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FIBER QUALITY INDICES OF *Corymbia* spp. AND *Eucalyptus* spp. WOOD FOR THE SELECTION OF GENETIC MATERIALS FOR PULP PRODUCTION

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ABSTRACT

The selection of genetic materials for obtaining cellulosic pulp and paper production necessitates evidence of efficiency in terms of silvicultural performance and industrial processing. In this context, this study aimed to select genetic materials from *Eucalyptus* spp. and *Corymbia* spp. for pulp production. The selection was achieved through cluster analysis, based on the morphological traits of the main anatomical elements of the wood, the screened brown pulp yield, and fiber quality indices (Runkel ratio, slenderness ratio, Mulsteph coefficient, and flexibility coefficient). Sixteen genetic materials were evaluated, each represented by three trees of average diameter, collected at 81 months of age with a planting spacing of 6x1.5 m, from plantations located in the municipality of Itamarandiba - MG, Brazil. Axiovision 4.8 software was used to measure the dimensions of fibers and vessels under an optical microscope. Information regarding the screened pulping yield for these genetic materials was obtained from literature. Three distinct groups of genetic materials emerged from cluster analysis. In group I, hybrids with longer and less flexible fibers (Runkel ratio >1, wall fraction >50%, and flexibility coefficient <50%) predominated, making them more suitable for manufacturing absorbent papers. In contrast, groups II and III comprised genetic materials with higher screened yields (>52.0%), lower wall fractions (<50%), and other fiber quality indices indicating a predominance of more flexible fibers (flexibility coefficient >50% and slenderness ratio >51%). These fibers are primarily more suitable for producing tear- and burst-resistant papers, intended for packaging and bags.

Keywords: Runkel ratio, Mechanical resistance of cellulose pulp, Fiber flexibility

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ÍNDICES DE QUALIDADE DAS FIBRAS DAS MADEIRAS DE *Corymbia* spp. *Eucalyptus* spp. PARA SELEÇÃO DE MATERIAIS GENÉTICOS DESTINADOS A PRODUÇÃO DE POLPA CELULÓSICA

RESUMO – A indicação de materiais genéticos para obtenção de polpa celulósica e produção de papel requer a comprovação da eficiência em relação ao desempenho silvicultural e de processamento na indústria. Neste contexto, buscou-se neste trabalho selecionar materiais genéticos de *Eucalyptus* spp. e *Corymbia* spp. para produção de polpas celulósicas destinadas à produção de papel, por meio de análise de agrupamento, a partir das características morfológicas dos principais elementos anatômicos da madeira, rendimento depurado da polpa marrom e índices de qualidade das fibras (Índices de Runkel, enfeltramento, Mulsteph e coeficiente de flexibilidade). Foram avaliados 16 materiais genéticos, sendo colhidas três árvores de diâmetro médio por tratamento, aos 81 meses de idade e espaçamento de plantio 6x1,5m, provenientes de plantios situados na cidade de Itamarandiba/MG. Para as medições das dimensões das fibras e vasos em microscópio ótico utilizou-se o software Axiovision 4.8. As informações sobre o rendimento depurado da polpação para estes materiais genéticos foram obtidas na literatura. Na análise de agrupamento foram obtidos três grupos distintos de materiais genéticos. Observou-se no grupo I a predominância de híbridos com fibras mais compridas e menos flexíveis (Índice de Runkel >1, fração parede >50% e Coeficiente de flexibilidade <50%), mais adequadas para a fabricação de papéis absorventes. Em relação aos grupos II e III, os materiais genéticos tiveram representantes com maiores rendimentos depurados nas polpações (>52,0%), menores frações paredes (<50%) e outros índices de qualidade das fibras que indicaram a predominância de fibras mais flexíveis (Coeficiente de flexibilidade >50% e Índice de enfeltramento >51%), mais adequadas principalmente para fabricação papéis resistentes ao rasgo e ao arrebentamento, destinados para embalagens e sacarias.

Palavras-Chave: Índice de Runkel, Resistência mecânica da polpa celulósica, Flexibilidade das fibras

1. INTRODUCTION

Obtaining high yields in cellulose pulp at competitive costs is directly dependent on the quality of the wood. Thus, one of the significant challenges for industries in this sector is the selection of appropriate genetic materials. The recent capability to produce pulps with diverse qualitative characteristics that satisfy various technical specifications demanded by industries has led to the development of customized high-performance products (Jardim et al., 2017; Baldin et al., 2020).

