HJTAS
Holistic: Journal of Tropical Agriculture Sciences
HJTAS 2(2): 112–126
ISSN 3025-4272

Institute for Advanced Science, Social and Sustainable Future
MORALITY BEFORE KNOWLEDGE

Yield and physical pulp properties of three *Eucalyptus Pellita F. Muell* clones at two active alkali concentrations: A study in tropical agriculture practices

Rian Palimirmo Adi[1]*, Sri Nugroho Marsoem[1], Ganis Lukmandaru[1]
[1] *Faculty of Forestry, Universitas Gadjah Mada, Sleman, Special Region of Yogyakarta, 10430, Indonesia.*
*Correspondence: rian.palimirmo.ac@gmail.com

Received Date: December 10, 2024 Revised Date: January 10, 2025 Accepted Date: January 31, 2025

ABSTRACT

Background: Efforts to enhance the genetic quality of Eucalyptus pellita F. Muell by PT. Riau Andalan Pulp and Paper included breeding several clones to optimize raw materials for pulp and paper production. Three clones—CEP06, CEP13, and CGP32—were selected to determine their potential based on pulp yield and physical properties. **Methods:** The wood samples from these clones were cooked using the sulfate process with active alkali concentrations of 13% and 15%, 25% sulfidity, a wood-to-liquor ratio of 1:4, a cooking temperature of 170°C, and a cooking duration of 2 hours. Pulp yields, kappa numbers, and pulp properties, including tear, burst, and tensile indices, were analyzed. Statistical analysis employed Analysis of Variance (ANOVA) and Honestly Significant Difference (HSD) tests. **Findings:** The clones CEP13 and CGP32 achieved higher screened yields at 38.34% and 38.26%, respectively, compared to CEP06. However, CEP06 demonstrated superior tear and burst indices of 6.36 $mN \cdot m^2/g$ and 3.60 $kPa \cdot m^2/g$, respectively. The highest tensile index of 41.75 Nm/g was observed in the CGP32 clone. Significant differences were found among the clones in terms of screened yield, kappa number, and certain pulp properties. Additionally, active alkali concentrations significantly affected the screened yield and kappa number, with interactions between clones and alkali concentrations significantly influencing kappa numbers. **Conclusion:** The CEP06 clone is recommended for pulp and paper production due to its favorable pulp properties, making it an excellent raw material candidate. **Novelty/Originality of this article:** This study highlights the potential of Eucalyptus pellita clones in optimizing raw materials for pulp and paper industries, emphasizing their specific advantages and contributions to sustainable forestry practices.

KEYWORDS: *eucalyptus pellita*; pulp properties; sulfate process; active alkali; clone performance.

1. Introduction

Industrial Forest Plantations (IFPs) are the primary source of raw materials for pulp and paper production by PT. Riau Andalan Pulp and Paper (RAPP). Among the various species cultivated in IFPs, *Eucalyptus pellita* F. Muell is particularly advantageous due to its short rotation period (7–8 years), rapid growth, straight trunk, high tolerance to different soil types, strong resistance to pests and diseases, and ease of cultivation (Harwood, 1998). This species is cultivated not only in Indonesia but also in other countries, including Australia and Brazil. Efforts to improve the genetic quality of *Eucalyptus pellita* have been undertaken through breeding programs in Australia, Brazil, and Indonesia, aiming to

Cite This Article:
Adi, R. P., Marsoem, S. N., & Lukmandaru, G. (2025). Yield and physical pulp properties of three Eucalyptus Pellita F. Muell clones at two active alkali concentrations: A study in tropical agriculture practices. *Holistic: Journal of Tropical Agriculture Sciences, 2*(2), 112-126. https://doi.org/10.61511/hjtas.v2i2.2025.1638

produce trees with higher productivity and consistent quality (Guimarães et al., 2010; Menucelli et al., 2019; Kartikaningtyas et al., 2020). Since 2016, PT. RAPP has initiated similar breeding programs by cultivating several clones, such as CEP06, CEP13, and CGP32, in experimental gardens located in Riau Province, Indonesia. These efforts are intended to increase wood production with superior quality to meet the growing demand for pulp raw materials. To determine whether these clones provide high-quality results, it is essential to evaluate their wood properties.

