-0,46	0,31	0,87*	-0,91*	-0,77*
C/SW	0,34	-0,25	0,33	0,52	-0,61*	-0,44
BDW ($g.cm^{-3}$)	0,43	-0,56	0,63*	0,69*	-0,86*	-0,57
SCVW ($Kcal.Kg^{-1}$)	-0,03	0,35	-0,39	0,33	-0,27	-0,32
EXT (%)	0,02	-0,11	0,22	0,46	-0,69*	-0,35
HOLO (%)	-0,35	0,38	-0,72*	-0,37	0,66*	0,24
LIG (%)	0,43	-0,38	0,72*	0,05	-0,22	0,01
S/G	-0,15	0,20	-0,44	-0,61*	0,85*	0,48
Clone GG157						
Age (years)	0,53	0,52	0,22	0,68*	-0,91*	-0,54
C/SW	0,07	0,34	0,02	0,37	-0,53	-0,29
BDW ($g.cm^{-3}$)	0,48	0,49	0,38	0,69*	-0,94*	-0,54
SCVW ($Kcal.Kg^{-1}$)	0,32	-0,19	-0,14	-0,17	0,06	0,18
EXT (%)	0,47	0,03	0,46	0,47	-0,40	-0,43
HOLO (%)	-0,53	-0,27	-0,73*	-0,55	0,40	0,52
LIG (%)	0,49	0,39	0,80*	0,52	-0,34	-0,51
S/G	-0,40	-0,30	-0,60*	-0,62*	0,81*	0,50
Clone GG680						
Age (years)	0,38	-0,38	0,52	0,42	-0,79*	-0,24
C/SW	0,42	-0,40	0,45	0,51	-0,79*	-0,33
BDW ($g.cm^{-3}$)	0,42	-0,49	0,60*	0,52	-0,80*	-0,34
SCVW ($Kcal.Kg^{-1}$)	-0,18	0,21	-0,24	-0,25	0,65*	0,09
EXT (%)	0,41	-0,40	0,30	-0,19	-0,10	0,22
HOLO (%)	-0,35	0,66*	-0,53	-0,05	0,38	-0,05
LIG (%)	0,23	-0,59*	0,48	0,13	-0,40	-0,03
S/G	-0,71*	0,62*	-0,85*	-0,58	0,48	0,48
Todos Clones						
Age (years)	0,37*	-0,09	0,26	0,58*	-0,70*	-0,47*
C/SW	0,13	-0,04	0,07	0,29	-0,34*	-0,24
BDW ($g.cm^{-3}$)	0,58*	-0,31	0,64*	0,71*	-0,89*	-0,57*
SCVW ($Kcal.Kg^{-1}$)	-0,11	0,22	-0,44*	-0,15	0,35*	0,07
EXT (%)	0,22	-0,07	0,26	0,26	-0,41*	-0,18
HOLO (%)	-0,35*	0,20	-0,56*	-0,30	0,46*	0,22
LIG (%)	0,31	-0,22	0,56*	0,23	-0,33	-0,17
S/G	-0,16	-0,13	-0,34*	-0,28	0,59*	0,15

Where: (C/SW Relation) core/sapwood relation. (BDW) basic density of the wood in $g.cm^{-3}$. (SCV) superior calorific value of the wood in $Kcal.Kg^{-1}$. (S/G) wood siringil/guaiacil relation. (CGY) charcoal gravimetric yield in percentage. (CSCV) charcoal superior calorific value in $Kcal.Kg^{-1}$. (CAD) charcoal apparent density in $g.cm^{-3}$. (Volatile) coal volatile levels in percentage. (Ashes) coal ashes content in percentage. (CFCC) coal fixed carbon content in percentage. *Significant correlations at 5% of significance by the *t* test.

4. DISCUSSION

By evaluating the C/SW relation, it is observed that the age effect was significant only for the GG 680 clone and the greater core/sapwood relation was obtained at the age of 7 for the three clones evaluated. It is noted that, for all ages, there was not a significant difference in the core/sapwood relation between the clones. On the research developed by Arantes (2009), who studied a *Eucalyptus grandis* x *Eucalyptus urophylla* clone at the age of six, it was stated that, for medium sized trees, the average percentage of the core was 35% and of the sapwood was 65%, in other word, the core/sapwood relation obtained was 0,54.