The large number of patents or intellectual property rights registered last year (2023), specifically related to the forestry sector, highlights the advancements in technological innovation in industrial production. Notable examples include improved products such as textile fibers from dissolving cellulose, new paper types, chemical compounds derived from wood, and clones with differentiated traits (Indústria Brasileira de Árvores, 2024).

In recent decades, Brazilian forestry has seen considerable progress with *Eucalyptus* plantations, particularly in terms of increased wood yield, improved stem shape, physiological adaptation, and resistance to pests and diseases (Pinto Júnior; Silveira, 2021). However, the need for plantations in non-traditional regions and addressing the impacts of climate change has highlighted *Corymbia* hybrids for their superior biomass production, wood quality, and resistance to wind power and physiological disturbances (Assis, 2015; Reis et al., 2013; Loureiro et al., 2019). In this regard, *Corymbia* species and hybrids are proving to be valuable raw materials for the forestry industry. Although hybrids between these species are less explored compared to *Eucalyptus* genetic materials, their use can meet the demand for wood for various applications such as pulp and paper, wood panels, sawn wood, posts, fence posts, and charcoal (Assis, 2015; Silva et al., 2023).

Obtaining cellulose pulp for producing various types of paper involves individualizing fibers through hydrolysis and solubilization of lignin, which strongly binds the fibers together without degrading the wood carbohydrates (Colodette and Gomes, 2015; Wastowski, 2018). The increased propensity for establishing interfiber bonds, due to their greater flexibility, contributes to the paper's enhanced tensile strength (Pego et al., 2019). This characteristic is particularly desirable for printing and writing papers. Fibers with greater average lengths and slenderness are recommended for the production of tear- and burst-resistant papers, such as packaging papers (Mendoza et al., 2021; Pego; Bianchi and Veiga, 2019).

Anatomical studies of the cellular elements comprising the xylem of wood provide initial indicators for screening potential fibrous raw materials for paper production (Carrillo et al., 2018; Pirralho et al., 2014). Nisgoski et al. (2012) noted that for papermaking purposes, the manner in which fibers intertwine during the manufacturing process can be assessed using the relationships between their morphological dimensions. As examples, the authors highlighted the Runkel and slenderness ratios, flexibility coefficient, and wall fraction. Accordingly, this study evaluated the interrelationships among the morphological characteristics of the main anatomical elements constituting the wood, their influence on pulping yield, and qualitative fiber indices for paper production.

2. MATERIAL AND METHODS

Sixteen genetic materials were utilized for the study (Table 1), with three trees of average diameter per treatment being collected at 81 months of age, with a planting spacing of 6x1.5 m, from plantations located in the municipality of Itamarandiba - MG, Brazil (latitude 17º 44' 45" S; longitude 42º 45' 11" W and altitude 1,000 m), resulting in a total of 48 sample units.

The clonal test was set up in plots consisting of eight rows with eight plants for each genetic material. The diameter at breast height of the selected trees ranged from 14.2 to 22.8 cm, averaging 18.3 cm. Merchantable height varied from 17.7 to 25.3 m, with an average of 22.11 m. The average annual increment (without bark) ranged from 26.2 to 56.7 m³ ha-1 year-1.

For the anatomical characterization of the wood, disks approximately 7 cm thick were removed and aligned longitudinally on the tree at positions corresponding to the base (position 0), diameter at breast height, and 25, 50, 75, and 100% of the merchantable height. For the morphological analyses of fibers and

Table 1. Description of the *Corymbia* spp. and *Eucalyptus* spp. genotypes

Tabela 1. Descrição dos genótipos de *Corymbia* spp. e *Eucalyptus* spp.

Genetic materials			
1	*Corymbia citriodora* x *Corymbia torelliana*	9	*Eucalyptus grandis* x *Eucalyptus urophylla*
2	*Eucalyptus cloeziana*	10	*Eucalyptus urophylla* x (*Eucalyptus camaldulensis* x *Eucalyptus grandis*)
3	*Corymbia citriodora* x *Corymbia torelliana*	11	(*Eucalyptus camaldulensis* x *Eucalyptus grandis*) x *Eucalyptus urophylla*
4	*Corymbia citriodora* x *Corymbia torelliana*	12	(*Eucalyptus camaldulensis* x *Eucalyptus grandis*) x *Eucalyptus urophylla*
5	*Corymbia citriodora* x *Corymbia torelliana*	13	(*Eucalyptus camaldulensis* x *Eucalyptus grandis*) x *Eucalyptus urophylla*
6	*Eucalyptus urophylla* x *Eucalyptus* spp.(*)	14	(*Eucalyptus camaldulensis* x *Eucalyptus grandis*) x *Eucalyptus urophylla*
7	*Eucalyptus urophylla* x *Eucalyptus* spp.(*)	15	(*Eucalyptus camaldulensis* x *Eucalyptus grandis*) x *Eucalyptus urophylla*
8	*Eucalyptus urophylla* x *Eucalyptus* spp.(*)	16	*Eucalyptus urophylla* x *Eucalyptus pellita*

