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Articles

Wood quality of *Corymbia* hybrids for kraft pulp production

Qualidade da madeira de híbridos de *Corymbia* para a produção de celulose kraft

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ABSTRACT

Brazil is the world's largest hardwood pulp producer and, despite the results achieved through the cultivation of eucalyptus, other crops such as species and hybrids of the *Corymbia* genus are being studied in breeding programs. In this context, this study aimed to evaluate the wood quality and rank ten hybrid clones of *Corymbia torelliana* and *Corymbia citriodora* for kraft pulp production, using a commercial clone of *Eucalyptus saligna* as a control. Wood quality was assessed for its chemical composition, basic density, and pulping performance. The following were evaluated regarding kraft pulping: screened pulp yield, kappa number, rejects content, and specific wood consumption. All the hybrid clones of the *Corymbia* genus had a higher basic density than the control treatment, with results ranging from 509 to 607kg/m³. *The Corymbia* hybrids had total extractives ranging from 2.53 to 8.16%, total lignin from 25.84 to 28.42%, ash from 0.5 to 1.17% and holocellulose from 65.35 to 70.84%. The *Corymbia* hybrid with the best pulping performance had a screened pulp yield of 53.24%, a Kappa number of 22.2, a rejects content of 0.91%, and a specific consumption of 3.11 m³/tsa. The study ranked and indicated the clones with the best wood quality for kraft pulp production.

Keywords: *Corymbia*; *Eucalyptus saligna*; Screened pulp yield; Basic density; Wood quality

RESUMO

O Brasil se destaca como o maior produtor de celulose de fibra curta do mundo e, apesar dos resultados alcançados através do cultivo do eucalipto, outras culturas, como as espécies e híbridos do gênero *Corymbia* estão sendo estudados em programas de melhoramento genético. Neste contexto, o presente trabalho teve como objetivo avaliar a qualidade da madeira e o ranqueamento de dez clones híbridos de *Corymbia torelliana* e *Corymbia citriodora* para a produção de celulose kraft, tendo como controle um clone comercial de *Eucalyptus saligna*. A qualidade da madeira foi avaliada quanto *à* composição química, densidade básica e desempenho na produção de celulose. Na polpação kraft foram avaliados: o rendimento depurado, número kappa, teor de rejeitos e consumo específico de madeira. Todos os clones híbridos do gênero *Corymbia* apresentaram densidade básica superior ao tratamento de controle, com resultados variando de 509 a 607kg/m³. Os híbridos de *Corymbia* apresentaram extrativos totais variando de 2,53 a 8,16%, lignina total de 25,84 a 28,42%, cinzas de 0,5 a 1,17% e holocelulose de 65,35 a 70,84%. O híbrido de *Corymbia* com melhor desempenho na polpação obteve rendimento depurado de 53,24%, número kappa de 22,2, teor de rejeitos de 0,91% e consumo específico de 3,11 m³/tsa. O estudo permitiu realizar o ranqueamento e indicar os clones com melhor qualidade da madeira para a produção de celulose kraft.

Palavras-chave: *Corymbia*; *Eucalyptus saligna*; Rendimento de polpa depurada; Densidade básica; Qualidade da madeira

1 INTRODUCTION

In 2022, the planted forest sector occupied a total area of 9.94 million hectares for industrial purposes, of which around 76% was dedicated to eucalyptus cultivation (IBÁ, 2023). The predominance of planted forests is closely linked to this genus' high volumetric productivity, driven by a variety of factors, among them the country's favorable climatic conditions, advanced silvicultural management techniques, and, especially, specific genetic improvement programs for eucalyptus (Assis, 2014).

Using wood from planted forests, Brazil has maintained its position as the world's second-largest pulp producer by reaching 25.0 million tons, with 21.9 million tons derived from eucalyptus short fibers (IBÁ, 2023).

Despite the extensive knowledge about the Eucalyptus genus, there has been an expansion in the use of other species regarding genetic breeding programs, aiming to develop productive materials resistant to biotic and abiotic factors. In this context, various studies have been conducted with species of the *Corymbia* genus, such as *Corymbia citriodora*, *Corymbia torelliana*, *Corymbia maculata* and their hybrids (Assis, 2014; Valente, 2015).

