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GROUPING OF CLONES OF 4-YEAR-OLD *Eucalyptus* spp. FOR PULP AND PAPER[1]

AGRUPAMENTO DE CLONES DE *Eucalyptus* spp. AOS 4 ANOS PARA PAPEL E CELULOSE[1]

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ABSTRACT - As in other countries, In Brazil, new genetic materials of *Eucalyptus* spp. and their hybrids are multiplied through cloning. These materials, currently in experimental trials, must undergo several stages to select the best ones for pulp and paper production. Therefore, new studies on wood quality are essential. Therefore, this study aimed to group 11 clones of *Eucalyptus* spp. wood, from a clonal plantation in the municipality of Palmital, São Paulo State, for the production of paper and cellulose. For this purpose, four trees of each clone of 4-year-old *Eucalyptus* spp. were collected. From each tree, a log of 1 m in length was taken from the base of the tree, for the study of the characterization of the basic density and cellular dimensions of the wood. The results showed that there were significant differences between clones for basic density, fiber length, vessel element length and fiber wall thickness. The Runkel ratio, wall fraction and stiffness coefficient did not show significant differences between the different genotypes. From the results obtained, we can conclude that clones can be differentiated only by basic density, fiber length, vessel element length and fiber wall thickness. The Runkel index, flexibility coefficient and wall fraction of *Eucalyptus* spp. were more efficient to group the clones into two groups.

Keywords: Genetic improvement; Density; Wood anatomy; Wood quality.

RESUMO - A exemplo de outros países, no Brasil os novos materiais genéticos de espécies do gênero Eucalyptus e seus híbridos multiplicados pelo processo de clonagem, existentes em ensaios experimentais, ainda necessitam passar por várias etapas para a seleção dos melhores materiais para a produção de papel e celulose. Com isso, novos estudos sobre a qualidade da madeira são indispensáveis. Sendo assim, este estudo teve como objetivo agrupar clones de *Eucalyptus* spp., provenientes de um plantio clonal da região de Palmital, estado de São Paulo, para a produção de papel e celulose. Para tanto, quatro árvores de cada clone de *Eucalyptus* spp., com quatro anos de idade, foram coletadas. De cada arvore foram retiradas uma tora de 1 m de comprimento da base da árvore, para o estudo da caracterização densidade básica e dimensões celulares da madeira. Os resultados mostraram que ocorreram diferenças significativas entre os clones, para a densidade básica, comprimento de fibras, comprimento de elemento de vaso e a espessura da parede da fibra. O fator de Runkel, fração parede e o coeficiente de rigidez não apresentaram diferenças significativas entre os diferentes genótipos. De acordo com os resultados obtidos até a idade de 4 anos, podemos concluir que os clones podem ser diferenciados apenas pela densidade básica, comprimento de fibra, comprimento de elemento de vaso e a espessura da parede da fibra. O índice de Runkel, coeficiente de flexibilidade e fração parede de *Eucalyptus* spp. foram mais eficientes para agrupar os clones em dois grupos.

Palavras-chave: Melhoramento genético; Densidade; Anatomia da madeira; Qualidade da madeira.

1 INTRODUCTION

Brazil continues to be a world reference when it comes to productivity of forest plantations, with a high volume of annual wood production per area and a short cycle. In addition to climate and soil conditions, the sector invests years in research and development of the best forest management techniques, combined with genetic improvement and sustainable practices (Indústria Brasileira de Árvores - IBÁ, 2023).

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The use of cloning of *Eucalyptus* spp. is a technology widely used by large companies in the Forest Sector, today this technology can also be used by rural producers interested in diversifying their activities, as in other countries. *Eucalyptus* plantations in 2022 occupied 7.58 million hectares, representing 76% of the total planted area in Brazil, concentrated mainly in the states of Minas Gerais, São Paulo and Mato Grosso do Sul (IBÁ, 2023).

In Brazil, the new genetic materials of *Eucalyptus* species and hybrids (clones or seeds) existing in experimental trials, or in commercial plantations, need to be tested for aptitudes for various uses of wood (Lima and Stape, 2017).

Some of these species have adapted well to the climate and different types of soil in Brazil, being versatile and widely used in the industrial sector. Initially, genetic improvement was linked to companies in the pulp, paper, sheet metal and steel industry and, later, it began to be used in the field of poles and wood for structures in civil construction (Lima et al., 2006).

The productivity of forest plantations of *Eucalyptus* clones must be incorporated into wood quality studies, to improve the understanding of the composition and organization of the cell types that make up the wood, as this can be a decisive factor for these new genetic materials to be processed and used in a rationally sustainable way (Protásio et al., 2014).

