WOOD RESEARCH doi.org/10.37763/wr.1336-4561/71.2.295302
e-ISSN 2729-8906
71(2): 2026 295-302 pp.

Short notes

THE PRODUCTION OF BLEACHED HARDWOOD KRAFT MARKET PULP UTILIZING CORYMBIA SPP. WOOD

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(RECEIVED APRIL 2026)

ABSTRACT

Forestry innovation in wood quality seeks to enhance pulp and paper industry performance, particularly in the production of bleached hardwood kraft pulp (BHKP), by reducing operating costs through lower specific wood consumption (SWC) and decreased bleaching chemical demand. In this study, 16 clones of *Eucalyptus spp.* and *Corymbia spp.*, developed by Aperam BioEnergia Co., were initially evaluated and ranked, with the top six selected for further analysis. The objective was to assess their performance during the bleaching stage of kraft pulping. Pulp quality was determined based on intrinsic viscosity, brightness, and chemical composition. The hybrid ID 3 (*Corymbia citriodora* × *Corymbia torelliana*) showed superior performance, achieving 93.0% ISO brightness, 54.8% oxygen delignification efficiency, an S/G ratio of 3.62, and xylan content of 16.4%. It also presented the highest intrinsic viscosity (912.5 dm^3/kg), indicating its strong potential for industrial application.

KEYWORDS: ECF pulp bleachability, selectivity, *Corymbia spp.* x *Eucalyptus spp.*

INTRODUCTION

The kraft process is the most widely used method for cellulose fibre separation, with improvements aimed at reducing costs and improving product quality (Yang et al. 2018). Technologies such as Lo-Solids and Compact cooking have contributed to these advances (Arce et al. 2020). Bleaching is required for several paper grades and aims to increase brightness and pulp purity by removing residual lignin while preserving viscosity and cellulose molecular weight (Boland 2006).

Corymbia, previously classified within Eucalyptus, comprises approximately 113 species of the Myrtaceae family native to Australia, with distinct wood characteristics. Corymbia citriodora, formerly known as Eucalyptus citriodora, is a medium- to large-sized tree reaching heights of approximately 50 m (Carvalho et al. 2014). Its chemical composition directly affects pulp production efficiency (Costa et al. 2022), with lignin contents ranging from 19 to 24% and approximately 8% higher hemicellulose content compared to Eucalyptus grandis (Costa & Colodette 2007). Corymbia spp. has shown oxygen delignification efficiencies above 75% and significant kappa reduction, allowing milder bleaching conditions with lower chemical and energy demand compared to *Eucalyptus urograndis* (Domingues et al. 2019).

This study evaluates the performance of six selected clones developed by Aperam BioEnergia Co. for bleached hardwood kraft pulp (BHKP) production.

MATERIAL AND METHODS

Analytical procedures

Kraft pulp from 16 samples was previously produced under modified conditions (Costa et al. 2022) and ranked based on the relationship between mean annual increment of cellulosic pulp (MAICel) and specific wood consumption (SWC), commonly used in the Brazilian forestry industry (Hart & Santos 2013). The six best-ranked clones were selected for bleaching.

The chemical characterization of the samples followed standardized analytical procedures. The TAPPI T280 pm-99 procedure was used to determine acetone extractives (Effland 1977) for Klason (insoluble) lignin determination, TAPPI UM 250 for acid-soluble lignin, TAPPI T 249 cm-85 for acid hydrolysis, (Wallis et al. 1996) for carbohydrate composition, (Scott 1979) for uronic acids, and (Lin & Dence 1992) for lignin S/G ratio determination. TAPPI T452 om-99 was used for brightness, TAPPI T236 cm-85 for kappa number, and TAPPI T230 cm-89 for intrinsic viscosity.

Efficiency, selectivity and bleachability

Bleaching efficiency, selectivity, and bleachability were defined based on kappa number reduction, viscosity loss, and chlorine dioxide (ClO_2) consumption, respectively (Jablonsky et al. 2018; Kwon et al. 2021).