(*) Spontaneous hybrid of *Eucalyptus* spp.

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vessels, samples from both the heartwood and sapwood regions were taken from each disk at the six longitudinal positions on the tree for maceration and histological sections. This approach was necessary due to difficulties in identifying the heartwood/sapwood transition region for some genetic materials, which is often used as a reference in various studies.

Individualized fibers were obtained from dissociated fragments by using a heated solution (water bath) in an oven at 60 °C, with a 1:1 ratio of hydrogen peroxide and acetic acid for 48 h (Dadswell, 1972). The material was subsequently rinsed in running water, and astra blue dye was applied. Thirty fibers per sample were measured to assess their length, width, and lumen diameter.

The fiber wall thickness was determined indirectly by the ratio between fiber width and lumen diameter. For microscopic analysis of vessel elements, samples from the heartwood and sapwood regions measuring 2x2x2 cm were immersed in hot water for 48 h (IBAMA, 1992). Subsequently, 16 µm thick histological sections were made in the transverse plane using a horizontal sliding microtome (Figure 1).

The sections were dehydrated in a series of alcohol, stained with safranin, and placed on a slide in a glycerin and water solution at a 1:1 ratio. Thirty vessels per slide were measured to determine the frequency per square millimeter and tangential diameter. An optical microscope equipped with a camera and Axiovision 4.8 software was used for all measurements.

To obtain the screened yield values of brown pulp for the same 16 genetic materials evaluated in this study, average results reported by Costa et al. (2022) were used. The authors conducted the Lo-Solids modified kraft pulping with an H factor of 1.031 and a kappa number of 19±1. The effective alkali (EA) demand ranged from 15.4 to 18.9%, with 55% of the EA load used for chip impregnation. The final temperature was maintained at 165 °C for 90 min, with a liquor/wood ratio of 4/1. The screened pulping yield was calculated as the percentage ratio between the dry weight of the purified cellulose and the dry weight of the wood. Fiber quality indices were derived from the main relationships between the dimensions of these anatomical elements (equations 1 to 5).

$$Wall\ fraction = \frac{2.e}{D}\ x\ 100 \quad \text{(Eq.1)}$$

$$Runkel\ ratio = \frac{2.e}{d} \quad \text{(Eq.2)}$$

$$Flexibility\ coefficient = \frac{d}{D}\ x\ 100 \quad \text{(Eq.3)}$$

$$Slenderness\ ratio = \frac{C}{D}\ x\ 100 \quad \text{(Eq.4)}$$

$$Mulsteph\ coefficient = \frac{D^2 - d^2}{D^2} \quad \text{(Eq.5)}$$

where e: fiber wall thickness (µm); D: fiber diameter (µm); d: fiber lumen diameter (µm); C: fiber length (mm)