New studies on wood quality must consider different genetic materials, growing environments, planting spacing, treatments and cutting ages, to allow greater knowledge about growth and factors that can influence the quality of wood produced and the adjustments that can help with forest management, processing and the most appropriate use of wood, in order to consider the best cost-benefit ratio (Lima et. al. 2021). Knowledge about the behavior of clones is restricted to the bioclimatic region for which they were developed. Consequently, testing these materials in small experimental plots in the municipality of Palmital, São Paulo State has great importance to generate the necessary knowledge for the successful implantation of future forests using this technology.

Therefore, this study aimed to group 11 clones of *Eucalyptus* spp. wood, from a clonal plantation in the municipality of Palmital, São Paulo State, for the production of paper and cellulose.

2 MATERIAL AND METHODS

2.1 Planting area and sampling

The material used in this research was obtained from experimental populations of Eucalyptus clones planted in Horto Florestal de Palmital, municipality of Palmital, São Paulo State, coordinates 22°48′S and 50°16′W, in elevation 400m (Figure 1 and Table 1). The local soil is classified as LVdf, precipitation of 1,377 mm, average temperature of 21.2°C and the climate according to Köppen is Cfa (Alvares et al., 2013). To test wood properties, samples from 11 clones of 4-year-old Eucalyptus spp., four trees of each clone were collected.

Figure 1. Overview of experimental populations of *Eucalyptus* clones planted in the municipality of Palmital, São Paulo State.

Figura 1. Visão geral das populações experimentais de clones de *Eucalyptus* plantados no município de Palmital, estado de São Paulo.

Table 1. Dendrometric survey of the experimental plot.

Tabela 1. Levantamento dendrométrico da parcela experimental.

Treatment	Clone	Age (years)	DBH (cm)	HT (m)
CP01	C 219 H	4	14.0	20.95
CP02	433 – *E. plathyphylla* (var *E. urophylla*)	4	15.6	21.10
CP03	162 – (*E. grandis* 0316201)	4	14.7	20.63
CP04	154	4	14.6	20.46
CP05	CLONE 105	4	14.2	21.00
CP06	CLONE H 15	4	15.9	20.13
CP07	H 77	4	14.8	19.58
CP08	UROCAM	4	15.5	19.46
CP09	608 – *E. grandis* x *E. resinifera*	4	13.3	18.13
CP10	TC50	4	14.7	20.58
CP11	GG100	4	16.1	21.70

Before felling the trees, the north direction was marked on each one of them. Afterwards, the first log of 1 m in length was taken, being properly identified and marked. Subsequently, they were unfolded and a central plank 7 cm thick was taken from each of the logs. From the planks, a 4 cm x 4 cm x 1 m batten was removed from the region close to the bark from the north direction and then samples were taken to study the wood properties.

2.2 Wood properties

The samples obtained were transformed into specimens for the study of basic density (BD), vessel element length (VEL), fiber length (FL), fiber diameter (FD), fiber lumen (FL), fiber wall thickness (FWT), Runkel ratio (RR), wall fraction (WF) and flexibility coefficient (FC).

To obtain the basic density (BD), the hydrostatic balance method was used according to NBR 11941 (ABNT, 2003). The 2 x 2 x 3 cm specimens obtained were saturated in water for a period of approximately one month, which made it possible to obtain the saturated and immersed mass of each sample. Subsequently, these specimens were dried in an oven until reaching constant dry mass at 105 ± 3ºC.

To determine the anatomical dimensions, other specimens measuring 2 x 2 x 3 cm were made, from which small fragments were removed to be macerated according to the modified Franklin method (Berlyn and Miksche, 1976). Measurements were performed using a microscope equipped with a digital camera and a computer with image analysis software. Photographs were taken of 25 different vessels and fibers, using the Image-Pro Plus 6.0 program to measure vessel length, fiber length, diameter and fiber lumen, using the methodology recommended by the IAWA (1989).

2.3 Anatomical ratios for pulp and paper

The samples obtained were transformed into specimens for the study of basic density (BD), vessel element length (VEL), fiber length (FL), fiber diameter (FD), fiber lumen (FL), fiber wall thickness (FWT), Runkel ratio (RR), wall fraction (WF) and flexibility coefficient (FC).