Pulp bleaching process

Kraft pulps were subjected to oxygen delignification (O) to selectively remove residual lignin while preserving carbohydrate integrity. In some cases, a two-stage sequence (O/O) was applied to increase lignin removal and further reduce kappa number prior to bleaching, improving overall process efficiency. The pulps were then bleached by hot chlorine dioxide delignification (D/A), followed by alkaline extraction reinforced with oxygen and hydrogen peroxide (EP), a chlorine dioxide stage (D1), and a final hydrogen peroxide stage (P) (Tab. 1). This sequence was designed to maximize lignin removal while minimizing carbohydrate degradation and reducing chemical consumption. The combined action of oxidative and extraction stages enhances delignification and brightness development throughout the process. Analyses included chemical characterization of wood sawdust and bleached pulp, as well as intrinsic viscosity and brightness, to evaluate final pulp quality, process performance, and the preservation of cellulose integrity.

Tab. 1: Kraft pulp ECF bleaching sequence (O/O) – D/A – (EP) – P.

Step	O/O	D/A	EP	D_1	P
Consistency (%)	12	12	12	12	12
Time (min)	15/90	120	90	90	90
Temperature (°C)	15/100	90	80	80	80
Kappa factor	1.3	0.16	-	-	-
ClO_2 (kg/Adt)	-	*	-	**	-
O_2 (kg/Adt)	17.65	-	-	-	-
H_2O_2 (kg/Adt)	-	-	4	-	3
H_2SO_4 (kg/Adt)	-	8.1	-	-	-
$MgSO_4$ (kg/Adt)	3	-	-	-	-
NaOH (kg/Adt)	22.01*	-	7	-	4

*ClO_2 specific load varies according kappa number of the kraft pulp. **ClO_2 specific load were 0.45, 1.35, 2.7.

RESULTS AND DISCUSSION

Modified kraft pulping – ranking

Among the six best-ranked clones, two are hybrids of *Corymbia citriodora* × *Corymbia torelliana*, while the others belong to Eucalyptus spp. Sample identification is presented in Tab. 2. Sample ID4 showed the highest ranking, due to its superior mean annual increment of cellulose (MAICel) and lowest specific wood consumption (SWC), being classified as a “super clone”.

Tab. 2: Identification, main sawdust chemical components, SWC, MAICel and ranking.

Parameter	Sample					
	ID 3	**ID 4**	**ID 5**	**ID 8**	**ID 13**	**ID 16**
	Corymbia citriodora x Corymbia torelliana	*Corymbia citriodora x Corymbia torelliana*	*Eucalyptus cloeziana*	*Eucalyptus urophylla x Eucalyptus spp.*	*(E. camaldulensis x E. grandis) x E. urophylla*	*Eucalyptus urophylla x Eucalyptus pellita*
Total lignin	23.4	23.2	28.5	26.1	28.8	27.6
Glycans	48.1	48.6	50.3	48.2	49.7	47.3
Xylans	13.3	15.3	10.1	11.3	10.2	11.0
Soluble lignin (%)	2.8	2.9	2.1	2.4	2.5	1.8
Insoluble lignin (%)	20.7	20.3	26.4	23.7	26.3	25.8
S/G ratio	3.62	2.70	2.09	2.49	2.65	1.97
Uronic acids (%)	5.57	5.15	5.29	5.21	5.22	5.25
Acetone extractables (%)	1.11	1.24	2.92	2.41	1.62	0.95
SWC ($m^3.ADt^{-1}$) *	3.3	2.7	3.1	3.4	3.6	3.7
MAICel ($ADt.ha^{-1}.year^{-1}$)*	15.6	24.6	14.8	17.5	14.8	14.7
Ranking **	4.7	9.0	4.8	5.1	4.1	4.0

*Values based on kraft pulp, respectively mean annual increments of cellulose (MAI_{Cel}) and specific wood consumption (SWC); ** Ranking was established by MAI_{Cel} /SWC ratio.

Wood chemical characterization

The comparison of carbohydrate and lignin contents in sawdust from the different samples is presented in (Tab. 2). Corymbia spp. exhibited higher xylan and lower total lignin contents than Eucalyptus spp. In market pulp production, lower lignin content is associated with reduced chemical consumption during kraft delignification.

Kraft pulp characterization

Pulp viscosity is related to the degree of polymerization of cellulose and hemicelluloses, reflecting carbohydrate degradation (Jardim et al. 2018). The intrinsic viscosity of unbleached pulps (Tab. 3) was higher for Corymbia spp. than for Eucalyptus spp. Higher initial brightness may reduce chlorine dioxide (ClO_2) consumption during bleaching; accordingly, Corymbia ID3 and Eucalyptus ID13 and ID16 showed the highest brightness values.