Corymbia wood has a basic density of around 600kg/m³, giving it advantages in pulp production, such as a specific reduction in wood consumption and, consequently, lower production costs. However, this characteristic also entails some risks: wear and tear on chippers, higher rejects formation, difficulties in impregnating the liquor, and increased consumption of soda and sulfide (Segura, 2015).

Studies on the use of *Corymbia* in pulp production aroused great interest, especially between the 1970s and 1990s when species of this genus were still classified as *Eucalyptus*. However, despite the technological potential, the lack of genetic improvement programs and the lower annual volumetric increase compared to eucalyptus reduced the sector's interest in using *Corymbia* species in pulp production (Reis *et al*., 2013; Segura, 2015).

Focusing on this context and based on the evolution of genetic improvement programs and the scarcity of research on the *Corymbia* genus, this study aimed to characterize the wood quality and rank ten clones of *Corymbia* hybrids regarding their performance in the kraft pulping process.

2 MATERIALS AND METHODS

2.1 Wood sampling and preparation

The trees used in this study were obtained from an experimental plantation belonging to the company CMPC Celulose Riograndense, located at geographic coordinates 30°07'52.6"S, 51°41'39.6"W, in the city of Eldorado do Sul, in the state of Rio Grande do Sul, Brazil.

Ten clones of Corymbia spp. hybrids and one clone of E. saligna (most used by the company) as a control, all six years old, were evaluated. The materials for the study are identified in Table 1.

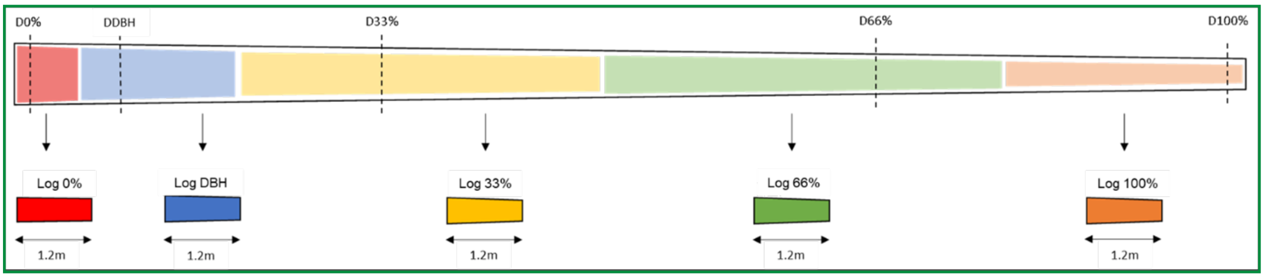
Table 1 – Identification of the clones used in the study

Clone	Treatment
Corymbia torelliana x *Corymbia citriodora*	T1
Corymbia torelliana x *Corymbia citriodora*	T2
Corymbia torelliana x *Corymbia citriodora*	T3
Corymbia torelliana x *Corymbia citriodora*	T4
Corymbia torelliana x *Corymbia citriodora*	T5
Corymbia citriodora x *Corymbia torelliana*	T6
Corymbia torelliana x *Corymbia citriodora*	T7
Corymbia torelliana x *Corymbia citriodora*	T8
Corymbia torelliana x *Corymbia citriodora*	T9
Corymbia torelliana x *Corymbia citriodora*	T10
Eucalyptus saligna	T11

Source: Authors (2024)

Regarding the sampling, three trees for each clone were felled, totaling 33 individuals. For each tree, five disks of 3 to 4cm were collected at 0, 33, 66, and 100% of the commercial height (height at a diameter equal to 5 cm) and the DBH (diameter at breast height) - 1.30m above the ground, as well as five logs of 1.20m at the area where the disks were sampled. The sampling positions of the disks and logs are shown in Figure 1.

Figure 1 – Sampling position of disks and logs of the studied trees



Source: CMPC (2021)

The logs were debarked and turned into chips using a DEMUTH model D3P250 disk chipper. After being chipped and air-dried, the chips were homogenized and sorted manually. For pulping and chemical characterization, the knots were removed and chips with a length of approximately 2.5 cm and a thickness of between 3 and 8 mm were used. For each disk at the 5 heights, a wedge equivalent to 1/4 of the disk was sectioned for basic density analysis.