Previous studies have demonstrated significant differences in wood properties across clones, which can influence their industrial applications. For instance, Sharma et al. (2015) identified significant variations in basic density, fiber length, fiber diameter, and fiber wall thickness between two hybrid clones of Eucalyptus (E. grandis × E. urophylla) grown in India. Similarly, Kim et al. (2008) reported notable differences in basic density and fiber length among six hybrid acacia clones (BV5, BV10, BV16, BV29, BV32, and BV33) cultivated in Vietnam. Veenin et al. (2005) observed significant differences in basic density and fiber diameter among five clones of Eucalyptus camaldulensis (clones T5, Kitti, S9, Y2, and K2) grown in Thailand. In Indonesia, significant differences in fiber length and basic density among three clones (D14, F35, and F21) of Tectona grandis. The further highlighted significant variations in the fiber and chemical properties of hybrid acacia clones (A. mangium × A. auriculiformis) in Indonesia. Apart from wood properties, variations among clones also significantly affect the characteristics of pulp produced during cooking.

Several studies have examined the differences in pulp properties among clones. Ramirez et al. (2009) found significant variations in pulp yield and physical properties among 14 clones of Eucalyptus globulus. It is reported that differences in pulp yield among six hybrid Eucalyptus clones (clones 5, 11, 12, 15, 18, and 19). Labosky et al. (1982) observed significant differences in the physical properties of pulp among three hybrid poplar clones (NE50, NE-252, and NE-388). Such findings highlight the importance of evaluating the quality of pulp produced from different clones of *Eucalyptus pellita*.

In pulp and paper production, the sulfate or kraft process is one of the most widely used methods globally. This process is particularly effective due to its ability to produce high-strength pulp, compatibility with various wood species, efficiency in chemical recovery cycles, and tolerance to bark (Bajpai, 2012; Shmulsky & Jones, 2019). Key variables in the sulfate pulping process include cooking liquor concentration (active alkali and sulfidity), cooking time, and temperature. Biermann (1996) noted that effective active alkali concentrations in sulfate pulping range from 12% to 18%, with significant effects on screened yield (Lukmandaru et al., 2002). Darmawan et al. (2020) utilized 16% active alkali in sulfate pulping of *Eucalyptus pellita*, achieving a screened yield of 52.84%. Similarly, Anggraeny & Marsoem (2013) found that 14% and 16% active alkali concentrations yielded screened yields of 31.78% and 40.91%, respectively. However, these studies focused solely on single clones of *Eucalyptus pellita*.

This study evaluates the pulp yield and physical properties of three *Eucalyptus pellita* clones (CEP06, CEP13, and CGP32) using two active alkali concentrations (13% and 15%). By reducing the alkali concentration, this study aims to conserve chemicals, minimize waste pollution, and identify the optimal conditions for sulfate pulping. The findings provide critical insights into the influence of clone variations and alkali concentrations on pulp properties, serving as a basis for selecting the best clones and cooking conditions for industrial applications.

2. Methods

2.1 Research materials

The raw materials used in this study are three clones of *Eucalyptus pellita* F. Muell, namely clones CEP06, CEP13, and CGP32. These clones, aged 2.5–2.8 years, were sourced from PT. Riau Andalan Pulp and Paper, Kabupaten Kuantan Singingi, Riau Province. The clones have been planted on operational land as a result of a selection process. The wood

was felled in log form, and discs were taken from the logs ranging from 1.5 meters to 3 meters above the ground. The disc samples used in the study have a diameter of 12–13 cm and a thickness of 3 cm. A photo of the disc wood is available in Appendix 23.

The study includes wood anatomical properties, lignin content, pulp yield, and the physical properties of the resulting pulp sheets. The chemicals used for analyzing the anatomical properties and fiber maceration include glacial acetic acid (CH_3COOH) and hydrogen peroxide (H_2O_2), which serve to break down the fibers, safranin solution as a fiber stain, xylene solution for removing alcohol and bubbles from the preparations, and Canada balsam solution for affixing the preparations onto object glasses. The wood chips were ground into wood powder. The wood powder was used for extractive content analysis, while the extractive-free wood powder was used for lignin content analysis.