Tab. 3: ECF bleaching main parameters from sequence (O/O) – D/A – (EP) – P.

Parameter	Sample					
	ID 3	ID 4	ID 5	ID 8	ID 13	ID 16
Kraft pulp brightness (% ISO)	37.45	33.45	35.02	35.85	37.55	37.42
Kraft pulp intrinsic viscosity (dm^3/kg)	1411	1415	1156	1275	1158	1055
Kraft pulp kappa #	18.8	18.6	18.9	18.8	19.1	19.0
Kraft-(O/O) pulp brightness (% ISO)	55.6	50.3	51.3	51.7	54.5	51.5
Kraft-(O/O) pulp intrinsic viscosity (dm^3/kg)	1130	1177	1011	1132	1042	1091
Kraft- (O/O) pulp kappa #	8.5	9.1	10.1	9.6	9.3	10.2
(O/O)-stage efficiency (%) (Δkappa #/Ki *100)	54.8	51.1	46.6	48.9	51.3	46.3
Final intrinsic viscosity*	835	913	711	765	722.5	728
Final kappa #	1.9	1.6	1.9	1.8	1.7	1.7
Selectivity (Δkappa #/ $\Delta[\eta]$)	0.02	0.03	0.03	0.02	0.024	0.023
Bleachability (Δkappa #/%ClO_2 @90%ISO)	0.591	0.499	0.437	0.477	0.519	0.423

*at ClO_2 (0,45 kg/Adt).

ECF pulp bleaching sequence (O/O) – D/A – (EP) – P

Chlorine dioxide (ClO_2) is the main reagent in ECF bleaching, used to achieve the brightness levels required by the market (Pinto et al. 2016). Oxygen delignification efficiency, presented in Table 3, is a key performance indicator of the process, with sample ID3 showing the highest efficiency. This sample also exhibited greater brightness development during the D1 and P stages compared to the others. In the D1 stage, ID3 reached brightness values above 90% ISO at a ClO_2 charge of 1.35 kg/Adt (Fig. 1a). In the P stage, all samples achieved approximately 90% ISO at the lowest ClO_2 charge (0.45 kg/Adt) (Fig. 1b).

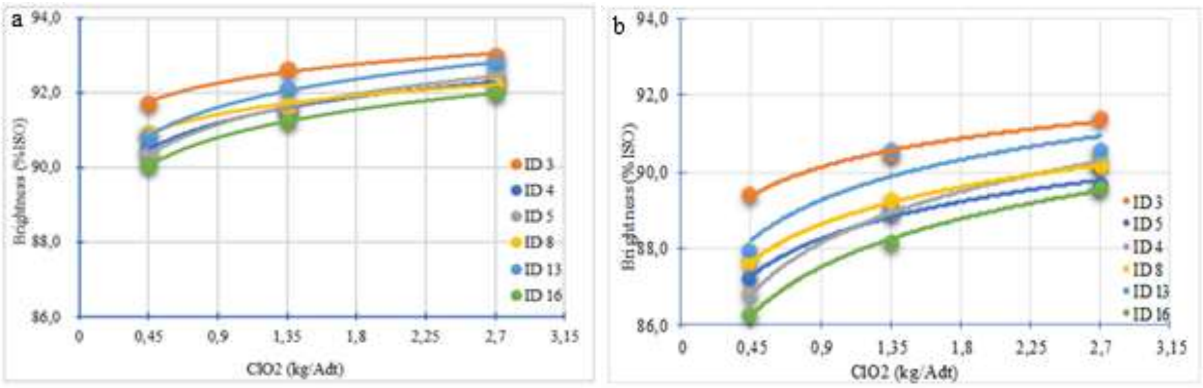

Fig. 1: Relation between ClO_2 load added and brightness on D_1 stage and (a) and Relation between ClO_2 load added and brightness on P stage (b).

Selectivity analysis

Considering that selectivity is inversely related to viscosity loss, it was observed that sample ID8 presented the lowest selectivity due to the highest viscosity loss during the process ($\Delta[\eta] = 367$). In contrast, the highest selectivity was observed for sample ID4, which exhibited the lowest viscosity loss ($\Delta[\eta] = 265$) (Tab. 3).