After obtaining the fiber dimension values, the fiber wall thickness (FWT), Runkel ratio (RR), wall fraction (WF) and flexibility coefficient (FC) were also calculated. We used equations (1-4) according to Paula and Alves (2007):

To calculate the wall thickness of the fibers, equation (1) was used:

$$\text{FWT} = \left(\frac{\text{FD}-\text{FLD}}{2}\right) \qquad \text{Eq. 1}$$

Where: FWT: fiber wall thickness (µm); FD: fiber diameter (µm), and FLD: fiber lumen diameter (µm).

To calculate the Runkel ratio, equation (2) was used:

$$\text{RR} = \left(\frac{2\text{FWT}}{\text{FLD}}\right) \qquad \text{Eq. 2}$$

Where: RR= Runkel ratio, FWT = fiber wall thickness (µm), and FLD= fiber lumen diameter (µm).

To calculate the wall fraction, equation (3) was used:

$$WF = \left(\frac{2FWT}{FD}\right)100 \qquad \text{Eq. 3}$$

Where: WF = wall fraction (%), FWT = fiber wall thickness (µm), and FD= fiber diameter (µm).

To calculate the flexibility coefficient, equation (4) was used:

$$FC = \left(\frac{FLD}{FD}\right)100 \qquad \text{Eq. 4}$$

Where: FC = flexibility coefficient (%); FLD = fiber lumen diameter (µm), and FD= fiber diameter (µm).

The results were assessed through analysis of variance (ANOVA) and the Duncan test at a 5% significance level to identify variations among genotypes. Additionally, a clustering analysis of the clones was conducted, employing a cluster dendrogram. To ascertain the properties exerting the greatest influence on clone grouping, a principal component analysis (PCA) was performed. All statistical analyses were executed using the R software (R Core Team, 2019).

3 RESULTS AND DISCUSSION

The mean and standard deviation of the wood properties evaluated are in Table 2. Table 3 serves as a literature reference for comparing the results of each variable in our study with those of other studies in different species of *Eucalyptus*. Table 2 has all values for 4-year-old Eucalyptus clones (Table 3), however, has values for different *Eucalyptus* species at older ages, between 6 to 11 years old.

According to the mean values and standard deviations of each variable according to each genotype the wood basic density values presented, they can be classified as being from low to medium density (Foelkel, 2009). Clone CP01 had the highest value, while clone CP03 had the lowest, which significantly differentiated these two genotypes (Table 2 and Figure 2A).

The values for wood basic density were observed by several authors in general (Table 3), we found that the average values (0.47 g cm^{-3}) observed for the basic density of the clones (4-years-old) are similar to those in the literature, however these ones were analyzed at older ages (6 to 11 years old) (Table 2, Table 3 and Figure 2A).

Fiber length showed a significant difference between clones, Clones CP04 and CP06 showed the highest values and clones CP07 and CP10 the lowest fiber length values. In general, we found that the mean values (928 µm) observed for the fiber length of the clones (4-year-old) are lower than those in the literature (Table 2, Table 3 and Figure 2B).

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Table 2. Mean and standard deviation for basic density (BD), fiber length (FL), vessel element length (VEL), fiber wall thickness (FWT), Runkel ratio (RR), flexibility coefficient (FC) and wall fraction (WF) of 4-year-old *Eucalyptus* spp. (11 clones).

Tabela 2. Média e desvio padrão para densidade básica (BD), comprimento da fibra (FL), comprimento do elemento de vaso (VEL), espessura da parede da fibra (FWT), índice de Runkel (RR), coeficiente de flexibilidade (FC) e fração parede (WF) de *Eucalyptus* spp. (11 clones) aos quatro anos de idade.