The cooking process to convert the wood into pulp was performed using the sulfate process with a cooking solution containing sodium hydroxide (NaOH) and sodium sulfide (Na_2S). For chemical testing, deionized water, 10% barium chloride ($BaCl_2$), 0.1 N hydrochloric acid (HCl), 0.1 N potassium permanganate ($KMnO_4$), 0.2 N sodium thiosulfate ($Na_2S_2O_3$), 10% potassium iodide (KI), 4 N sulfuric acid (H_2SO_4), methyl orange, and 0.2% starch solution were used. The chemicals used in extractive content analysis were toluene ethanol, and sulfuric acid 72% was used for lignin content analysis.

2.2 Material sampling

This study was conducted from August 2020 to December 2020. The cooking and pulp production processes were carried out at the Wood Processing Laboratory, Faculty of Forestry, UGM. The stages of moisture content testing, lignin content, kappa number, active alkali consumption, and the physical properties of the resulting pulp sheets were conducted at the Chemical Conversion Laboratory, Sub Lab Wood Pulp, Faculty of Forestry, UGM. The raw materials for this study were three clones of *Eucalyptus pellita* F. Muell, namely CEP06, CEP13, and CGP32.

These materials were obtained in disc form with a diameter of 12–13 cm and a thickness of 3 cm, as shown in Appendix 23. The discs were then cut into chips measuring 3 cm in length, 3 cm in width, and 2–3 mm in thickness. The chips were shade-dried to achieve equilibrium moisture content before their moisture levels were measured using an oven.

2.3 Fiber maceration and measurement

Maceration samples were prepared by cutting chips into matchstick-sized pieces (3×0.2×0.2cm) along the longitudinal direction, with three replicates. Sampling was conducted randomly from the pith to the bark region of the wood disc. The maceration process involved heating the samples in test tubes containing a solution of glacial acetic acid (CH_3COOH) and hydrogen peroxide (H_2O_2) in a 1:20 ratio. Heating continued until the samples swelled and turned white. The samples were then rinsed with clean water, stained with safranin, and left for one day to allow the fibers to develop a red hue for easier observation. The stained fibers were prepared as slides and photographed using an Olympus digital microscope.

Fiber length, diameter, lumen diameter, and cell wall thickness were measured using maceration slides with a 4x objective lens. The Image Pro Plus software was used to analyze the images. Calibration was performed by selecting the measurement calibration menu and adjusting the image scale. Fiber length was measured using the trace feature, while fiber diameter, lumen diameter, and wall thickness were measured with the line feature. A total of 100 fibers per clone were measured, with diameter, lumen diameter, and wall thickness evaluated at three sections (base, middle, and tip) of each fiber. Fiber diameter was determined by measuring the outermost edges, lumen diameter was assessed at the outer lumen walls, and wall thickness was calculated as the difference between fiber and lumen diameters divided by two. Data were exported to Microsoft Excel for further analysis.

2.4 Determination of raw material moisture content and specific gravity

Moisture content was determined by comparing the water weight in the wood to the oven-dry weight. This step ensured the equivalence of air-dried raw material to oven-dry material for pulp production. Random samples of approximately 5 grams were taken, with three replicates. The moisture content was expressed as the percentage of the wet weight minus the oven-dry weight relative to the oven-dry weight, calculated as

$$MC\ (\%) = \frac{Ww-g}{g} \times 100\% \quad \text{(Eq. 1)}$$

MC is the moisture content (%), Ww is the initial sample weight (g), and Wod is the oven-dry sample weight (g). The drying oven and sample measurement process for the three *Eucalyptus pellita* clones. Then, specific gravity was measured on oven-dried wood chips using a water displacement method. Chips were immersed in water in a graduated cylinder placed on an analytical balance. A pin and stand stabilized the sample during immersion, ensuring the balance was zeroed beforehand. The wet volume was indicated by the weight shown on the balance after immersion. Specific gravity was calculated following TAPPI Standard T258, using the oven-dry weight and wet volume with the formula:

$$Specific\ gravity\ of\ wood = \frac{Dried\ wood\ chips\ weight}{Wet\ wood\ volume} \quad \text{(Eq. 2)}$$