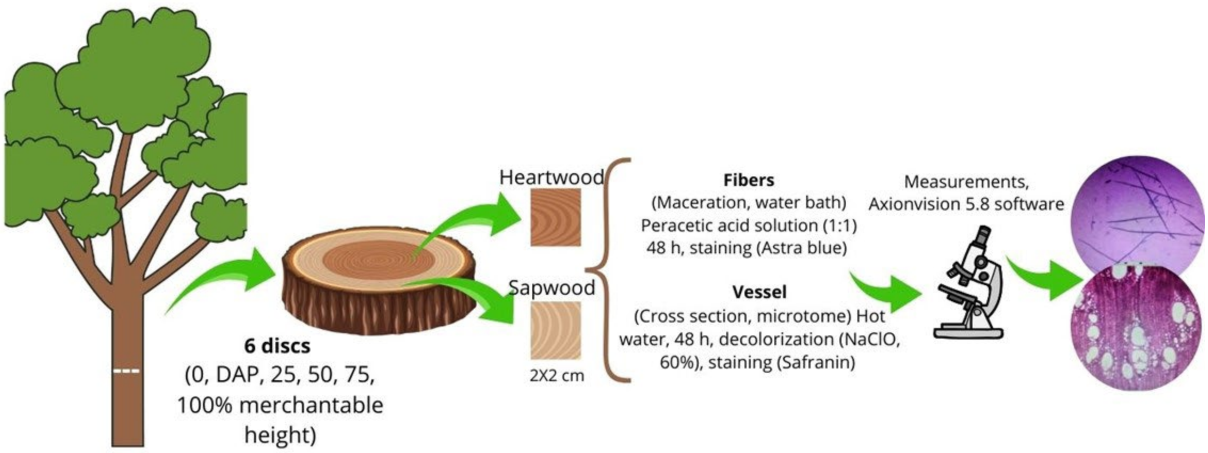

Figure 1. Simplified flowchart for obtaining fiber suspension and cross-sectional histological sections from the 16 genetic materials

Figura 1. Fluxograma simplificado para obtenção da suspensão de fibras e cortes histológicos transversais a partir dos 16 materiais genéticos

The values obtained for the fiber quality indices underwent Shapiro-Wilk and Bartlett tests to analyze the normality of the data and the homogeneity of variances, respectively. The data were then subjected to ANOVA. A Pearson's correlation matrix (r) at a 5% significance level was utilized to identify associations between anatomical variables and the screened brown pulp yield, as well as their relation to fiber quality indices. From the variables that showed significant correlations with one or more properties (pulping yield or fiber quality indices), agglomerative hierarchical cluster analysis (Complete Linkage method) was used to establish homogeneous groups.

3. RESULTS

The screened yield values reported by Costa et al. (2022) ranged from 49.8 to 54.1% for *Corymbia* hybrids and from 50.8 to 53.8% for *Eucalyptus*. The values for fiber length and wall fraction in *Eucalyptus* varied by 28% and 23%, respectively, among the 12 hybrids evaluated. The frequency of vessels showed a variation of 34% in this group of genetic materials. The tri-cross hybrids among the *Eucalyptus* genetic materials were notable for having the lowest average values for fiber length (0.95 mm), width (18.4 µm), lumen diameter (9.1 µm), and wall thickness (4.6 µm). However, these hybrids also exhibited vessels with larger average lumen diameters (121.5 µm) and a higher frequency per square millimeter (10.9).

The anatomical dimensions for the *Corymbia* hybrids showed similar mean values when compared to the results obtained for the 12 *Eucalyptus* hybrids. However, within the four *Corymbia* hybrids, important variations were observed in length (14%), width (10%), wall fraction (8%) of the fibers, and vessel frequency (10%) (Table 2). The variation in the screened yield among these hybrids was approximately 9%, with the highest yield of 54.1% observed in one of the *Corymbia* hybrids, the highest of all 16 genetic materials evaluated (Costa et al., 2022).

Runkel ratios in *Eucalyptus* varied by 45%, indicating the existence of materials to supply fibers with adequate flexibility

Table 2. Mean values and descriptive analysis of the anatomical dimensions of the fibers, vessel elements, and fiber quality indices of the 16 genetic materials

Tabela 2. Valores médios e análise descritiva das dimensões anatômicas das fibras, elementos de vasos e índices de qualidade das fibras para os dezesseis materiais genéticos

Anatomical dimensions and related indices	*Corymbia* hybrids (genetic materials 1, 3, 4, 5)				*Eucalyptus* hybrids (genetic materials 2, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16)			
	Mean(*)	Minimum	Maximum	Range	Mean(*)	Minimum	Maximum	Range
Fiber length (mm)	0.98 (4.2)	0.91	1.04	0.13	0.97 (4.6)	0.86	1.1	0.24
Fiber width (µm)	18.83 (3.6)	18.1	20	1.9	18.86 (5.53)	16.6	21.3	4.7
Fiber lumen diameter (µm)	9.3 (6.8)	7.9	10.1	2.2	9.38 (6.96)	7.7	10.8	3.1
Fiber wall thickness (µm)	4.72 (5.51)	4.6	5	0.4	4.73 (5.91)	4.2	5.4	1.2
Fiber wall fraction (%)	50.3 (2.31)	48.3	52	3.7	50.2 (3.9)	45.1	55.4	10.3
Vessel lumen dia-meter (µm)	120.4 (4.8)	111.8	131.4	19.6	119 (4.5)	110.3	132.1	21.8