Treatment	**BD (g cm^{-3})**	**FL (μm)**	**VEL (μm)**	**FWT (μm)**	**RR**	**FC (%)**	**WF (%)**
CP01	0.54 (0.04)	951 (95.47)	562.41 (29.55)	3.76 (0.20)	0.99 (0.17)	52.15 (4.90)	47.85 (4.90)
CP02	0.44 (0.06)	975 (81.11)	602.34 (85.42)	3.81 (0.18)	0.91 (0.23)	53.85 (6.20)	46.15 (6.20)
CP03	0.42 (0.02)	969 (47.17)	546.11 (28.94)	3.75 (0.63)	0.80 (0.15)	57.14 (4.52)	42.86 (4.52)
CP04	0.43 (0.03)	1017 (126.59)	554.99 (23.03)	4.09 (0.48)	1.04 (0.33)	51.20 (7.01)	48.80 (7.01)
CP05	0.48 (0.02)	928 (76.82)	558.28 (89.27)	3.60 (0.20)	1.09 (0.20)	50.10 (4.81)	49.90 (4.81)
CP06	0.48 (0.01)	1031 (25.07)	567.98 (30.54)	3.39 (0.39)	0.93 (0.34)	54.68 (8.99)	45.32 (8.99)
CP07	0.51 (0.04)	816 (111.31)	459.23 (110.90)	4.12 (0.54)	1.19 (0.36)	49.05 (7.63)	50.95 (7.63)
CP08	0.47 (0.02)	872 (81.69)	478.55 (29.77)	3.84 (0.35)	1.15 (0.47)	50.52 (9.84)	49.48 (9.84)
CP09	0.49 (0.04)	851 (13.29)	481.62 (69.67)	3.63 (0.31)	0.86 (0.36)	56.56 (8.61)	43.44 (8.61)
CP10	0.47 (0.04)	819 (123.07)	502.60 (53.19)	3.47 (0.45)	0.83 (0.28)	57.96 (7.77)	42.04 (7.77)
CP11	0.47 (0.04)	974 (56.51)	598.89 (32.48)	3.81 (0.26)	0.77 (0.20)	59.20 (5.83)	40.80 (5.83)
Mean	0.47 (0.04)	928 (76.76)	537.55 (49.27)	3.75 (0.23)	0.96 0.14)	53.86 (3.50)	46.14 (3.50)

Values in parentheses represent the SD = standard deviation.

Os valores entre parênteses representam o DP = desvio padrão.

Table 3. Basic density (BD), fiber length (FL), vessel element length (VEL) in *Eucalyptus* spp. as a function of age, data obtained according to the reference.

Tabela 3. Densidade básica (BD), comprimento de fibra (FL), comprimento de elemento de vaso (VEL) em *Eucalyptus* spp. em função da idade, dados obtidos na literatura.

Species	**Age (years)**	**BD (g cm^{-3})**	**FL (µm)**	**VEL (µm)**	**Reference**
Eucalyptus grandis x Eucalyptus urophylla	2	0.40	878	-	Zanuncio et al. (2018)
Eucalyptus benthamii	5	-	903	374	Baldin et al. (2017)
Eucalyptus dunnii	5	-	982	412	Baldin et al. (2017)
Eucalyptus grandis	5	-	1036	530	Baldin et al. (2017)
Eucalyptus saligna	5	-	1078	503	Baldin et al. (2017)
Eucalyptus grandis x Eucalyptus urophylla	6	0.46	-	-	Talgatti et al. (2018)
Eucalytus benthamii	6	0.48	937	-	Bonfatti Júnior et al. (2023)
Eucalytus dunnii	6	0.49	960	-	Bonfatti Júnior et al. (2023)
Eucalytus saligna	6	0.46	937	-	Bonfatti Júnior et al. (2023)
Eucalytus cloeziana	6	0.49	1030	-	Bonfatti Júnior et al. (2023)
Eucalyptus grandis x Eucalyptus urophylla	7	0.51	-	-	Talgatti et al. (2018)
Eucalyptus dunnii	7	-	970	-	Sbardella et al. (2021)
Eucalyptus urophylla	7	-	-	313	Monteiro, et al. (2017)
Eucalyptus urophylla	8	0.49	1059	618	Paulino and Lima (2018)
Eucalyptus grandis x Eucalyptus camaldulensis	8	0.47	-	-	Talgatti et al. (2018)
Eucalyptus grandis x Eucalyptus urophylla	8	0.46	-	-	Talgatti et al. (2018)
Eucalyptus grandis	11	0.40	-	-	Talgatti et al. (2018)

