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Artigos

Physical and chemical properties of wood from *Eucalyptus* and *Corymbia* clones in different planting densities

Propriedades físicas e químicas das madeiras de clones de *Eucalyptus* e *Corymbia* em diferentes densidades de plantio

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ABSTRACT

The present work aimed to evaluate some technological characteristics of the wood of two commercial hybrid clones of *Eucalyptus* spp and two hybrid clones of *Corymbia* spp, implanted in three different planting spacings, at 24 months of age. Four trees per clone were sampled at each spacing to determine the following wood characteristics: basic density, gross calorific value, energy density and cellulose, hemicellulose, lignin, ash and carbon contents. There was a significant effect of the clone x spacing interaction for the basic density, energy density, lignin and cellulose contents of the wood. *Eucalyptus* showed the highest levels of lignin and cellulose, and hybrid clones of *Corymbia* the highest values of basic density and energy density of wood, with emphasis on clone C3, where the highest averages of the study were verified. For the levels of hemicelluloses and ash in the wood, the clone effect and spacing effect were observed. As for the carbon content and the gross calorific value in the wood, there was no significant effect, either from the clone, the spacing or the interaction of these two factors. The results show that there is variability in the characteristics between the genetic materials evaluated and in relation to the planting spacing tested. It should be noted that the choice of the best genetic material should be based on the technological characteristics of the wood, but also the forest productivity associated with good silviculture of the species should be evaluated.

Keywords: Energetic forest; Wood characteristics; Biofuel

RESUMO

O presente trabalho teve como objetivo avaliar algumas características tecnológicas da madeira de dois clones híbridos comerciais de *Eucalyptus* spp e dois clones híbridos de *Corymbia* spp, implantados em três diferentes espaçamentos de plantio, aos 24 meses de idade. Quatro árvores por clone foram amostradas em cada espaçamento para determinar as seguintes características da madeira: densidade básica, poder calorífico superior, densidade energética e teores de celulose, hemiceluloses, lignina, cinzas e carbono. Observou-se efeito significativo da interação clone x espaçamento para a densidade básica, densidade energética, teores de lignina e de celulose da madeira. Os clones de *Eucalyptus* apresentaram os maiores teores de lignina e celulose, e coube aos clones híbridos de *Corymbia* os maiores valores de densidade básica e da densidade energética da madeira, com destaque para o clone C3, onde se verificou as maiores médias do estudo. Para os teores de hemiceluloses e cinzas na madeira, observou-se o efeito de clone e efeito de espaçamento. Quanto ao teor de carbono e ao poder calorífico superior na madeira, não houve efeito significativo, seja do clone, do espaçamento ou da interação desses dois fatores. Os resultados demonstram que há variabilidade das características entre os materiais genéticos avaliados e em relação aos espaçamentos de plantio testados. Cabe ressaltar que a escolha do melhor material genético deve ser baseada nas características tecnológicas da madeira, mas também deve ser avaliada a produtividade florestal associada à boa silvicultura da espécie.

Palavras-chave: Floresta energética; Características da madeira; Biocombustível

1 INTRODUCTION

The increase in productivity provided by the cloning of the genus *Eucalyptus* from the end of the 1970s, placed Brazil among the most efficient nations in the production of forestry raw material (VENTURIM; CAMPINHOS; MACEDO; VENTURIM, 2014). The species of this genus stand out among the various options for the formation of energy forests due to rapid growth, high energy mass, tolerance to extreme conditions and the possibility of densification of plantations (LOPES; LAIA; SANTOS; SOARES; PINTO LEITE; MARTINS, 2017).

The great part of the area of energetic forests in Brazil has been carried out with species and hybrids of the genus *Eucalyptus*, which normally present low basic density of wood. Thus, the challenge is to find genetic materials of high basic density that can produce biomass of high energy quality. In this sense, recently, some companies in the forestry sector have sought to form energy forests based on the *Corymbia* genus species. This genus is composed of 113 species that are associated with high basic density of wood, extractives, proportion of carbohydrates and lower levels of lignin (SEGURA; SILVA JÚNIOR, 2016). It is noteworthy that the hybrids between *Corymbia* species are crosses that are still little explored, but they can produce promising genetic materials for the formation of forests to obtain energy biomass. Hybrids created from *Corymbia citriodora* and *Corymbia torelliana* genotypes increase the chance that the resulting plants will be more vigorous than either parent (REIS; PROTÁSIO; MELO; TRUGILHO; CARNEIRO, 2014).