The values presented for basic density of *Eucalyptus* sp. wood used for charcoal production, must be classified as average density, meaning 0,54 $g.cm^{-3}$ (BRITO et al., 1983).

In this research, it was noted that the basic density of the wood increased with age, highlighting that only at the age of seven, it was observed values similar to the ideal values for charcoal production, as defined by Brito et al. (1983). It was verified a significant difference for the basic density of the wood, between the clones of all ages, the clone GG 680 presented average superior values at the four ages analyzed. Oliveira et al. (2010) evaluated *Eucalyptus pellita* clone at the age of five, and they found a basic density of the wood of 0,56 g.cm^{-3}, higher than what was found for the clones studied.

The superior calorific value of the wood did not present variance homogeneity, therefore, it was performed a non-parametric analysis by applying the Kruskall-Wallis test. Based on the results, it is possible to infer that the age affected the calorific value of the wood, and a significant difference between the clones, at all ages. Santana (2009) stated little influence of the age for this variable, and obtained an average value of 4610 Kcal/Kg for an *Eucalyptus grandis* clone at the age of three and seven years.

For the extractive level, it is observed that the age effect for the GG 100 and GG 157 clones, besides, it was verified a significant difference between the clones of all ages evaluated. Gomide et al. (2005), evaluated ten *Eucalyptus* sp. clones, and found extractive levels varying from 1,76% to 4,13%, the average value was 3,01%. These values are similar to what was observed in this research.

Regarding the lignin content, it was observed the age effects for GG 100 and GG 680 clones, and it was not stated a significant difference between the clones, at the ages evaluated. The values observed in this research are similar to what was obtained by Santos (2010), who verified that for *Eucalyptus* sp. clones at the age of seven, the average value was 32% of total lignin.

By analyzing the S/G relation, it was observed a decreasing of this relation regarding the age increasing for the three clones evaluated. Besides, it is observed the existence of a significant difference between the hybrid clones of *Eucalyptus* sp., at the age of seven, the average values vary from 2,6 to 3,25.

Generally, the S/G relation decreased as the age increased, which indicated that using older woods is more advantageous, when it comes to the quality of the wood for charcoal production, since the guaiacil lignin presents a condensed structure, being thermally stable. The GG 680 clone presented lower values for the S/G relation at all ages.

By analyzing Table 2, we observe the age effect for the three clones evaluated. It was stated a significant difference between clones at all ages, except at four and five. The holocellulose content is inversely proportional to the lignin level, therefore, to produce charcoal, wood containing lower holocellulose levels are preferable. Santos (2010) obtained a similar result while studying *Eucalyptus* sp. clones, at the age of seven, since the average value for this variable was 65,0%.

Greater values for the coal gravimetric yields are desirable, because they result in a greater amount of charcoal and, consequently, improves the productivity of the furnaces. However, the gravimetric yield varies in function of the differences of the carbonizations, in other words, when the heating rate is modified, the carbonization time and final temperature modify the yield. Therefore, it is difficult to compare the results with other works due the modifications on the variables presented.

By analyzing Table 3, it is observed the lack of influence of the age in the gravimetric yield for charcoal. However, it is observed a difference between the clones, except the ones at the age of four. Greater values of gravimetric yields in charcoal are desirable, because they result in a greater mass of charcoal and, consequently, greater furnace productivity.

Still according to Table 3, it was verified the lack of influence of the age over the calorific value for the three clones evaluated. However, there was a significant difference between the clones of all ages, except at the age of seven.

It is observed on the literature a huge variation on the results regarding the calorific value of the coal. Said difference might be related to the use of different carbonization marches. It is known that the coal calorific value is related to the fixed carbon content, which increases with the wood degradation. However, by exposing the wood to carbonization temperatures for a longer period, the wood is damaged and, consequently, loses the apparent density and resistance. Therefore, it is necessary to stablish a carbonization march that provides ideal values for coal proprieties in function of the genetic material used.

The charcoal used in the steel industry must present the maximum value of 25% of volatile materials (SANTOS, 2008). It is observed that all coal prevenient from the different clones evaluated in this experiment, regardless the age, obtained values for volatile materials in accordance to what was specified.