2.5 Lignin content, raw material, cooking process and pulp washing

Lignin content was analyzed using the Klason method following SNI 0492-2008. Approximately 1 gram of extractive-free wood powder was weighed into a 50 ml beaker and mixed with 15 ml of 72% H_2SO_4, stirred slowly for two hours, and then dissolved in a 20°C water bath. The dissolved sample was transferred to an Erlenmeyer flask, diluted with distilled water to 575 ml, and heated gently for four hours to maintain a constant volume. The residue was filtered, washed with hot water, and dried at 100 ± 3°C for three hours. After cooling in a desiccator, the residue was weighed, and lignin content was calculated as:

$$Lignin\ content\ (\%) = \frac{Weight\ of\ dry\ sludge}{Sample\ dry\ weight} \times 100\% \quad \text{(Eq. 3)}$$

Raw material weighing ensured equivalence to 300 grams of oven-dried material for each cooking process. The air-dried material required was calculated using the formula.

$$Weight\ of\ raw\ material\ for\ each\ cooking\ (gr) = \left(1 + (\frac{water\ content}{100})\right) \times 300\ g \quad \text{(Eq. 4)}$$

The cooking solution was prepared by mixing NaOH (13% or 15%) and Na_2S (25%) at a 4:1 ratio to the raw material. The raw materials were soaked in this solution for 10 minutes, with stirring every 5 minutes to ensure uniform penetration. After soaking, the materials were transferred into an autoclave, sealed tightly, and moved to a rotary digester. The temperature was gradually raised to 1Z70°C, and the autoclave valve was opened briefly to release pseudo-air pressure, replacing it with pressure generated by the reaction of NaOH and Na_2S. The cooking process continued at 170°C for 2 hours, after which the rotary digester was turned off, and the autoclave valve was opened to release the internal pressure. The cooked pulp was then removed for washing.

After cooking, the pulp was washed using a 100-mesh sieve and clean water in a 50L bucket to remove black liquor, which was collected for alkali consumption analysis. The pulp was then screened using a flat screen to separate mature pulp from impurities and immature chips. The filtered pulp was collected on a 100-mesh wire sieve, with the retained pulp classified as screened yield and the rejected pulp as "reject." Both screened pulp and

reject were gently pressed to reduce water content, wrapped in plastic, and weighed to determine yield percentages.

2.6 Determination of pulp moisture content and pulp yield

The moisture content is determined by randomly selecting a 5-gram sample of screened pulp, with three replicates conducted to ensure accuracy. The sampled pulp is then dried in an oven until it reaches a constant weight. The moisture content is calculated using the following formula (Marsoem, 2012) where *MC* represents the moisture content, *Ww* is the initial weight of the sample, and g is the oven-dried weight of the sample.

$$MC\ (\%) = \frac{Ww-g}{g} \times 100\% \qquad \text{(Eq. 5)}$$

In addition, the yield is assessed by comparing the oven-dried weight of the pulp to the oven-dried weight of the raw material (chips). The yield percentage is determined using the following formula (Marsoem et al., 2009). These calculations play a crucial role in evaluating the efficiency of the pulp production process by ensuring consistent quality and optimizing material utilization.

$$Yield\ (\%) = \frac{Pulp\ tannery\ dry\ weight}{Raw\ material\ tannery\ dry\ weight} \times 100 \qquad \text{(Eq. 6)}$$

2.7 Testing of black liquor

The black liquor test assesses active alkali consumption during the cooking process. Black liquor collected in a 600 ml bottle is measured at 25 ml and mixed with 25 ml of 10% $BaCl_2$ in a 500 ml graduated cylinder, diluted with distilled water to 500 ml, and left to settle for approximately one day. After settling, 25 ml of the clear solution is pipetted into an Erlenmeyer flask, with 5 drops of methyl orange added as an indicator. The mixture is then titrated with 0.1 N HCl until a pink color appears. Residual alkali and alkali consumption are calculated using the formulas.

$$Remaining\ alkali = \frac{A}{B \times C} \times V1 \times V2 \times N\ HCl\ \times 31 \qquad \text{(Eq. 7)}$$