For a better use of new clones in the formation of energy forests it is of fundamental importance to characterize some physical and chemical properties of forest biomass in order to obtain better raw material for this purpose. It is important to note that the physical and chemical properties of biomass influence the quality of the material, directly affecting yield, conversion and energy quality. In addition, it is important to know if there are dependencies between clones and planting spacing in determining the characteristics of biomass and how these interactions can influence the use of forest stands. Thus, the choice of species, the planting location and the analysis of this interaction becomes of fundamental importance, since they can reflect on the modification of the chemical composition and physical properties of the wood (NEVES; PROTÁSIO; COUTO; TRUGILHO; SILVA; VIEIRA, 2011), and this affects the production and quality of this biomass for power generation.

Basic density constitutes one of the most important biomass characteristics to identify promising forest species for bioenergy. This characteristic is strongly correlated with energy production, therefore, the higher the basic density, the greater the amount of energy stored per unit volume (CARNEIRO; CASTRO; CASTRO; SANTOS; FERREIRA; DAMÁSIO; VITAL, 2014). The basic density can vary between botanical species, between trees of the same species, between individuals of the same clone and along the stem of the same tree (COUTO; PROTÁSIO; REIS; TRUGILHO, 2012).

The chemical composition of wood is directly related to the fuel quality of forest biomass (LOPES; LAIA; SANTOS; SOARES; LEITE; MARTINS, 2017) exerting a great influence on the biomass beneficiation process (ZANUNCIO; COLODETTE; GOMES; CARNEIRO; VITAL, 2013). Chemically, wood consists of lignocellulosic biopolymer, structurally formed by cellulose, hemicellulose and lignin, which are the three main chemical components of the cell wall (GARCIA; GUERRA; EUFRADE JUNIOR; SANSÍGOLO; LANÇAS; YAMAJI, 2016). Cellulose and hemicelluloses, which are polysaccharide polymers, and lignin, which is a phenolic macromolecule, are basically compounds of carbon, hydrogen and oxygen (VITAL; CARNEIRO; PEREIRA, 2013) that are directly associated with the energy performance of combustible materials (PROTÁSIO; SANTANA; GUIMARÃES NETO; GUIMARÃES JÚNIOR; TRUGILHO; RIBEIRO, 2011).

It should be noted that the quality of wood for bioenergetic use can be influenced by the age of genetic materials (NEVES; PROTÁSIO; TRUGILHO; VALLE; SOUSA; VIEIRA, 2013). Thus, the age of a forest is a very important factor in the assessment of biomass, since the aging of trees in the forest stands promotes several transformations in the wood, including changes in its chemical, physical and anatomical compositions (CARNEIRO; CASTRO; CASTRO; SANTOS; FERREIRA; DAMÁSIO.; VITAL, 2014).

Trees grown for use in bioenergy had, over time, their cutting cycle reduced from seven to five or four years, due to the success of breeding programs and changes in planting spacing. In this context, it is essential that studies of wood quality be carried out in advance, taking into account the trend of harvesting trees at earlier ages to obtain energy products (LOPES; GONÇALVES; MARTINS; PENA; COELHO; LAIA, 2022). Therefore, it is necessary to know the properties of the wood and its variation according to the spacing, in order to use it for a specific use, in order to promote its best use.

Thus, the present work aimed to evaluate the physical and chemical characteristics of the wood of two commercial hybrid clones of *Eucalyptus* spp and two new hybrid clones of *Corymbia* spp, cultivated in three different planting spacing, at 24 months of age.

2 MATERIALS AND METHODS

2.1 Experimental area characterization and plant material sampling

Experimental area was located in Itamarandiba, Jequitinhonha Valley region, Minas Gerais State, Brazil. Geographical coordinates are 17°46'22"S and 42°54'12" W at 946 m.

Region's climate is defined as tropical high altitude, humid temperate, with two well-defined seasons, hot and humid summer and dry winter. Köppen and Geiger classification is Cwa type. Region temperature average is 21,2ºC, annual relative humidity varies between 60 and 70% and the historical annual rainfall average is 1.132 mm. (LOPES; LAIA; SANTOS; SOARES; PINTO LEITE; MARTINS, 2017).

In this study, four clones were used, two commercial *Eucalyptus* hybrid clones and two *Corymbia* hybrid clones: Spontaneous hybrid of *Eucalyptus urophylla* S. T. Blake (C1); Hybrid controlled pollination of *Eucalyptus urophylla* S. T. Blake x (*Eucalyptus camaldulensis* Dehnh x *Eucalyptus grandis* W. Hill ex Maiden (C2); Spontaneous hybrid of *Corymbia citriodora* (Hook.) K.D. Hill & L.A.S Johnson x *Corymbia torelliana* (F. Muell.) K.D. Hill & L.A.S Johnson (C3); Spontaneous hybrid of *Corymbia torelliana* (F. Muell.) K.D. Hill & L.A.S Johnson x *Corymbia citriodora* (Hook.) K.D. Hill & L.A.S Johnson (C4).