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Anatomical dimensions and related indices	*Corymbia* hybrids (genetic materials 1, 3, 4, 5)				*Eucalyptus* hybrids (genetic materials 2, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16)			
	Mean(*)	Minimum	Maximum	Range	Mean(*)	Minimum	Maximum	Range
Vessel frequency (vells.mm^{-2})	9.47 (5.5)	8.9	10.5	1.6	10.69 (6.6)	9	12.1	3.1
Runkel ratio	1.02 (6.1)	0.94	1.17	0.23	1.01 (7.2)	0.82	1.19	0.37
Flexibility coefficient (%)	49.3 (4.1)	43.9	51.7	7.8	49.7 (3.6)	46.1	54.9	8.8
Slenderness ratio	51.9 (6.5)	46.5	57.4	10.9	51.7 (4.9)	45.6	57.5	11.9
Mulsteph coefficient	0.76 (2.5)	0.73	0.81	0.08	0.75 (2.38)	0.70	0.79	0.09

(*) Values in parentheses represent the coefficient of variation (%).

for various products based on specific requirements. Overall, the genetic materials of *Corymbia* exhibited higher Runkel ratios, with minimum values closer to 1. The flexibility coefficients were higher for the *Eucalyptus* hybrids compared to those of *Corymbia*, with a difference of approximately 6% between the highest FC obtained for *Eucalyptus* and the highest value recorded for *Corymbia*.

The analysis of slenderness ratio revealed the existence of genetic materials from the genera *Corymbia* and *Eucalyptus* with values above 50, making them more likely to produce tear-resistant papers. However, genetic materials with lower SR were noted in both genera, showing an average reduction of nearly 25% compared to materials with higher ratios. The Mulsteph coefficient recorded a minimum value of 0.73 for *Corymbia* genetic materials and 0.70 for *Eucalyptus*. Despite the low coefficient of variation for this index in both genera (less than 2.5%), the variation between the highest and lowest values obtained for EI was 11% and 13%, respectively, for *Corymbia* and *Eucalyptus* genetic materials.

The study of the correlations between the dimensions of the cellular elements and their respective results identified the measurements that most influenced the final values obtained. The most significant correlations were related to the wall fraction and lumen diameter of the fibers (Table 3).

No significant correlations were found between the anatomical dimensions and the screened yield, except for an inverse correlation observed with the frequency of vessels (r=-0.649). Increases in the lumen diameter of the fibers correlated with a decrease in the Runkel ratio (RR) (r=-0.704) and MI (r=-0.655) and an increase in the FC (r=0.681). The results confirmed the impact of the wall fraction on fiber flexibility; fibers with a higher wall fraction exhibited a higher RR (r=0.976) and a lower FC (r=-0.930), indicating genetic materials with fibers displaying different flexibility patterns. Another significant correlation was observed between fiber width and SR, confirming that fibers with larger diameters have a lower SR (r=-0.650).

Based on the dimensions of the cellular elements and related quality indices, along with the contribution of the screened yield values described by Costa et al. (2022), the genetic materials were grouped by similarity. According to characteristics relevant to pulp extraction and paper production, three homogeneous groups were defined in the agglomerative hierarchical cluster analysis (Figure 2).

Group I consisted of genetic materials 1, 4, 9, and 15, including two *Corymbia* hybrids and two *Eucalyptus* hybrids. Group II was formed by clones 2 and 5, specifically

Table 3. Correlation matrix and respective coefficients obtained for the anatomical dimensions of the cellular elements (fibers and vessels), screened brown pulp yield, and fiber quality indices

Tabela 3. Matriz de correlação e respectivos coeficientes obtidos para as dimensões anatômicas dos elementos celulares (fibras e vasos), rendimento depurado da polpa marrom e índices de qualidade das fibras

	SPY	RR	FC	SR	MC
FL	0.247	0.361	-0.382	0.429	0.421
FW	0.010	-0.340	0.297	-0.650*	-0.270
FLD	0.076	-0.704*	0.681*	-0.778*	-0.655*
FWT	-0.135	0.300	-0.313	-0.229	0.332
FWF	-0.184	0.976*	-0.930*	0.622*	0.919*
VLD	0.019	-	-	-	-
VF	-0.649*	-	-	-	-

Legend: FL: fiber length (mm); FW: fiber width (µm); FLD: fiber lumen diameter; FWT: fiber wall thickness; FWF: fiber wall fraction; VLD: vessel lumen diameter; VF: vessel frequency; SPY: screened pulping yield; RR: Runkel ratio; FC: flexibility coefficient; SR: slenderness ratio; MC: Mulsteph coefficient. *Significant correlation (p=0.05).