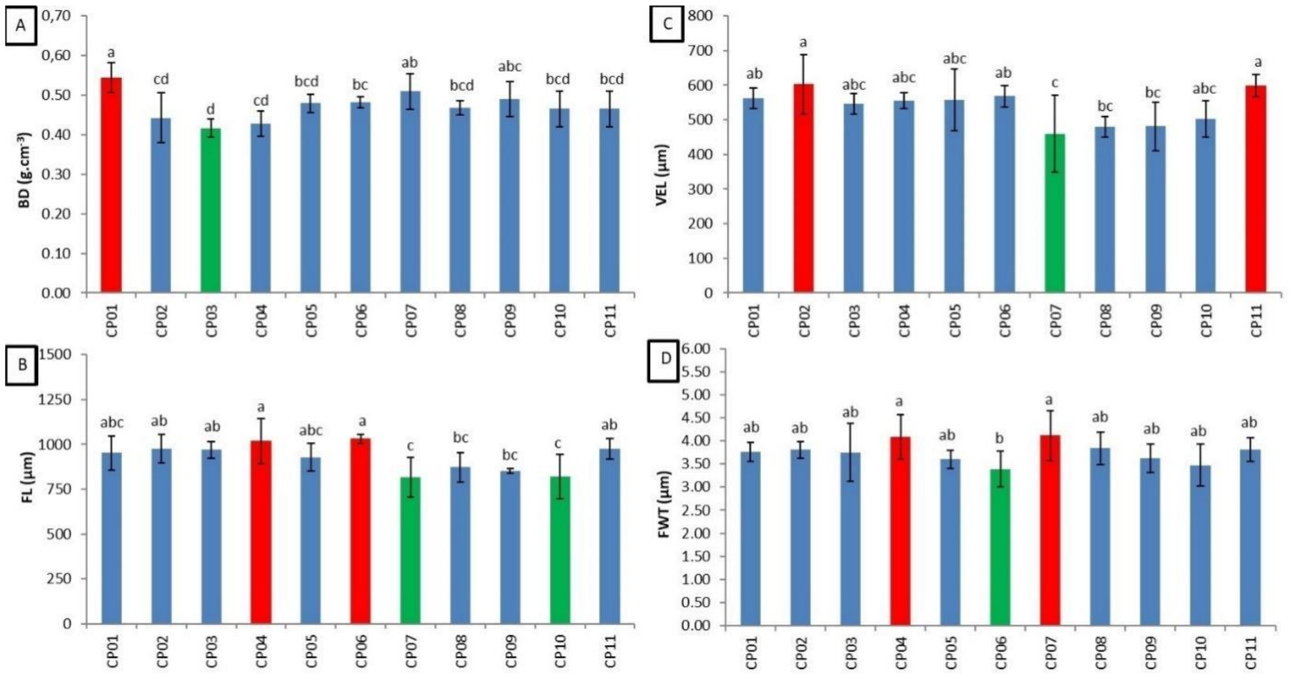

Figure 2. Basic density (A), fiber length (B), vessel element length (C) and Fiber wall thickness (D) of 4-year-old *Eucalyptus* (11 clones). Distinct letters differ in p>0.05 by Duncan's test. The red color represents the highest value and green the lowest.

Figura 2. Densidade básica (A), comprimento de fibra (B), comprimento de vaso (C) e espessura da parede da fibra (D) de Eucalyptus (11 clones) aos quatro anos de idade. Letras distintas diferem em p>0,05 pelo teste de Duncan.

Clones CP02 and CP11 had the highest vessel element length values and clone COP05 had the lowest value. The values for vessel element length observed by several authors. In general, we verified that the average values (537.55 µm) observed for the vessel element length of the clones (4-year-old) are higher than those in the literature, but those at a higher age (5 to 8 years old) (Table 2, Table 3 and Figure 2C).

The basic density and the length of the fibers showed little variability from an industrial point of view, which is interesting because the material has good homogeneity in these characteristics, which favors the impregnation and removal of lignin from the chips in the cooking processes and, consequently, in the paper formation there will be a better connection between fibers, thus improving the paper in quality (Gonçalez et al., 2014). The vessel element length observed in these woods from these clones are somehow considered to be large, which may favor some characteristics of these *Eucalyptus* and disfavor others, in the processes of conversion to cellulose, they are excellent examples to improve the impregnation of the chips (Paulino and Lima, 2018).

Among all the properties of wood, basic density is the one most influenced by genetic material. Other authors corroborate this pattern, as demonstrated by Freitas et al. (2019) in their study on the impact of site conditions on the growth and wood quality of clonal populations of Eucalyptus. They reported that genetic material exhibited greater variation in growth and basic wood density compared to environmental factors. Based on the Diameter at Breast Height (DBH) and height data from the sampled trees, it seems that there is minimal variation between the clones (Table 1). This is a factor that could potentially influence the results of the evaluated wood characteristics.

Table 4 serve as a reference in the literature for compare the variables fiber wall thickness, Runkel ratio, flexibility coefficient, and wall fraction of different species of *Eucalyptus* with our study.

Table 4. Fiber wall thickness (FWT), Runkel ratio (RR), flexibility coefficient (FC) and wall fraction (WF) in *Eucalyptus* spp. as a function of age. Data obtained according to the reference.

Tabela 4. Espessura da parede da fibra (FWT), índice de Runkel (RR), Fração parede (WF) e Coeficiente de rigidez (FC) em *Eucalyptus* spp. em função da idade. Dados obtidos na literatura.