The four clones were evaluated in three different planting spacing, with different planting densities and vital growth spaces: 3,0 x 3,0 m (1111 plants/hectare and 9,0 m²/plant); 3,0 x 1,5 m (2222 plants/hectare and 4,5 m²/plant); and 3,0 x 1,0 m (3333 plants/hectare and 3,0 m²/plant).

At 24 months old, four trees with diameter at breast height (DBH) in the average class were selected for each clone on each one of three planting spacing, totaling 48 samples. These 48 trees were harvestesd and then discs with bark, 2,5 cm thick, were collected in the positions 0%, 25%, 50% and 75% of total height for each tree. In addition, an extra disc was colected at DBH.

The dry mass of wood per hectare was obtained by multiplying the volume of wood (m^3 ha^{-1}) by the basic density of the wood (kg m^{-3}), according to the folllwing Equation (1):

$$DM = Vol \times BD \tag{1}$$

where: DM - dry mass of the wood (t ha^{-1}); Vol - volume of wood (m^3 ha^{-1}); and, BD - basic density of the wood (kg m^{-3}).

For volume determination, the sampled trees were rigorously cubed using the Smalian method. Subsequently, the averages of the individual volumes obtained in each treatment were multiplied by the planting densities at the different spacings.

2.2 Physical and chemical analysis

Wooden discs were identified and referenced to the sampled heights. They were send to wood basic density determining. All basic density procedures were donne in accordance to immersion in water method, described by NBR 11941 (ABNT, 2003). Tree trunk wood basic density was obtained by compute the longitudinal sampling points arithmetic mean, without considering DAP sample.

Wood structural chemical analysis was done from a pooled sampling. Disks obtained along the trees stem were subsampled, pooled and tested together in a single vial. Wood samples were triturated in a Willey mill. Cellulose, hemicellulose and lignin contents were method determinated by Van Soest method (VAN SOEST, 1967) and ash content was determined according to the Instituto Adolfo Lutz (IAL, 2008).

Elementary carbon analysis was carried out using the fraction passed through 200 mesh and retained on 270 mesh sieves from a pooled sample of all longitudinal tree disks samples. A mass equivalent to 2,0 mg (± 0,5 mg) of sawdust dry was used. Carbon levels determination was carried out in a LECO® analyzer, model TruSpec Micro CHNS/O, in the same way as used by Lopes, Gonçalves, Martins, Pena, Coelho e Laia (2022).

To determine the gross calorific value of wood from different clones, the samples were sieved and the fraction that passed through the 40 mesh sieve and was retained on the 60 mesh sieve was used. Subsequently, the samples were dried in a conventional oven at 103 ± 2°C until constant mass was obtained. The gross calorific value was determined in an adiabatic calorimeter, according to NBR 8633 (ABNT, 1984).

For the determination of the superior gross calorific value of the wood of the different clones, the samples were sieved and the fraction that passed through the 40 mesh sieve and was retained on the 60 mesh sieve was used. Subsequently, the samples were dried in a conventional oven at 103 ± 2°C to constant mass. The gross calorific value was determined in an adiabatic calorimeter, according to NBR 8.633 (ABNT, 1984).

To determine the energy density (ED), basic density and gross calorific value were multiplied according to the following Equation (2):

$$ED = WDB \times GCV \tag{2}$$

where: ED = Energy Density (kcal m^{-3}); WBD = basic density (kg m^{-3}) and GCV = gross calorific value (kcal kg^{-1}).

To convert the energy into kcal m^{-3}, the values in kcal were divided by 238,845.

2.3 Data analysis

Effects of different spacings and clones on basic density, structural chemical composition and carbon content in wood were evaluated in a factorial completely randomized design, in which four clones were compared in three planting spacing, with four replications (trees), totaling twelve treatments and 48 observations. Data were submitted to analysis of variance (ANOVA) and F test ($p < 0,05$). All significant differences between treatments were subjected to Tukey test at 5% significance level. The data were submitted to statistical analysis using the SISVAR 5.6 Software (FERREIRA, 2019)

3 RESULTS AND DISCUSSION

Table 1 presents the summary of the forest inventory of productivity in terms of volume and dry mass of wood, observed in each clone, in the different planting spacings.