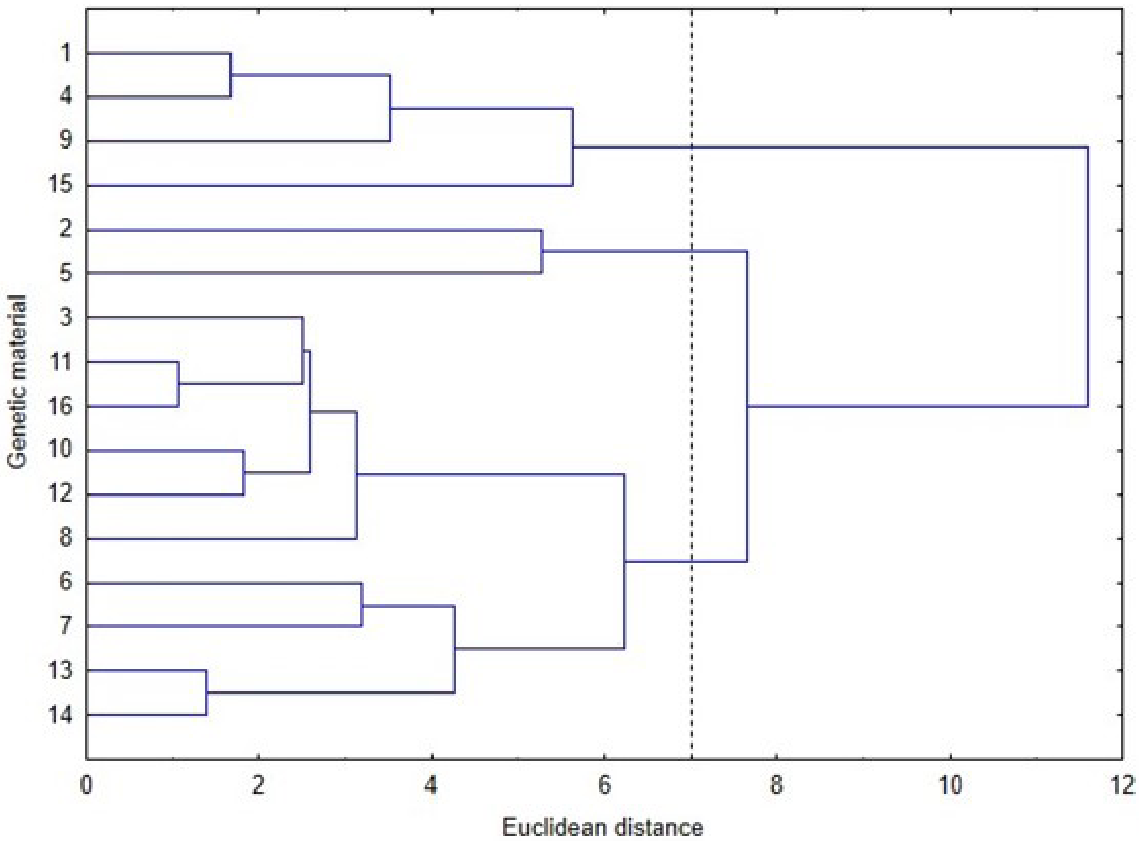

Figure 2. Dendrogram for the 16 genetic materials according to the mean values of the dimensions of cellular elements, screened yield, and fiber quality indices

Figura 2. Dendrograma para os dezesseis materiais genéticos de acordo com os valores médios das dimensões dos elementos celulares, rendimento depurado e índices de qualidade das fibras one genetic material from *Corymbia* and another from *Eucalyptus*. Group III, the most comprehensive of the three groups, comprised clones 3, 6, 7, 8, 10, 11, 12, 13, 14, and 16. This group contained genetic materials from *Corymbia*, all spontaneous hybrids of *E. urophylla*, most of the three-cross hybrids, and the *E. urophylla* x *E. pellita* hybrid (Table 4).

The screened yield values were similar across the three groups, which initially makes it difficult to determine the superior genetic materials based on this indicator alone. Therefore, the analysis of the interrelations between the anatomical dimensions of the fibers, as expressed in various indices, is critical in selecting the materials with the best performance.