The chips used in the chemical analysis were prepared following the TAPPI T 257 (2012) and TAPPI T 264 (2007) standards.

2.2 Wood characterization

The methodologies used to characterize the wood are displayed in Table 2.

Table 2 – Wood characterization analyses

Parameter	Methodology
Basic density (kg/m³)	SCAN-CM 43:95
Ash (%)	TAPPI T 211 (2011)
Acetone extractives (%)	TAPPI T 204 (2007)
Hot water extractives (%)	TAPPI T 207 (2008)
Total extractives (%)	*TE = AcE + HWE*
Insoluble lignin (%)	TAPPI T 222 (2011)
Soluble lignin (%)	Goldshmid (1971)
Total lignin (%)	*TL = IL + SL*
Holocellulose (%)	*H* = 100 – (*TL* + *TE*)

Source: Authors (2024)

In where: TE = Total extractives; AcE = Acetone extractives; HWE = Hot water extractives; TL = Total lignin; IL = Insoluble lignin; SL = Soluble lignin; H = Holocellulose.

2.2 Pulp cooking and characterization

Kraft pulping was carried out at the Pulp and Paper Laboratory of the Federal University of Pelotas in a Regmed model AUE/20 digester with the cooking capacity of four simultaneous samples. Each sample had 100g of chips (dry basis). Cooking was conducted in duplicate.

The cooking conditions were defined based on the values required to obtain a Kappa number of 18±1 in the pulps produced from the control treatment (*E. saligna*). Previous tests determined the cooking parameters used for the genetic materials obtained, as shown in Table 3.

Table 3 – Cooking conditions

Conditions
Active alkali (NaOH base) - 22%
Sulfidity - 30%
Liquor/wood ratio - 4:1
Maximum temperature - 158ºC
Time to maximum temperature - 60 minutes
Time at maximum temperature - 120 minutes

Source: Authors (2024)

The cellulose pulps were extracted from the cooking cells and rinsed in a washing box to eliminate the remaining black liquor. Subsequently, the fibers were separated in a Regmed DSG-21 laboratory disintegrator.

After individualizing the fibers, the pulps were screening in a Regmed model SM-21 Somerville-type screening.

The methodology used to determine each parameter for the pulps obtained is described in Table 4.

Table 4 – Pulping parameters and methodology used

Parameter	Methodology
Screened pulp yield (%)	Relationship between cellulose pulp dry mass and chips dry mass
Rejects (%)	Relationship between dry mass of rejects and dry mass of chips
Kappa number	TAPPI T 236 (2006)
Specific wood consumption (m^3/tsa)	$SWC = \frac{(1000 \times 0{,}9)}{(BD \times SY \times 0{,}95}$
Selectivity	$S = \frac{RD}{Kappa}$

Source: Authors (2024)

In where: SWC = Specific wood consumption; SY = Screened pulp yield; DB = Basic density; S = Selectivity.