Table 1 – Volume per hectare (Vol.), in $m^3 ha^{-1}$, and wood dry mass per hectare (DM), in ton ha^{-1}, of the four clones in the three different planting spacings

Clones	Spacing (m)					
	3,0 x 3,0		3,0 x 1,5		3,0 x 1,0	
	Vol	DM	Vol.	DM	Vol.	DM
C1	30,5	12,3	46,4	18,6	61,8	24,9
C2	37,7	14,5	48,4	18,6	58,4	22,3
C3	28,4	13,8	42,7	20,3	56,3	26,1
C4	21,8	9,2	31,0	13,0	42,4	18,0

Source: Authors (2021)

It was observed that the *Eucalyptus* clones obtained higher volumetric productivity than the *Corymbia* clones, at the three spacings evaluated. The highest average volumetric yields were observed for the four clones evaluated at the 3,0 × 1,0 m spacing, a result that was expected due to the higher density of plants per hectare at this spacing. This higher productivity at denser spacings is also reported by other authors (FERREIRA; LELES; MACHADO; ABREU; ABILIO, 2014; SEREGHETTI; LANÇAS; SARTORI; REZENDE; SOLER, 2015).

In the 3,0 × 3,0 m spacing, the highest wood dry mass values were observed in clones C2 and C3, and in the 3,0 × 1,5 m spacing and 3,0 × 1,0 m, C3 clone presented the highest means for this variable. For all studied clones, the highest wood dry mass values were found in the spacing of 3,0 × 1,0 m. These results are corroborated by other studies on the direct influence of planting density on biomass production in forest plantations (MÜLLER; COUTO; LEITE; BRITO, 2005; ELOY; SILVA; SCHMIDT; TREVISAN; CARON; ELLI, 2016; TUN; GUO; FANG; TIAN, 2018). It should be noted that the evaluation of dry matter mass is more important than the isolated use of volumetric power and wood density variables for the selection of the most promising genetic materials for energy production (LOPES; GONÇALVES; MARTINS; PENA; COELHO; LAIA, 2022).

Table 2 presents the summary of the analysis of variance for some characteristics evaluated (basic density, energy density, gross calorific value and chemical properties) in the wood of the clones. A significant effect was observed in the clone x spacing interaction for the basic density, energy density and for the cellulose and lignin content of the wood, showing the existence of dependence between the factors considered. The effect of the clone x spacing interaction was not significant for the hemicellulose content of the wood, but there was a significant effect of clone. For the ash content, a significant effect was observed only for the clone. As for the carbon content and gross calorific value, there was no significant effect of the clone and spacing, as well as for their interaction.

Table 2 – Summary of the analysis of variance of basic density, chemical and energetic characteristics of wood of wood from hybrid clones of *Corymbia* and *Eucalyptus*

Variation Sources	DF	Mean Squares							
		WBD	**Wcarbon**	**GCV**	**ED**	**WLig**	**WCel**	**WHem**	**WAsh**
Clone	3	0,05254*	1,4192ns	37484,76ns	1114538,3*	81,53*	46,40*	36,89*	0,0178*
Spacing	2	0,00066*	1,5156ns	1290,19ns	10367,8ns	7,83*	13,92*	3,44 *	0,0010 ns
Clone*Spacing	6	0,00060*	0,4851ns	6380,04ns	22963,3*	2,03*	3,13*	1,30ns	0,0037 ns
Error	36	0,00017	2,05472	9515,47	3424,6	0,53	1,18	0,59	0,0051

Source: Authors (2021)

In where: DF – Degrees of fredom; WBD – wood basic density; WCarbon – wood carbon content; GCV - gross calorific value; ED = energy density; WLig – wood lignin; WCel – wood cellulose; WHem – wood hemicellulose; Ash – wood ash; * – significant at 5% by F test; ns – not significant at 5% by F test.

Table 3 shows the average of wood basic density, energy density, lignin and cellulose content wood, for the four clones at three planting spacings considering the unfolding of the factors.

The clone effect within each spacing level, for basic wood density, showed that clone C3 had the highest average of basic density in the three spacing, while clones C1 and C2 had the lowest averages. Spacing effect evaluating within each clone level showed no spacing influences on basic wood density for clones C1, C2 and C4. However, clone C3 presented a lower mean for that variable in 3,0 x 1,0 m planting spacing.

Table 3 – Average values and multiple comparison test for basic density, lignin and cellulose content and energy density of wood of clones the *Corymbia* and *Eucalyptus*