Species	**Age (years)**	**FWT (μm)**	**RR**	**FC (%)**	**WF (%)**	**Reference**
Eucalyptus grandis x Eucalyptus urophylla	2	3.84	-	-	42.88%	Zanuncio et al. (2018)
Eucalyptus urophylla x *Eucalyptus grandis*	4	-	1.44	42.20%	57.80%	Benites et al. (2018)
Eucalyptus grandis x *Eucalyptus camaldulensis*	4	-	1.36	43.99%	56.01%	Benites et al. (2018)
Eucalyptus benthamii	5	3.4	0.77	57.39%	42.61%	Baldin et al. (2017)
Eucalyptus dunnii	5	4.3	1.07	58.96%	51.53%	Baldin et al. (2017)
Eucalyptus grandis	5	3.8	0.76	58.00%	41.99%	Baldin et al. (2017)
Eucalyptus saligna	5	3.2	0.72	68.96%	41.11%	Baldin et al. (2017)
Eucalytus benthamii	6	-	-	-	41.12%	Bonfatti Júnior et al. (2023)
Eucalytus dunnii	6	-	-	-	62.07%	Bonfatti Júnior et al. (2023)
Eucalytus saligna	6	-	-	-	56.74%	Bonfatti Júnior et al. (2023)
Eucalytus cloeziana	6	-	-	-	50.03%	Bonfatti Júnior et al. (2023)
Eucalyptus dunnii	7	3.5	0.79	58.18%	41.81%	Sbardella et al. (2021)
Eucalyptus urophylla	7	3.5	-	-	42,50%	Monteiro et al. (2017)
Eucalyptus urophylla	8	5.34	1.01	50.83%	-	Paulino and Lima (2018)
Eucalyptus grandis x Eucalyptus urophylla	8	5.61	2.05	33.15%	66.70%	Gonçalez et al. (2014)

Fiber wall thickness showed a significant difference between clones. Clones CP04 and CP07 had the highest fiber wall thickness and clone CP06 the lowest, the values for fiber wall thickness observed by several authors. In general, we found that the mean values of the fiber wall thickness of the clones (4-years-old) are in accordance with the literature, considering the range of ages sampled (2 to 8 years old) (Table 2, Table 4 and Figure 2D). Trees with a thicker fiber wall have a higher relative cellulose content than thinner-walled fibers, with a positive correlation between wall thickness and yield in cellulose pulp production (Paula and Alves, 2007).