3 RESULTS AND DISCUSSIONS

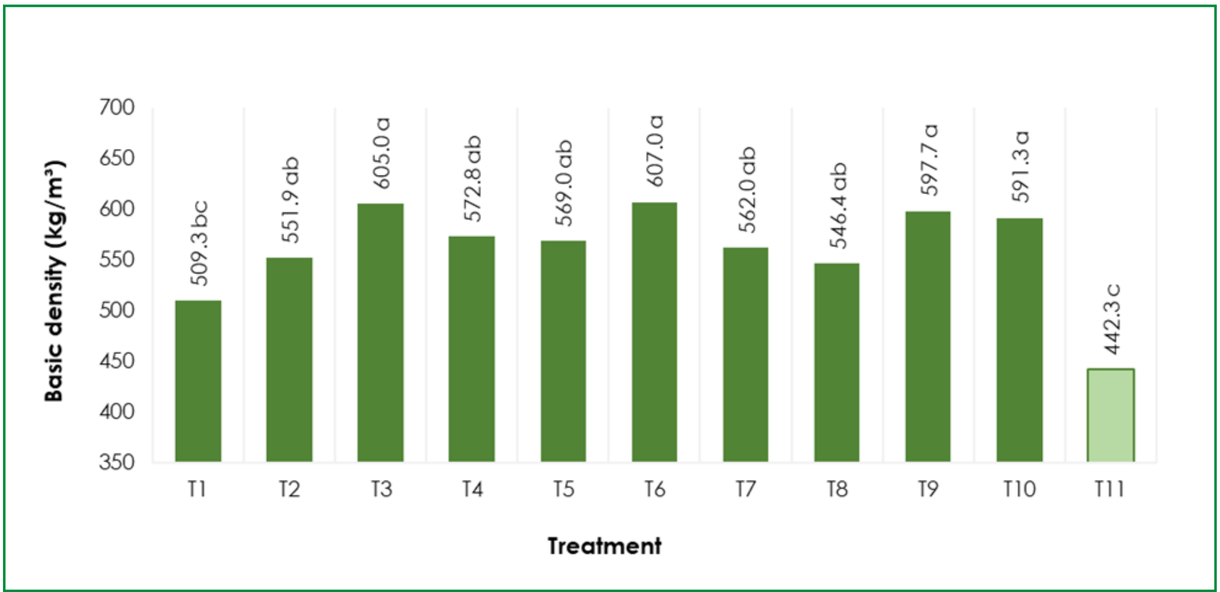
3.1 Basic density

According to the results shown in Figure 2, it can be seen that, except for treatment T1, all the other *Corymbia* hybrid clones had a statistically higher basic density (BD) than *Eucalyptus saligna* (442 kg/m³), as was expected due to the characteristics of the *Corymbia* genus.

For the *Corymbia torelliana* X *Corymbia citriodora* hybrid clones, the basic density results varied between 509 and 605kg/m³. Treatment T6 was the only one of the hybrids studied to have *Corymbia citriodora* as its maternal parent and its wood had a BD of 607kg/m³.

Segura (2015), in a study of Corymbia hybrids, obtained results of 599 and 637kg/m³ for 7-year-old clones, while Moutinho (2012), showed an average result of 610kg/m³ for 5-year-old ones. Therefore, clone T1, as seen, was the only one to show a BD lower than the range reported in the literature.

Figure 2 – Basic density of wood



Source: Authors (2024)

In where: Averages followed by the same letter do not differ statistically using the Tukey test at 5% probability.

The industry desires higher-density wood since it can reduce its specific consumption to obtain a ton of pulp. In this context, *Corymbia* wood stands out when compared to the control treatment (Mokfienski *et al*., 2008; Gomide *et al*., 2010; Foelkel, 2009a; Queiroz *et al*., 2004).

3.2 Chemical characterization

The average results in Table 5 display the wood chemical characterization of the studied clones.

Table 5 – Wood chemical characterization

Treatment	Parameters			
	TE (%)	TL (%)	Ash (%)	H (%)
T1	5.03[c*]	26.80[abc]	1.17[a]	68.18[a]
T2	5.11[c]	28.42[a]	0.73[cd]	66.48[ab]
T3	8.16[a]	26.50[bc]	0.64[de]	65.35[a]
T4	4.01[e]	27.91[ab]	0.70[cd]	68.08[b]
T5	5.66[b]	26.44[bc]	0.66[de]	67.90[b]
T6	2.53[g]	26.63[abc]	0.50[ef]	70.84[c]
T7	4.12[e]	27.75[ab]	0.75[cd]	68.13[b]
T8	3.33[f]	25.84[c]	1.09[a]	70.84[c]
T9	2.49[g]	26.99[abc]	0.88[bc]	70.53[c]
T10	5.67[b]	27.22[abc]	0.97[ab]	67.11[ab]
T11	4.53[d]	28.24[ab]	0.42[f]	67.23[b]

Source: Authors (2024)

In where: * Means followed by the same letter in the same column do not differ statistically by Tukey's test at 5% probability; TL = Total lignin; TE = Total extractives; H = Holocellulose.