Characteristics of wood	**Clones**	**Spacing (m)**		
		3,0 x 3,0	**3,0 x 1,5**	**3,0 x 1,0**
Wood basic density (kg m^{-3})	C1	466,8 cA	473,2 cA	470,2 cA
	C2	445,1 cA	448,7 cA	452,8 cA
	C3	619,5 aA	599,8 aA	576,6 aB
	C4	519,9 bA	499,7 bA	500,5 bA
Wood Lignin (%)	C1	19,6 bAB	21,2 bA	19,3 bB
	C2	23,1 aA	23,1 aA	21,5 aB
	C3	17,7 cA	17,2 cA	17,3 cA
	C4	18,1 cA	17 cA	15,7 dB
Wood cellulose (%)	C1	39,5 aA	40,9 abA	41,3 abA
	C2	39,9 aB	41,3 aAB	42,2 aA
	C3	36,1 bB	38,8 bcA	39,4 bA
	C4	37,0 bA	37,9 cA	36,3 cA
Energy density (MJ m^{-3})	C1	8727,0 cA	8914,6 bcA	8886,6 bcA
	C2	8276,6 cA	8451,0 cA	8516,6 cA
	C3	11765,4 aA	11399,8 aA	10724,9 aB
	C4	9470,5 bA	9053,8 bA	9256,4 bA

Source: Authors (2021)

In where: Averages followed by the same lower case letter in the column and capital in the row do not differ by Tukey test at 5% significance level.

The basic wood density values of the *Eucalyptus* and *Corymbia* clones are consistent with those found in other studies at similar ages. Hsing, Paula e Paula (2016) obtained average values of basic wood density of 449 kg m^{-3} for five clones of the *E. grandis* x *E. urophylla* hybrid, at 27 months of age. Gouvêa, Trugilho, Gomide, Silva, Andrade e Alves (2011), studying six *E. grandis* x *E. urophylla* clones, at 36 months, observed mean values of basic wood density of 444 kg m^{-3}. Medeiros, Guimarães Junior, Ribeiro, Lisboa, Guimarães e Protásio (2016), studying the physical and chemical characteristics of *E. grandis* x *E. urophylla* and *C. citriodora* wood, at 48 months, observed a basic density of 460 kg m^{-3} and 570 kg m^{-3}, respectively. Loureiro, Vieira, Costa, Silva, Assis e Trugilho (2019), studying different genetic materials of crosses between *C. citriodora* and *C. torelliana*, at 45 months, found basic wood density values between 506 kg m^{-3} to 641 kg m^{-3}, corroborating the values found in this study, which ranged from 499 kg m^{-3} to 619 kg m^{-3}.

It was verified that the wood basic density values of the *Corymbia* clones (C3 and C4) were significantly higher than those of the *Eucalyptus* clones (C1 and C2). This fact can be explained by the fact that hybrid clones of *C. citriodora* and *C. torelliana* present longer fibers in the wood, smaller lumen width, greater wall thickness and greater wall fraction in relation to clones of *E. grandis* x *E. urophylla* (SEGURA; SILVA JÚNIOR, 2016), which directly influenced the higher wood density of *Corymbia* genetic materials. Medeiros, Guimarães Junior, Ribeiro, Lisboa, Guimarães e Protásio (2016) also found a higher basic wood density of *C. citriodora* (570 kg m^{-3}) compared to the hybrid *E. urophylla* x *E. grandis* (460 kg m^{-3}), at the age of 48 months. The basic density of trees is under strong genetic control, and this characteristic is much more influenced by genetic inheritance than by the environment (ELOY; CARON; SILVA; SCHMIDT; TREVISAN; BEHLING; ELLI, 2014).

A lower basic density of wood from clone C3 was observed in the 3,0 x 1,0 m planting spacing. Thus, as the tested plant materials have the same genotype and age, it can be inferred that the spacing factor influenced the variation of the basic density of the wood in clone C3. However, for other clones, this trend has not been registered. The results found in the literature are divergent in relation to the influence of planting spacing on the basic density of the wood. Sereghetti, Lanças, Sartori, Rezende e Soler (2015) did not find differences in the basic density of the wood in a hybrid *E. urophylla* x *E. grandis* in different spacing. Eloy, Caron, Silva, Schmidt, Trevisan, Behling e Elli (2014), studying the influence of planting spacing on the basic density of *E. grandis* wood, at 12 months, observed a higher basic density of wood in more open planting spacing.

According to Instituto de Pesquisas Tecnológicas do Estado de São Paulo (IPT) classification (IPT, 1985), wood can be classified into three classes: low basic density wood (less than or equal to 500 kg m^{-3}), medium density wood (500 kg m^{-3} to 720 kg m^{-3}) and dense woods (above 720 kg m^{-3}). Thus, it was observed that the *Corymbia* spp clones had medium density wood, while the *Eucalyptus* spp clones had low density.

For energy use it is desirable that the wood presents high values of basic density, as this characteristic is directly related to the production of energy, being one of the main criteria for the selection of genetic materials suitable for direct burning (CARNEIRO; CASTRO; CASTRO; SANTOS; FERREIRA; DAMÁSIO; VITAL, 2014).