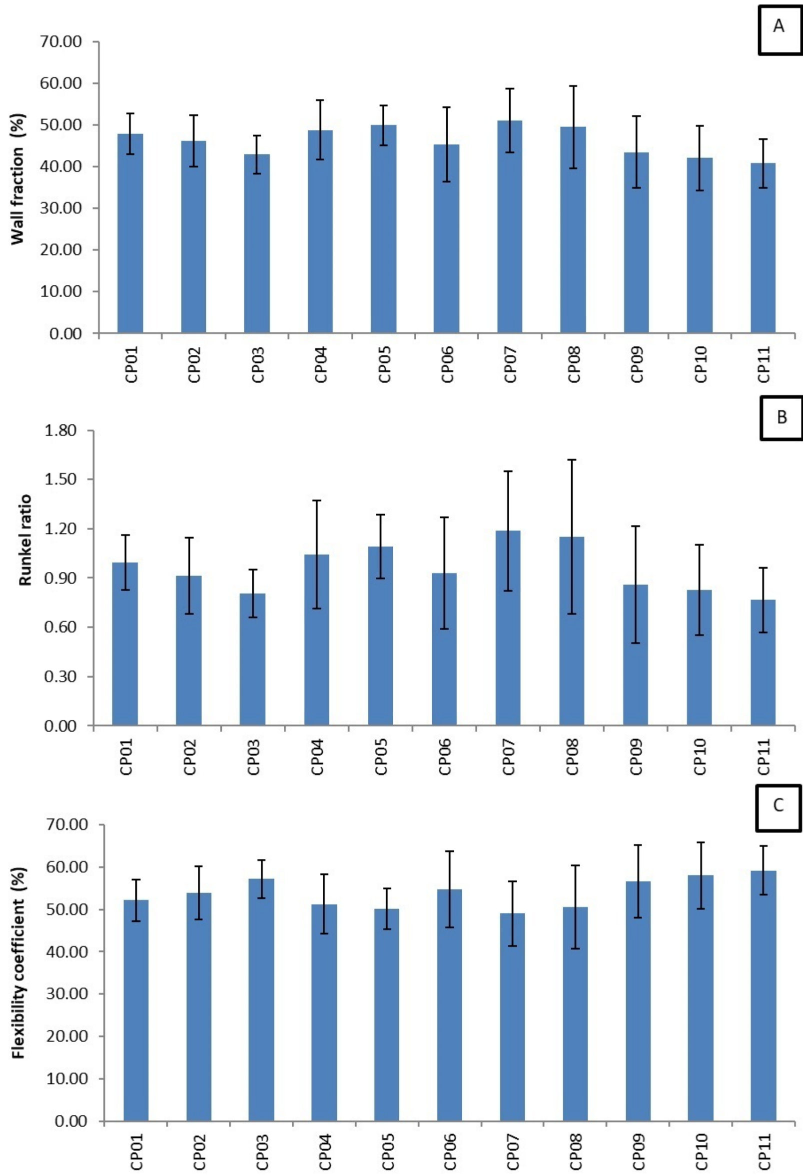

Figure 3. Wall fraction (A) Runkel ratio (B) and flexibility coefficient (C) of 4-year-old *Eucalyptus* clones.

Figura 3. Fator de Runkel (A), fração parede (B) e coeficiente de rigidez (C) de *Eucalyptus* (11 clones) aos 4 anos de idade.

The wall fraction, Runkel ratio and flexibility coefficient did not show significant differences between the different genotypes (clones) and the mean value observed for the Runkel ratio was 0.96 (Table 2 and Figures 3A-C).

The higher the Runkel ratio value is, the less suitable the wood is for papermaking, and the ideal values would be less than 1, wood with higher values should not be used for papermaking, in view of the low degree of collapse (Burger and Richter, 1991; Baldin et al., 2017). We can see that most clones had a factor less than 1, except for clones CP06 and CP07, where the factors were greater than 1 (Table 2).

The average value presented for the wall fraction was 46.14% (Table 2). Woods with fibers with a higher wall fraction index result in greater dimensional instability, however, this high index provides greater mechanical resistance of the wood (Zanuncio et al., 2018). Fibers with a high wall fraction are indicated for the manufacture of tissue paper, as they absorb more liquids (Bonfatti Júnior et al., 2023).

For the flexibility coefficient, the mean value presented was 53.86% (Table 2). The higher the flexibility coefficient, the greater the flattening and better the cell shaping, and a high value also means the existence of thinner walled cells (Burger and Richter, 1991).

With the aim of classifying the clones into groups according to their characteristic similarities, considering all variables under study, a Cluster analysis and principal component analysis (PCA) were carried out (Figures 4 and 5).

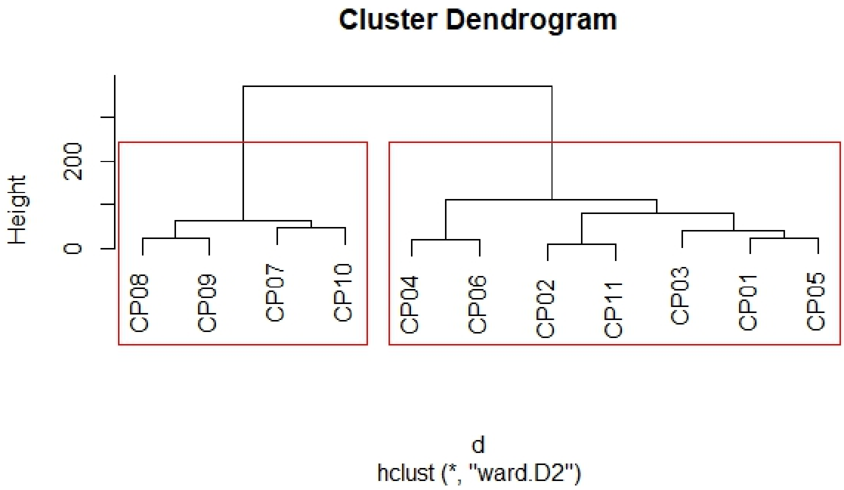

Figure 4. Cluster analysis of *Eucalyptus* clones dendrogram.

Figura 4. Dendrograma de cluster dos clones de *Eucalyptus*.