It was verified that the value of coal volatiles increased in function of the age, except for the GG 680 clone, which did not present a significant difference among the ages. It was observed that the genetic material used influenced the volatile material levels during the charcoal production, except at the age of seven.

Generally, the ashes content in the coal used in the steel industry must be under 1% (SANTOS, 2008). It is observed that the charcoal from the GG 680 clone presented, regardless the age, ashes contents under 1%. As for the other clones, it was verified that only at the age of four, the contents remain under 1%.

By evaluating the age effect on the coal ashes content, regardless the clone, it was verified that the variable decreased, when the age of the tree increased. It is due the changes on the nutritional state of the trees (WADT et al, 1999).

The fixed carbon content of the coal used in the steel industry must be from 70% to 80% (SANTOS, 2008). It was observed that the values obtained for this research attend the demands of the steel industry. It was verified that the age did not affect the fixed carbon content of the charcoal, except for the GG 157 clone, which presented a lower value for this variable at the age of seven. A significant difference was observed among the genetic materials, except at the age of five. Generally, the GG 100 presented greater fixed carbon contents.

It is necessary to emphasize that variations can occur between the fixed carbon values found in the literature and the ones obtained for this research, it might be related to the use of different carbonization marches. The increase of the fixed carbon content is related to the increasing of the temperature or of the carbonization time.

The proprieties of the charcoal are influenced by the wood that originated it and by the carbonization process. Generally, it is known that when the carbonization time and final temperature, it is expected an increasing in the fixed carbon content and on the calorific value of the coal, beyond a reduction of the density values, on the volatile material content, on the mechanical resistance and on the gravimetric yield of the charcoal. It is known that the basic density is directly connected to the apparent density of the coal. Besides, it is expected that by increasing the wood lignin content and decreasing the S/G relation, occur a gain on the gravimetric yield and on the fixed carbon of the coal. These tendencies had already been proved by the literature, although, in this research, no all correlations presented results according to what was expected.

By analyzing Table 4, it was verified a negative correlation between the age and the ashes content, regardless the clones evaluated. It might be related to the fact that in aged forests, the age of the trees reflect their development stage. Therefore, among different age groups, it is possible to find differences on the cycling of the nutrients dynamics, and, on the trees nutritional state (WADT et al., 1999).

As observed on Table 4, there was a positive correlation between the basic density of the wood and the apparent density of coal for the GG 100 and GG 680 clones, when compared to the other clones. Such correlation can guide the choice and improvement of the species designed for coal production.

Still on Table 4, it is observed a positive correlation between the lignin content and the apparent density of the coal. According to Brito and Barrichelo (1977), the wood chosen to obtain coal containing the best chemical proprieties (greater fixed carbon contents and lower levels of volatile substances and ashes), must have high levels of lignin. Regarding the increasing of the volumetric yield in coal, the woods must contain, beyond the elevated lignin content, greater levels of basic density to increase the quality of the dry matter, allocated in a carbonization furnace.

The S/G relation presented a negative correlation with the gravimetric yield for charcoal, being more representative in the GG 680 clone. Therefore, the decreasing of the S/G relation indicates increasing on the guaiacil lignin, which increases the coal gravimetric yield, since it has a condensed structure, and, probably, greater thermal stability.

5. CONCLUSIONS

Based on the results obtained, it is possible to conclude that:

The age of the tree influenced the proprieties of the wood, regardless the clone, providing improvements on the coal quality.

The age of the genetic material did not affect the gravimentri yield in charcoal.

Considering the proprieties of the wood to choose the best genetic material, it can be stated that the GG 680 clone was the best option for charcoal production.

Finally, it is concluded that the three genetic materials studies, regardless the age of the trees, attend the demands of the steel industry, showing a satisfactory gravimetric yield.

6. ACKNOWLEDGEMENTS

To the FAPEMIG (Foundation for Research Support of Minas Gerais, Brazil) for financing the project; to Gerdau, for donating the wood, to the Federal University of Viçosa and the employees of the Laboratory of Panels and Wood Energy (LAPEM/UFV) and to the Universidade Federal de Lavras.

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