A significant clone effect was observed within the spacings for the lignin content of the wood, with clone C2 presenting the highest average and clones C3 and C4 the lowest averages of this characteristic. Regarding the spacing effect, no significant effect was found for clone C3, and clones C1, C2 and C4 showed the lowest levels of lignin in the 3,0 x 1,0 m planting spacing.

The wood of clone C2 presented the highest levels of lignin obtained in the present study and the hybrids *C. torelliana* and *C. citriodora* (C3 and C4) presented the lowest levels of lignin in relation to the hybrid clones of *Eucalyptus*. This same trend was observed by Segura & Silva Júnior (2016), who found, at age seven years old, values of lignin content of *E. grandis* x *E. urophylla* (27,1%) higher than *C. citriodora* (22,3%).

The lignin content of clones C1 and C2 are in the same range as those observed in some studies with *Eucalyptus* spp hybrids at young ages. Hsing, Paula e Paula (2016) found insoluble lignin content between 20,41% to 22,93%, in five hybrid trees of *E. grandis* x *E. urophylla*, with 27 months. Garcia, Guerra, Eufrade Junior, Sansígolo, Lanças e Yamaji (2016), studying a hybrid clone of *E. urophylla* x *E. grandis* at different planting densities, at 24 months, found insoluble lignin content ranging from 21,16% to 23,64%. In contrast, the levels of lignin found by us are below those observed in other studies. Moulin, Arantes, Vidaurre, Paes e Carneiro (2015), evaluating two *E. grandis* x *E. urophylla* clones, at 12 months, found lignin levels between 28,99% to 32,28%, and Morais, Longue Júnior, Colodette, Morais e Jardim (2017) found lignin content in *E. grandis* x *E. urophylla* wood clones ranging from 30,70% to 31,63%, at 12 and 36 months, respectively. Medeiros, Guimarães Junior, Ribeiro, Lisboa, Guimarães e Protásio (2016) observed levels of lignin of *C. citriodora* of 27,36%, and Loureiro, Vieira, Costa, Silva, Assis e Trugilho (2019) observed levels between 25,71% to 27,31% in *Corymbia* hybrid clones, at 45 months.

It was observed that the lowest lignin content occurred in the densest spacing (3,0 x 1,0 m) for clones C1, C2 and C4. Presumably, in the more open spaces there is a greater growth of trees and a higher percentage of juvenile wood produced, thus influencing a greater production of lignin. Oliveira, Rocha, Pereira, Carneiro, Carvalho e Vital (2011), studying the effect of thinning on energy production and on the chemical characteristics of the wood of an *E. grandis* x *E. camaldulensis* clone, at 85 months of age, also observed that the lignin content was significantly lower in the treatment with greater number of plants per unit area. For clone C3, this same trend was not observed.

In this study, the hybrid clones of *Eucalyptus* stood out for presenting the highest values of wood lignin in relation to the hybrid *Corymbia* clones. However, the highest values of basic wood density were found in the hybrid clones of *Corymbia*. Thus, these results demonstrate the importance of considering several aspects of the quality of forest biomass for the selection of genetic materials most suitable for bioenergetic use. Aspects related to the clone's productivity should also be taken into account when assessing its energy potential. In addition, the low values found for wood lignin, indicates that none of the studied clones is still suitable for use in the production of biomass intended for energy use.

Clones C1 and C2 showed higher averages of cellulose content in wood compared to clones C3 and C4. When the spacing effect within each clone was considered, the lowest levels of wood cellulose were found in clones C2 and C3 at 3 x 3 m spacing, while no significant spacing effect was observed for clones C1 and C4.

The values of the cellulose content of the wood found in our study are similar to those obtained by Morais, Longue Júnior, Colodette, Morais e Jardim (2017), in two hybrid clones of *E. grandis* x *E. urophylla*, at 12 months (39,2%) and at 36 months (42,4%), and are slightly lower than those found by Hsing, Paula e Paula (2016), who observed in five *E. urophylla* x *E. grandis* clones, at 27 months, values between 46,04% to 50,12%. Zanuncio, Colodette, Gomes, Carneiro e Vital (2013), evaluating the chemical composition of wood in a hybrid clone of *E. grandis* x *E. urophylla*, found in treatments with greater spacing between plants, a reduction in the content of polysaccharides, mainly hemicelluloses and cellulose. This fact can be corroborated, in the present study, by the lower cellulose contents of clones C2 and C3, observed in the planting spacing of 3,0 x 3,0 m.

The participation of cellulose in mass and volume is very relevant for the generation of energy through direct burning. However, it must be taken into account that this constituent has a profile that is not very resistant to thermal degradation, which corroborates a low yield in the production of charcoal, and in addition, the burning of this component results in higher percentages of condensable and non-condensable, to the detriment of higher charcoal yields (SANTOS; CARNEIRO; CASTRO; CASTRO; BIANCHE; SOUZA; CARDOSO, 2011).