A represents the volume of the precipitated solution (ml), B is the volume of the clear solution (ml), C denotes the volume of $BaCl_2$ (ml), V_1 is the volume of collected black liquor (l), V_2 is the titration volume of HCl (ml), and N_hCl refers to the normality of HCl. S_1 represents the initial active alkali concentration multiplied by the oven-dried weight of chips (g), S_2 is the residual alkali (g), and W refers to the oven-dried weight of chips. These calculations are crucial for assessing chemical utilization during the pulping process, ensuring optimal efficiency and resource management.

$$Alkali\ consumption = \frac{S1-S2}{W} \times 100\% \qquad \text{(Eq. 8)}$$

2.8 Determination of pulp kappa number

The kappa number measures the volume of 0.1 N potassium permanganate solution absorbed by one gram of oven-dried pulp, indicating the degree of maturity and delignification. Testing follows SNI 0494:2008. Approximately 3 g of oven-dried pulp is mixed with 500 ml of distilled water, stirred for 15 minutes, and further diluted to 795 ml. Then, 100 ml of 0.1 N $KMnO_4$ and 100 ml of 4 N H_2SO_4 are added. The solution is titrated with 0.2 N sodium thiosulfate ($Na_2S_2O_3$) until it turns straw yellow, followed by the addition of three drops of starch solution. The titration continues until the solution becomes clear. The kappa number is calculated as:

$$K\ (Kappa) = \frac{p \times f}{w} \quad \text{(Eq. 9)}$$

f represents the correction factor based on the p-value, w is the oven-dried sample weight, and p is the volume of $KMnO_4$ absorbed (ml). The value of p is obtained using the equation. b is the $KMnO_4$ volume in blank titration (ml), a is the $KMnO_4$ volume in sample titration (ml), and N represents the normality of $Na_2S_2O_3$. The correction factor (f) is determined after obtaining the p value by referring to the correction factor table, which provides appropriate values based on p. This calculation is essential in assessing pulp quality, as the Kappa number indicates the residual lignin content, influencing the bleaching process and final pulp properties.

$$p = \frac{(b-a)N}{0{,}1} \quad \text{(Eq. 10)}$$

Table 1. f score and p score references

P score	f score									
	0	1	2	3	4	5	6	7	8	9
30	0.958	0.960	0.962	0.964	0.966	0.968	0.97	0.972	0.974	0.976
40	0.978	0.981	0.983	0.985	0.987	0.991	0.994	0.994	0.996	0.998
50	1.000	1.002	1.004	1.006	1.009	1.011	1.013	1.013	1.017	1.019
60	1.022	1.024	1.026	1.028	1.030	1.033	1.033	1.037	1.039	1.042
70	1.044									

If the p value falls outside the range specified in the table, the kappa number is calculated using the following equation:

$$log\ log\ K = log\ log\ (\frac{p}{w}) + 0{,}00093(p - 50) \quad \text{(Eq. 11)}$$

If no water bath is used during the test, the reaction temperature is measured after 5 minutes of reaction, which is assumed to represent the average reaction temperature during testing. If the temperature does not exceed 30°C, the kappa number is calculated as follows. t represents the actual reaction temperature (°C), p is the volume of $KMnO_4$ absorbed by the sample (ml), f is the correction factor, and w is the weight of the oven-dried sample (g). This formula accounts for temperature variations during the reaction, ensuring accuracy in determining the lignin content in the pulp. The Kappa number serves as a key indicator in assessing pulp quality, influencing bleaching efficiency and final product properties.

$$K = \frac{p \times f}{w}[1 + 0{,}013(25 - t)] \quad \text{(Eq. 12)}$$

2.9 Pulp milling, sheet production, and physical properties

Pulp milling is performed using a Niagara Beater to flatten fibers. Freeness, indicating water retention after standard screening, is measured using a Canadian Standard Freeness Tester, per SNI 14-0490-1989-A. The target freeness value is 200–300 CSF. Then, pulp sheets are prepared using a Handsheet Machine, forming sheets with a diameter of 15.9 cm and a basis weight of 80 g/m^2.

Sheets are pressed and made following SNI 14-0489-1989-A. In this study, the physical properties of pulp sheets to be tested include tensile strength, burst strength, and tear strength. Prior to testing, the prepared pulp sheets are conditioned following the procedure outlined in SNI 14-0498-1989-A.