Bleached pulp quality parameters

Intrinsic viscosity (Tab. 3) is an important parameter of pulp quality. Corymbia hybrids (ID3 and ID4) showed higher intrinsic viscosity than Eucalyptus, even at the lowest ClO_2 charge (0.45 kg/Adt), indicating lower carbohydrate degradation and potential improvement in mechanical properties. Carbohydrate composition (Tab. 4) showed that Corymbia hybrids had the highest xylan content, while clone ID5 presented the highest glycan content. Higher xylan content may improve refining behaviour and enhance the physical-mechanical properties of the final paper.

Tab. 4: ECF bleached pulp chemical composition.

Sample	Extractives (%)	Carbohydrates (%)					Ashes (%)	Silica (%)
		Arabinans	Galactans	Glucans	Xylans	Mannans		
ID 3	0.16	0	0.3	89	15.5	0	0.53	0.03
ID 4	0.16	0	0.2	78.6	16.4	0	0.46	0.05
ID 5	0.17	0	0.3	93.3	12.1	0	0.29	0.03
ID 8	0.18	0	0.3	83.5	12.6	0	0.45	0.06
ID 13	0.16	0	0.3	85.3	11.4	0	0.33	0.03
ID 16	0.14	0	0.3	85.2	11.7	0	0.34	0.03

Discussion

Corymbia clones showed lower insoluble lignin and higher soluble lignin than Eucalyptus. S-type lignin (syringyl units), due to its less condensed structure and higher reactivity, is more susceptible to cleavage, whereas G-type lignin is more condensed and more resistant (Lopes et al. 2023). Uronic acids (4-O-methylglucuronic acids) are partially converted into hexuronic acids (HexA) during kraft pulping, which help preserve yield by protecting carbohydrates from excessive degradation but increase bleaching chemical demand, especially in ECF sequences (Rosenau et al. 2017; Fearon et al. 2020).

Bleachability reflects the efficiency of chlorine dioxide consumption per unit of kappa number reduction. Sample ID3 showed the best bleaching performance (Tab. 3). The process significantly reduces lipophilic extractives, with an average reduction of approximately 87% (Lehr et al. 2021; Sriranganadane et al. 2021). Extractives and silica contents were similar between Corymbia and Eucalyptus, while Corymbia showed slightly higher ash content (0.3–0.4%), consistent with literature values for bleached hardwood pulps (Segura 2015; Vieira et al. 2021).

Lignin content influences bleaching, as higher levels increase resistance to delignification and chemical consumption (Starrsjö et al. 2021; He et al. 2023). Although ID4 presented the lowest lignin content (Tab. 2), ID3 showed superior bleaching performance (Tab. 3). This indicates that lignin content alone does not determine bleaching efficiency, and structural factors must be considered. The higher syringyl/guaiacyl (S/G) ratio in ID3 likely explains this behaviour, as syringyl units form less condensed structures, facilitating bond cleavage and increasing susceptibility to chemical degradation (Rosado et al. 2023; Zhu et al. 2025).

These characteristics reduce chemical and energy consumption during kraft cooking and bleaching, allowing lower kappa numbers and reduced chemical demand, since a significant fraction of lignin is removed in earlier stages (Henriksson et al. 2024; Mboowa 2021; Almeida et al. 2022; Bonfatti Júnior & Silva Júnior 2025).

CONCLUSIONS

Corymbia spp. hybrids showed high forestry and industrial potential for bleached hardwood kraft pulp production, with superior performance compared to Eucalyptus spp. at 6.5 years. Sample ID4 (*Corymbia citriodora* × *Corymbia torelliana*) achieved the highest ranking due to its greater mean annual increment of pulp and lower specific wood consumption, being classified as a super clone under the same age and site conditions. Sample ID3 showed the best ECF bleaching performance, with higher bleachability, oxygen delignification efficiency, and favourable xylan content in the final pulp. This performance is associated with its higher syringyl/guaiacyl (S/G) ratio. In addition, Corymbia clones (ID3 and ID4) presented higher intrinsic viscosity and xylan content, representing an important advantage from an industrial and commercial perspective.

ACKNOWLEDGMENTS

This study was conducted with the support of the Coordination for the Improvement of Higher Education Personnel - Brazil (CAPES), Federal University of Viçosa (UFV), Department of Forest Engineering (DEF-UFV) and the Pulp and Paper Laboratory (LCP UFV).

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