Table 4. Mean values of anatomical dimensions, screened yields, and fiber quality indices according to the three groups of genetic materials established in the dendrogram

Tabela 4. Valores médios para as dimensões anatômicas, rendimentos depurados e índices de qualidade das fibras de acordo com os três grupos de materiais genéticos estabelecidos no dendrograma

Anatomical dimensions and related indices	GROUP		
	I	II	III
	1, 4, 9, 15 (*)	2,5	3, 6, 7, 8, 10, 11, 12, 13, 14, 16
Screened yield (%)	52.5	51.9	52.0
Fiber wall fraction (%)	52.1	49.4	49.6
Runkel ratio	1.09	0.98	0.99
Flexibility coefficient (%)	48.1	50.6	50.0
Slenderness ratio	55.0	47.4	51.4
Mulsteph coefficient	0.77	0.74	0.75

(*)Genetic materials.

4. DISCUSSION

In evaluating the results among the genetic materials from the genera *Corymbia* and *Eucalyptus*, despite similar mean values for some anatomical dimensions, a greater range was observed in the *Eucalyptus* hybrids. This suggests that within the same group, there could be genetic materials suited for different purposes.

For hybrids of *Eucalyptus* spp. and *Corymbia* spp., at similar ages to the materials used in this study, the studies reported dimensional variations ranging from 0.88 to 1.15 mm in length, 14.4 to 23.9 μm in width, 6.4 to 12.8 μm in lumen diameter, and 3.4 to 6.5 μm in wall thickness of the fibers. For vessel elements, the variation ranged from 92.9 to 129.6 μm in tangential diameter and 7.9 to 13.5 (units/mm²) in the number of vessels per square millimeter (Couto et al., 2023; Cruz et al., 2021; Evangelista et al., 2010; Gouvea et al., 2012; Melo et al., 2016; Sette Jr. et al., 2012).

Brawner et al. (2012) assessed the kraft pulping yield of *C. citriodora* in three progeny trials conducted in Australia at six years of age, with values ranging from 53.8% to 55.9%. Segura and Junior (2016) compared the screened yield of *C. citriodora* at eight years of age with the hybrid *E. urophylla* x *E. grandis*, at kappa numbers of 18 and 18.5 respectively, and reported similar yields around 54% for both. Despite the comparable yields, they emphasized the advantages of using the *Corymbia* genus, particularly due to its lower specific consumption of wood and alkali load.

The fiber dimensions of the different genetic materials, when analyzed individually, make it difficult to interpret their suitability for different paper types. According to Nisgoski et al. (2012), the selection of wood for papermaking depends on the morphological characteristics of the fibers and their interconnection. In this context, Guimarães Junior et al. (2010) reported that the mathematical relationships between fiber dimensions reflect key properties for papermaking, such as interfiber bonding potential, group agglomeration, and microfibril percentage.

The Runkel ratio (RR) and the flexibility coefficient (FC) are indicators of not only fiber flexibility but also their propensity to form interfiber bonds (Boschetti et al., 2015). A higher RR suggests that the wood is less suitable for manufacturing papers that require greater strength, while a higher FC indicates more flattened fibers, increasing tensile and burst strengths (Burger and Richter, 1991; Guimarães Junior et al., 2010; Paulino and Lima, 2018; Pego et al., 2019). The desirable Runkel ratio values are generally below 1, indicating the existence of genetic materials suitable for paper manufacturing according to different classifications (Burger and Richter, 1991).

Regarding the flexibility coefficient, some genetic materials displayed average values within the recommended limits for papermaking, which classify fibers with a flexibility coefficient between 50 and 75% as elastic (Bektas et al., 1999). The slenderness ratio (SR) is similarly associated with fiber flexibility and directly correlates with tear resistance in papers; the higher the index, the more tear-resistant the paper (Mendoza et al., 2021; Miranda and Castelo, 2012). For SI, most of the genetic materials evaluated had a value above 50, considered desirable for producing papers such as those intended for packaging (bags) (Rusch et al., 2019).

The Mulsteph coefficient (MC) relates to the fiber's propensity to collapse, as it is calculated as the ratio between the relative area of the cell wall and the entire fiber (Pego et al., 2019). Thus, the higher the index, the lower the propensity for fiber collapse. The average values obtained for MC are classified in class III (>0.6), according to raw material selection criteria for pulp and paper (Sitilonga, 1972, cited in Hartono et al., 2022). This classification is organized by the author into three classes, in decreasing order of collapse tendency. Therefore, according to this criterion, all genetic materials in this study have fibers that are not prone to collapse. Of the indexes evaluated, MC showed the least variation among the genetic materials.