2.10 Tensile strength and tensile index

Tensile strength refers to the sheet's resistance to pulling forces applied to both ends under standard conditions. The tensile index is the tensile strength divided by the sheet grammage. This test is conducted using a Tensile Strength Tester, adhering to SNI 14-0437-1989-A. At least 10 test samples, each measuring 200 mm in length and 15 mm in width, are prepared.

Both ends of the sample are clamped vertically and subjected to a load. The machine is then operated, causing the pendulum and pointer to move until the sample breaks. The pointer reading indicates the tensile strength (kgf). The tensile strength is calculated as the average scale reading and expressed in kN/m. Conversion from 1 kgf/15 mm to kN/m is 0.6538. In SI units, the tensile index can be calculated using the formula:

$$Tear\ index\ \left(\frac{Nm}{g}\right) = \frac{Tensile\ resistance\ \left(\frac{N}{m}\right)}{Gramature\ \left(\frac{g}{m^2}\right)} \quad \text{(Eq. 13)}$$

2.11 Tear strength and tear index

Tear strength is the force in grams-force (*gf*) or millinewtons (mN) required to tear the paper under standard conditions. The tear index is the tear strength divided by the grammage. The test is performed using an Elmendorf Tearing Tester, following SNI 14-0436-1989. Samples measuring 76±2 mm in length and 63 ± 0.15 mm in width are prepared.

The sample is clamped horizontally and torn approximately 2 cm using the device's blade. The pointer on the scale is set to zero, and the clamp is released, allowing the pendulum to swing freely. The pointer reading represents the tear strength. The average tear strength is calculated using this formula.

$$Average\ tear\ strength\ (gf) = \frac{16 \times A}{B} \quad \text{(Eq. 14)}$$

A represents the average scale reading (*gf*), and B is the number of test sheets. To express the results in SI units, the value in gram-force (*gf*) is converted by multiplying by 9.807 to obtain the measurement in milliNewtons (mN). This conversion ensures consistency with international measurement standards, allowing for accurate comparisons and evaluations of material strength.

2.12 Burst strength

Burst strength is the force required to rupture the pulp sheet under standard conditions, expressed in kgf/m^2 or kilopascals (kPa). The burst index is calculated by dividing the burst strength by the grammage. This test is conducted using a Burst Tester, as outlined in SNI 14-0489-1989.

Pulp sheet samples measuring 62 x 62 mm are clamped in the tester. The pressure gauge is set to zero, and the pump is operated until the sheet ruptures. The pressure gauge is then returned to zero, and the scale reading is recorded.

The burst strength is averaged and converted to kPa using 1 kgf/cm2 = 98,07 kPa. The burst index is calculated as:

$$Index\ breakdown\ \left(kPa\frac{m^2}{g}\right) = \frac{Cracking\ Resistance\ (mN)}{Grammatical\ \left(\frac{g}{m^2}\right)} \quad \text{(Eq. 15)}$$

3. Results and Discussion

3.1 Fiber dimensions and derivatives of fiber dimensions from three clones of eucalyptus pellita F. Muell

The measured fiber dimensions include fiber length, fiber diameter, lumen diameter, and wall thickness. After obtaining these fiber dimensions, calculations were made to determine the derived fiber parameters such as Runkel ratio, Muhlsteph ratio, felting power, rigidity coefficient, and flexibility ratio. The table presents a comparative analysis of fiber dimensions and their derived parameters for three clones of *Eucalyptus pellita* and one clone of *Eucalyptus hibrida*. The measured fiber characteristics include fiber length, fiber wall thickness, and specific gravity, while the derived parameters consist of Runkel ratio, weaving power, Muhlsteph ratio, stiffness coefficient, and flexibility value. The results indicate variations among the clones, with notable differences in fiber dimensions and structural properties. These findings are essential in evaluating the suitability of different Eucalyptus clones for various industrial applications, such as pulp and paper production.