Clone C3 showed the best performance for wood energy density, with average values ranging between 10724,9 and 11765,4 MJ m^{-3}, with *Eucalyptus* clones (C1 and C2) having the lowest values for this variable. No significant differences were observed in wood energy density in the three planting spacings for clones C1, C2 and C4. However, for clone C3, a reduction of this variable was observed in the densest spacing (3,0 x 1,0m).

It was verified that the gross calorific value did not influence the estimation of the energy density of the Wood, since no significant differences were observed for this variable. Differences in wood energy density can be explained by the differences found in the basic wood densities of different clones. Thus, the two hybrid clones of *Corymbia* (C3 and C4) showed the highest average values of basic density and energy density of wood. It can be inferred that clones of *Corymbia* they tend to present better performance for the production of energy through direct combustion, as well as for the production of charcoal. However, aspects related to the productivity and forestry of these clones must be taken into account.This result highlights the importance of selection and evaluation of clones aimed at optimizing bioenergy production, since the higher the energy density, the greater the availability of energy per volume of wood (NEVES; PROTÁSIO; TRUGILHO; VALLE; SOUSA; VIEIRA, 2013).

Table 4 presents the effect of clone and spacing for hemicellulose, ash, carbon contents and for the gross calorific value of wood.

Table 4 – Effect of the clone and the planting spaces for some characteristics of the wood of *Corymbia* and *Eucalyptus* clones

Characteristics of wood	Clones			
	C1	C2	C3	C4
Whem (%)	27,09 b	27,38 b	30,25 a	30,27 a
WAsh (%)	0,23 a	0,25 a	0,17 b	0,18 b
WCarbon (%)	46,38	46,79	45,84	46,17
GCV (Kcal kg^{-1})	4493,0	4477,4	4506,1	4365,2
Characteristics of wood	**Planting spaces (m)**			
	3,0 x 3,0	**3,0 x 1,5**	**3,0 x 1,0**	
Whem (%)	28,27 b	28,77 ab	29,20 a	
WCarbon (%)	46,31	46,52	45,80	
GCV (Kcal kg^{-1})	4448,3	4466,2	4466,6	

Source: Authors (2021)

In where: WHem - wood hemicellulose; WAsh - wood ash; WCarbon - wood carbon. GCV - gross calorific value; Means followed by the same letter in the row do not differ by Tukey test at 5% significance.

It was observed that the hemicelluloses content of wood measured in clones C3 and C4 (*Corymbia* clones) showed higher values in relation to clones C1 and C2 (*Eucalyptus* clones). As for ash content, clones C1 and C2 showed significantly higher values than clones C3 and C4. Statistically, no significant differences were found for the carbon content and gross calorific value between the different clones. Considering the planting spacing as a variation factor, it was found that the hemicellulose content was lower in the 3,0 x 3,0 m spacing.

The hemicellulose values found in this study are close to those found by Raad, Pinheiro e Yoshida (2006), who also observed higher levels of hemicellulose in wood from *C. citriodora* (31,3%) compared to wood from *E. urophylla* (26,8%) and *E. grandis* (26,5%). Hemicelluloses together with cellulose are part of the holocellulose fraction present in wood (CARNEIRO; VITAL; FREDERICO; FIGUEIRÓ; FIALHO; SILVA, 2017).

Hemicelluloses are the main non-cellulosic polysaccharide and the analysis of its content in wood is essential in the energy evaluation of the different genetic materials, because the behavior in the face of thermal degradation presents an unstable and not very resistant profile, as it is a compound that has an amorphous nature and branched, thus contributing to a lower energy efficiency (NEVES; PROTÁSIO; COUTO; TRUGILHO; SILVA; VIEIRA, 2011). Despite the fact that hemicelluloses participate from 20% to 30% in the constitution of wood, this components contribute only about 10% to the energy efficiency due to its thermal instability (PROTÁSIO; NEVES; REIS; TRUGILHO, 2014). Thus, when energy production is aimed at, low hemicelluloses genetic materials are desirable, as this compound contributes little to the gravimetric and energetic yield of wood.

The values of wood ash content are significantly higher in clones C1 and C2 than in clones C3 and C4. However, none of the studied clones showed high ash production, this variable being within the range observed in other studies for commercial clones indicated for bioenergetic use (MOULIN; ARANTES; VIDAURRE; PAES; CARNEIRO, 2015; NEVES; PROTÁSIO; TRUGILHO; VALLE; SOUSA; VIEIRA, 2013). These results are positive, since the minerals present in the ashes are undesirable in the generation of direct energy, since they do not participate in the biomass burning process (REIS; PROTÁSIO; MELO; TRUGILHO; CARNEIRO, 2012), with high percentages of this constituent in the genetic materials destined for the energy production, use is undesirable. In addition, ashes can form incrustations and corrosion in pipes and equipment used in the production of bioenergy (PROTÁSIO; NEVES; REIS; TRUGILHO, 2014).