The significant correlations observed between the wall fraction and other fiber quality indices confirmed the influence of the cell wall on flexibility and collapse propensity. Fibers with thinner cell walls, indicating a lower tendency to collapse, are more suitable for producing papers classified as tissue. Gomes et al. (2015) noted that the ability to absorb water is an essential characteristic for these papers. Furthermore, they emphasized the importance of bulk (apparent specific volume), showing that stiffer and less refined fibers have greater difficulty accommodating the fibrous network.

Regarding the correlations between the dimensions of the cell elements and the screened brown pulp yield, no significant correlations were observed. However, a significant negative correlation was noted when considering the frequency of vessel elements and pulping yield. The presence of a higher number of vessels with smaller lumen diameters may have hindered the impregnation of the chips with the cooking liquor, thus reducing the pulping yield. It is noteworthy that the *Corymbia* hybrids, on average, exhibited a lower number of vessel elements per area compared to the *Eucalyptus* genetic materials. Additionally, clone 2 (*E. cloeziana*) showed the highest average frequency of vessels among all evaluated genetic materials, coinciding with the lowest screened yield.

Based on the aforementioned classification criteria, it was observed that genetic materials in group I, on average, displayed higher values for wall fraction and all fiber quality indices, except for the flexibility coefficient. Moreover, all genetic materials in this group demonstrated an RR > 1 and a CF < 50, suggesting that the fibers are less prone to collapse, exhibit lower interfiber bond intensity, and contribute to the formation of papers that are less resistant to traction and bursting. Nonetheless, these characteristics may qualify these cellulose pulps for producing tissue-type papers. The higher slenderness ratio suggested that, on average, the genetic materials in this group possess slender fibers—longer and less wide.

The genetic materials in group II are characterized by desirable average values for the manufacture of papers more resistant to traction and bursting, suitable for packaging and bags, highlighted by a lower wall fraction, RR, and MC, and a higher CF. Despite being grouped together, Costa et al. (2022) noted that the genetic material from the cross *C. torelliana* x *C. citriodora* achieved a 54.1% screened yield, which is 8.6% higher than that of *E. cloeziana*, making it notably superior within this group.

The analysis of the results from the genetic materials in group III shows that, on average, they possess characteristics suited for manufacturing papers resistant to traction, bursting, and tearing. These genetic materials display desirable features for certain types of paper, such as fibers with a lower wall fraction and adequate flexibility, as indicated by the Runkel ratio, slenderness ratio, and flexibility coefficient. Thus, these genetic materials are identified as potential candidates for paper production, mainly intended for bag making. However, given the diversity within this large group, genetic materials with fibers having morphological characteristics suitable for the production of printing and writing papers were also identified, such as hybrids 6 and 7 (spontaneous hybrids of *E. urophylla*).

5. CONCLUSION

Genetic materials 1 and 4, from the genus *Corymbia*, genetic material 9, a hybrid of *E. urophylla* x *E. grandis*, and genetic material 15, a three-cross hybrid from group I, exhibited a higher wall fraction and Runkel ratio, along with a lower fiber flexibility coefficient. These traits qualify these materials for the production of tissue papers.

In groups II and III, there was a predominance of genetic materials with more flexible fibers, which are more conducive to producing papers intended for packaging and bags.

The fiber wall fraction was significantly correlated with several quality indices, highlighting its importance as a dimensional parameter for selecting genetic materials for producing various types of papers.

With the exception of the frequency of vessel elements per area, the anatomical dimensions showed no significant correlations related to the screened pulping yield.

It is recommended that further studies be conducted, based on the groups of genetic materials established in this study, to evaluate the physical-mechanical properties relevant to the manufacturing process and quality of papers intended for printing and writing, tissue, packaging, and bags.

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AUTHOR CONTRIBUTIONS

WPSJ: Conceptualization, methodology, investigation, original draft preparation, writing. AMMLC: Conceptualization, Supervision, review, editing. ACOC: Supervision, review, editing. IFD: Methodology, review, editing. RSO review, editing, Resources. LACR: Methodology, review, editing. LAL: Investigation. SDAM: Data Curation, review, editing.

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