Extractives in wood negatively affect several stages of the pulp extraction process, increasing production costs and reducing the final product quality. Extractives cause an increase in the demand for reagents in cooking and bleaching, as well as causing adhesion in equipment, forming pitch (Bajpai, 2016; Silvério *et al*., 2006; Silvestre *et al*., 1999).

From total extractive content results, treatments T6 and T9, as seen, were the ones with the best results and differed statistically from the other clones. Also noteworthy were clones T4, T7, and T8, which differed statistically from the control treatment and are desirable for the pulping process. The other treatments had higher extractive contents than treatment T11.

The total extractive content for *Corymbia* hybrids reported in the literature present values ranging from 2.38 to 10.35%, so it is possible to verify that all the clones studied are within that range (Segura, 2015; Loureiro *et al*., 2019; Valente, 2017).

A higher lignin content, as extractives, is detrimental to pulping, demanding a higher need for reagents, reducing yield projections, and affecting final product quality (Antunes, 2009; Foelkel, 1977). In this aspect, treatment T8 was the most suitable *Corymbia* hybrid clone, with a total lignin content statistically lower than the control treatment.

The total lignin content for *Corymbia* hybrids is reported in the literature with a range from 25.71 to 29.36%, like those obtained in this study (Segura, 2015; Loureiro *et al*., 2019; Valente, 2017).

Regarding the ash content, treatment T6 was the only *Corymbia* clone with a result statistically like the control treatment. Treatments T2, T3, T4, T5, and T6 showed results close to 0.70% ash content, while treatments T1 and T8 showed unsatisfactory results of over 1%. The ash content values for the *Corymbia* clones are within the range of 0.28 to 1.00% described in the literature, except for the treatments T1 and T8 (Brito; Barrichelo, 1977; Segura, 2015; Loureiro *et al*., 2019; Valente, 2017).

Knowledge of the ash content is important when selecting clones for kraft pulp production, as high levels of this parameter can cause fouling and pipe corrosion in residual black liquor recovery (Mata, 2016).

As for holocellulose, which refers to the carbohydrates in the wood, treatments T6, T8, and T9 showed statistically higher levels than the control treatment, thus indicating a higher presence of cellulose and hemicellulose in their composition. Treatment T3 was the only *Corymbia* clone with statistically lower levels than treatment T11.

3.2 Kraft pulping and characterization

Based on the cooking parameters used, we achieved the desired Kappa number for the control clone, which allowed the conditions for the other treatments to be standardized.

Table 6 shows the pulp characterization results produced for each treatment. Except for T2 and T3, all the treatments were statistically like the control for the screened pulp yield.

Among the *Corymbia* clones, a variation in screened pulp yields ranging from 48.71 to 53.24% was verified, with treatment T4 showing the highest value and T3 the lowest.

The literature reports screened pulp yield results for the *Corymbia* genus ranging from 46.5 to 54.1%, as observed in this study. Costa *et al*. (2022) found values between 51.6 and 54.1%. Severo *et al*. (2013) found 49.73 and 51.93%. Segura (2015) from 46.5 to 54.1%.

Table 6 – Kraft pulping results for hybrid clones of *Corymbia* and *Eucalyptus saligna*

Treatment	Parameters			
	SY (%)	Kappa	Rejects (%)	SWC (m^3/tsa)
T1	49.75^{abc*}	26.90^{ab}	2.33^{ab}	3.74^{d}
T2	49.18^{bc}	26.40^{abc}	1.26^{ab}	3.49^{cd}
T3	48.71^{c}	28.70^{a}	1.39^{ab}	3.22^{ab}
T4	53.24^{a}	22.20^{bcd}	0.91^{ab}	3.11^{ab}
T5	49.95^{abc}	28.05^{ab}	2.98^{a}	3.34^{bc}
T6	51.71^{abc}	23.75^{abcd}	0.54^{b}	3.02^{a}
T7	52.91^{a}	25.05^{abc}	1.14^{ab}	3.19^{ab}
T8	52.44^{ab}	28.60^{a}	2.32^{ab}	3.31^{bc}
T9	52.07^{abc}	25.45^{abc}	1.13^{ab}	3.04^{a}
T10	50.97^{abc}	29.05^{a}	1.41^{ab}	3.14^{ab}
T11	53.06^{a}	17.70^{d}	0.08^{b}	4.04^{e}