In the cluster analysis, it was possible to group the clones based on similarity where, according to the analyzed properties, the clones were divided into two clusters, the first cluster with four clones and the second with six clones (Figure 4). According to the dendrogram, we can separate the clones in group 1: clones 7, 8, 9 and 10 and group 2: clones 1, 2, 3, 4, 5, 6 and 11. The properties Runkel Index (RR), Wall Fraction (WF) and Stiffness Coefficient (FC) had a greater influence on the grouping of clones and wall thickness and basic density had a lesser influence (Figures 4 and 5).

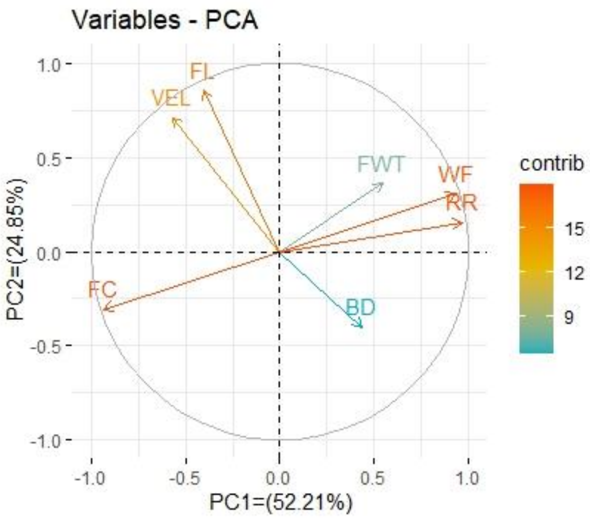

Figure 5. Principal Components Analysis (PCA) of the properties of wood of *Eucalyptus* clones. The greater the intensity of the red color, the more the property contributes to the grouping. The magnitude is represented by color intensity. Additionally, the smaller the angle between the vectors, the stronger the relationship between the variables. The longer the vector and closer to the outer circle, the greater the significance of the variable represented by the vector.

Figura 5. Análise dos componentes principal (PCA) das propriedades da madeira de clones *Eucalyptus*. Quanto maior a intensidade da cor vermelha, mais a propriedade contribui para o agrupamento. A magnitude é representada pela intensidade da cor. Adicionalmente, quanto menor o ângulo entre os vetores maior é a relação entre as variáveis. Quanto mais longo o vetor e próximo do círculo externo, maior e a significância da variável representada pelo vetor.

Therefore, the reference to the suitability of wood for pulp and paper manufacturing in terms of coefficients and factors were more efficient to group *Eucalyptus* clones. This was also addressed by Baldin et al. (2017). This result demonstrates that clones can be separated by cluster through cluster analysis considering the wood properties analyzed.

We can highlight the importance of new comprehensive studies of each clone, to define the best use of its wood in terms of the productivity of forest plantations and the quality of the wood for the region of Palmital, SP. These studies will support the implantation of future forests by rural producers interested in diversifying their activities.

Figure 5 depicts the correlations among the variables that demonstrated significance in the first and second ordination axes, accounting for 77.06% of the explained variance in PCA. Axis 1 contributed 52.21% to the overall variability, while axis 2 contributed 24.85% to the variability.

The PCA analyses indicate that the vector representing fiber wall thickness is correlated with the vectors representing basic density, suggesting that these characteristics influence wood density. This relationship is widely recognized in the literature, as fibers with thicker walls contribute positively to higher wood density (Hoadley, 2000; Wiedenhoeft and Eberhardt, 2021). The vector representing the flexibility coefficient is inversely correlated with the vectors representing Runkel ratio and wall fraction. These results, in accordance with the values presented by Trianoski (2012), allow us to infer that in materials with a high flexibility coefficient value, e.g., >75%, indicating good collapse between the cells, a substantial contact surface, and effective union between the elements of cell walls, a lower Runkel ratio will be found. This makes the material more flexible, with excellent accommodation capacity and in excellent condition for paper production. Additionally, a lower wall fraction makes the cell walls less rigid and more flexible, but with lower interconnection capacity, resulting in greater tensile and bursting resistance and lower tearing resistance.

4 CONCLUSIONS

According to the results presented, we can conclude that:

-at 4 years of age there were significant differences for: basic density, fiber length, vessel element length and fiber wall thickness of the different clones;

-the Runkel ratio, flexibility coefficient and wall fraction did not show significant differences in the wood between the different clones;

-through of analysis to the dendrogram of Cluster one can separate the clones in two groups;

-Runkel Index, Wall Fraction and Stiffness Coefficient had a greater influence on the grouping of clones;

-basic density and fiber wall thickness had little influence in the grouping of clones.

We can highlight the importance of new comprehensive studies of each clone, to define the best use of its wood according to age.

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