There was no significant effect on the carbon content of the wood due to the effect of clones, spacing and the interaction between clones and spacing. The carbon content values in this work are close to those found in several other studies on the elementary composition of wood in different forest species (DALLAGNOL; MOGNON; SANQUETTA; CORTE, 2011; SANTOS; CARNEIRO; CASTRO; CASTRO; BIANCHE; SOUZA; CARDOSO, 2011; SANTOS; CARVALHO; PEREIRA; OLIVEIRA; CARNEIRO; TRUGILHO, 2012; CARNEIRO; CASTRO; CASTRO; SANTOS; FERREIRA; DAMÁSIO; VITAL, 2014), ranging from 45,9% to 46,3%.

According to Santos, Carneiro, Castro, Castro, Bianche, Souza e Cardoso (2011), there are no major differences in relation to the carbon content in the wood of different species of the genus *Eucalyptus*, ranging from 45% to 50%. When the objective is charcoal or wood direct burning production, carbon higher levels are desirable (SANTOS; CARVALHO; PEREIRA; OLIVEIRA; CARNEIRO; TRUGILHO, 2012). According to Carneiro, Castro, Castro, Santos, Ferreira, Damásio e Vital (2014), in forest biomass direct burning, carbon is fully consumed, while for charcoal production carbon is converted into fixed carbon, which is the main responsible for energy stored. Carbon content quantification is great importance in forest energetic biomass evaluation, since it is positively correlated to fuel caloric power and fuel energetic performance (PROTÁSIO; SANTANA; GUIMARÃES NETO; GUIMARÃES JÚNIOR; TRUGILHO; RIBEIRO, 2011). Thus, forest species with highest carbon content also have a higher thermal capacity due to the greater energy released (SANTOS; CARNEIRO; CASTRO; CASTRO; BIANCHE; SOUZA; CARDOSO, 2011).

No significant differences were observed for the gross calorific value (GCV) among the clones, the average value found being 4460,25 kcal kg^{-1}. GCV is one of the main characteristics for the selection of the best genetic materials for bioenergy, because it is related to the amount of energy released by the wood during its burning (CARNEIRO; CASTRO; CASTRO; SANTOS; FERREIRA; DAMÁSIO; VITAL, 2014). The GCV values found are consistent with that reported in several studies that evaluated this characteristic in different species and clones of the *Eucalyptus* and *Corymbia* genera (LOUREIRO; VIEIRA; COSTA; SILVA; ASSIS; TRUGILHO, 2019; PROTÁSIO; NEVES; REIS; TRUGILHO, 2014; SANTOS; CARVALHO; PEREIRA; OLIVEIRA; CARNEIRO; TRUGILHO, 2012). It was found that planting spacing had no influence on the GCV of the wood for the evaluated clones. One hypothesis to explain these non-discrepant values is that the GCV is a characteristic closely related to the elemental chemical composition, especially regarding carbon contents, which did not show significant differences among the clones in the present study. Eloy, Caron, Silva, Schmidt, Trevisan, Behling e Elli (2014), studying the influence on energy characteristics of four forest species as a function of different spacings in short rotation plantings, also found no variation in GCV in relation to the evaluated living spaces.

4 CONCLUSIONS

There is a significant effect of the interaction of clones x planting spacing for density for some technological characteristics such as wood, demonstrating its influence on the quality of forest biomass.

The *Eucalyptus* clones show the highest levels of lignin and cellulose, but not the highest values of basic density of the study wood. Thus, the *Corymbia* hybrid clones have the highest wood density values, with emphasis on the C3 clone, which have the highest average of the study. For this clone, there is a significant effect of the spacing on the basic density of the wood, with the most densely spaced (3,0 x 1,0 m) responsible for the reduction of this variable, being an important indication that this spacing is not suitable for this specific genetic material.

There are a clone and spacing effect for hemicellulose levels. The *Corymbia* clones show higher hemicellulose contents in relation to the hybrid clones of *Eucalyptus*, and a denser spacing (3,0 x 1,0 m) provide the highest values of this characteristic.

Results show that there is wood variability between genetic materials evaluated and in relation to tested planting spacing. Thus, one property should not be used to classify wood because several factors affect the forest biomass energy performance. It should be noted that when choosing the best genetic material, you should also take into account aspects related to mass productivity.

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