Source: Authors (2024)

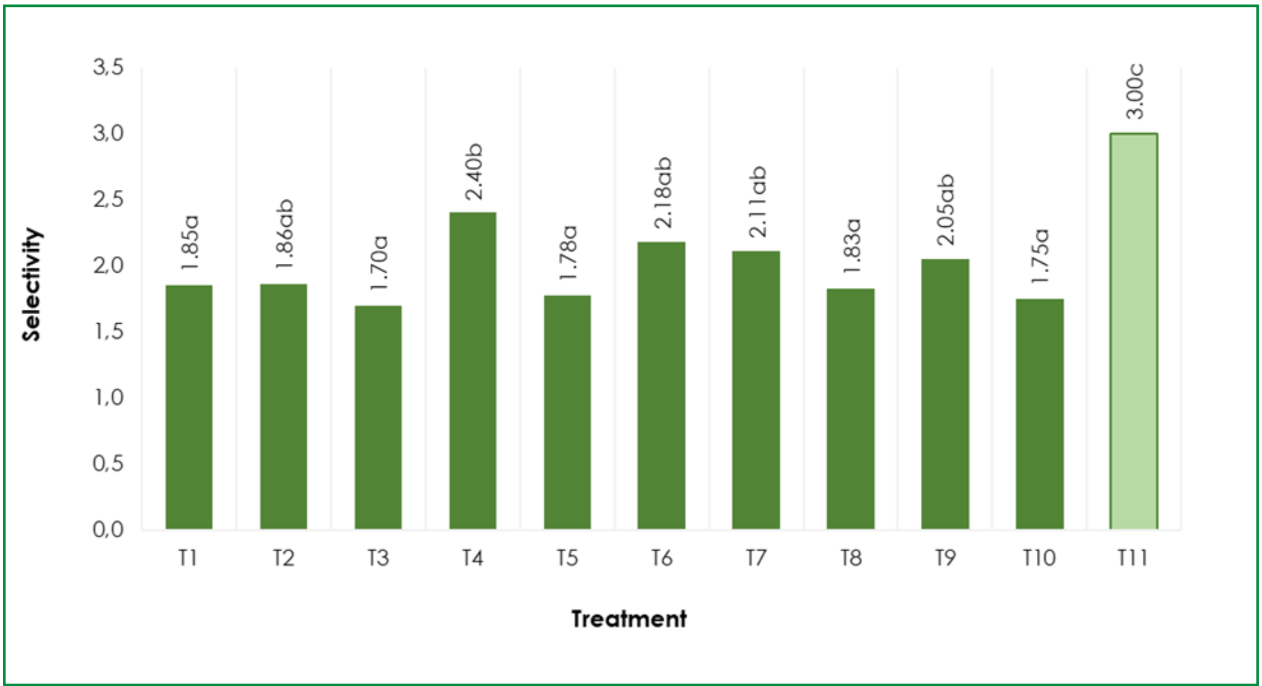
In where: * Means followed by the same letter in the same column do not differ statistically according to Tukey's test at 5% probability; SY = Screened pulp yield; SWC = Specific wood consumption.

Although yield values matter for assessing pulping quality, evaluating the Kappa number in conjunction with this parameter is paramount. The relationship between these two parameters is known as selectivity, and the higher the screened pulp yield (a low kappa number), the greater the selectivity and the lower the loss of pulp quality during cooking (Vivian *et al*., 2022; Silva Júnior, 1997).

Since yields and kappa numbers obtained in the cooking process varied, selectivity was applied to evaluate the behavior of the wood subjected to kraft pulping with the results displayed in Figure 3.

Selectivity indicated that T4 was superior to the other *Corymbia* treatments without statistically differing from T2, T6, T7, and T9. The control treatment selectivity was statistically superior among all.

Figure 3 – Selectivity of *Corymbia* and *Eucalyptus saligna* hybrid clones



Source: Authors (2024)

In where: Averages followed by the same letter do not differ statistically from each other by Tukey's test at 5% probability.

As for the rejects content, there was little statistical variability between the treatments, where only T5 differed statistically from treatments T6 and T11 and was like the other clones of the *Corymbia* genus.

Treatments T4 and T6 had an average rejects content of less than 1.00%, which is desirable in the pulping process, as small rejects amounts can have an economic impact, both due to the loss of fibers and the cost of reprocessing the rejects (Castanho, 2002; Foelkel, 2007).

Concerning specific wood consumption, all the Corymbia treatments showed higher results than the control treatment, indicating that compared to Eucalyptus saligna, a smaller amount of Corymbia wood is needed to produce 1 ton of pulp.

The SWC results are within the range reported in the literature, where Costa *et al*. (2022) obtained values ranging from 2.74 to 3.32m³/tsa, while Segura (2015) found SWCs ranging from 3.32 to 3.8 m³/tsa for hybrid clones of *C. citriodora* and *C. torelliana*.

3.3 Correlation analysis

To evaluate the behaviors observed for the Corymbia hybrids, a Pearson correlation matrix (r) was performed between the parameters analyzed in this study. The correlations are shown in Table 7.

Table 7 - Pearson's correlation matrix for the parameters analyzed

	BD	**TE**	**H**	**Ash**	**TL**	**SY**	**Kappa**	**Rejects**	**SWC**
BD	1.00								
TE	0.02	1.00							
H	0.16	-0.89	1.00						
Ash	0.06	-0.06	0.23	1.00					
TL	-0.39	-0.02	-0.44	-0.39	1.00				
SY	-0.24	-0.70	0.53	-0.15	0.22	1.00			
Kappa	0.57	0.39	-0.06	0.62	-0.62	-0.62	1.00		
Rejects	0.13	0.27	0.04	0.61	-0.62	-0.47	0.75	1.00	
SWC	-0.95	0.21	-0.34	-0.07	0.34	-0.08	-0.42	-0.04	1.00

Source: Authors (2024)

In where: BD = Basic density; SY = Screened pulp yield; SWC= Specific wood consumption; TE = Total extractives; TL = Total lignin; H = Holocellulose.

A strong negative correlation (r= -0.95) between basic density and specific wood consumption can be observed in the correlation matrix. This trend has been reported by Queiroz *et al*. (2004) and Mokfienski *et al*. (2008).

Total lignin correlated with Kappa number and rejects content showed negative correlations (r= -0.62), indicating that this parameter did not significantly influence the wood delignification.

The increase in BD resulted in pulp with a higher Kappa number, as identified by the correlation (r=0.57) of these parameters, which may be related to greater difficulty in impregnation and less chip delignification. Similarly, the rejects content showed a positive correlation (r=0.75) with the Kappa number, reinforcing the influence of the wood on pulp quality.

A positive correlation was found for holocellulose and screened pulp yield (r=0.53), demonstrating that the greater availability of cellulose and hemicellulose in the wood contributed positively to the increase in screened pulp yield.

Sarto and Sansigolo (2010) and Gomide *et al*. (2005) affirm that extractives may react with alkali in the pulping process and cause a decrease in the screened pulp yield. This trend was evidenced in the present study, when total extractives and screened pulp yield were analyzed, a negative correlation was observed (r= -0.70).

4 CONCLUSIONS

Based on the wood quality evaluation of the hybrid Corymbia clones, treatments T4, T6, T9, and T7 are recommended as the best for kraft pulp production, respectively.

Treatment T4 was the most favorable clone for pulp production, with an average screened pulp yield of 53.24% and kappa 22.2, indicating high selectivity in the pulping process and low specific wood consumption.

Treatments T6 and T9 displayed interesting BD and chemical characteristics for pulp production, beyond good results for screened yield and specific wood consumption.

Treatment T7 showed similar performance to T4 but with less selectivity in pulping.

The total extractive and holocellulose contents were the parameters that most influenced the screened pulp yield.

All *Corymbia* clones showed lower results than *Eucalyptus saligna* under the cooking conditions used in kraft pulping. We suggest that further studies must assess the viability of the wood commercial use from species of this genus, considering growth and wood quality characteristics.

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