Table 2. Comparison of Fibers from Three Clones of *Eucalyptus pellita*

Criteria	*E. pellita*			*E. pellita*[b]	*E. hibrida*[c]
	CEP06	CEP13	CGP32		
Fibet length (mm)	1.17 (III*)	1.12 (III*)	1.12 (III*)	1.07 (III*)	1.23 (III*)
Fiber wall thickness (µm)	3.08	4.05	3.09	3.1	2.3
Specific gravity	0.46	0.59	0.47	0.64	-
Runkel Ratio	0.54 (III*)	0.92 (III*)	0.51 (III*)	0.82 (III*)	0.17 (I*)
Weaving power	65.01 (III*)	65.53 (III*)	59.03 (III*)	76.25 (II*)	48.07 (III*)
Muhlsteph Ratio (%)	55.72 (II*)	67.95 (III*)	53.43 (II*)	69.47 (III*)	31.86 (II*)
Stiffness coeffient	0.17 (III*)	0.22 (IV*)	0.16 (III*)	0.23 (IV*)	0.09 (I*)
Flexibility value	0.66 (II*)	0.55 (III*)	0.68 (II*)	0.54 (III*)	0.82 (I*)

Notes: *: Class and fiber dimension derivatives (Directorate General of Forestry, 1976), b: (Anggraeny & Marsoem, 2013), c: (Roliadi et al., 2010)

The fiber length of clones CEP06, CEP13, and CGP32 is longer, at 1.17 mm (class III), 1.12 mm (class III), and 1.12 mm (class III), respectively, compared to Anggraeny & Marsoem (2013), which reported 1.07 mm (class III), but shorter compared to Roliadi et al. (2010), which reported 1.23 mm (class III). According to the Directorate General of Forestry (1976), these lengths fall into the short fiber class. The fiber wall thickness for clones CEP06 and CGP32 is close to that found by Anggraeny & Marsoem (2013), but higher than Roliadi et al. (2010), while clone CEP13 has a thicker fiber wall than both studies.

The Runkel ratio for clones CEP06 and CGP32 is better than the values found by Anggraeny & Marsoem (2013), with lower values indicating thinner fiber walls and wider lumen diameters, which facilitate easier flattening. However, these clones show higher Runkel ratio values compared to Roliadi et al. (2010), and clone CEP13 has the highest due to thicker cell walls. All clones fall into class III based on the Directorate General of Forestry (1976) criteria.

The felting power values for the clones are lower than those in the study by Anggraeny & Marsoem (2013), but higher than those found by Roliadi et al. (2010). According to Anthonio & Antwi-Boasiako (2017), felting power values above 33 are acceptable for pulp raw material. All three clones fall into class III according to the Directorate General of Forestry (1976). The Muhlsteph ratio is lower for the three clones compared to Anggraeny & Marsoem (2013) but higher than Roliadi et al. (2010). A lower Muhlsteph ratio means a larger lumen diameter, which makes the fibers easier to flatten. Based on the Directorate General of Forestry (1976), clones CEP06 and CGP32 fall into class II, while clone CEP13 falls into class III.

The rigidity coefficient for clones CEP06 and CGP32 is lower than that found by Anggraeny & Marsoem (2013) but higher than Roliadi et al. (2010). Clone CEP13 has a higher value compared to both studies. A low rigidity coefficient indicates lower fiber density. According to the Directorate General of Forestry (1976), clones CEP06 and CGP32 fall into class III, while clone CEP13 falls into class IV.

The flexibility ratio for clones CEP06 and CGP32 is higher than that found by Anggraeny & Marsoem (2013), but lower than Roliadi et al. (2010). The flexibility ratio for clone CEP13 is lower than for the other two clones, but similar to Anggraeny & Marsoem (2013). According to Syafii & Siregar (2006), fibers with a high flexibility ratio have thinner walls and can change shape more easily, leading to better fiber bonding, resulting in stronger pulp sheets. Based on the Directorate General of Forestry (1976), clones CEP06 and CGP32 fall into class II, while clone CEP13 falls into class III.

3.2 Pulp yield of three clones of Eucalyptus pellita F. Muell

Pulp yield consists of screened yield and rejects. Pulp production for *E. pellita* F. Muell was carried out with three clones: CEP06, CEP13, and CGP32, with active alkali concentrations of 13% and 15%. The screening yield of sulfate pulp ranges from 30%-60%. The average screened yield for the three clones at 13% and 15% alkali concentrations is 31.55% and 41.48%, respectively.

Compared to Darmawan et al. (2020) with *E. pellita* (specific gravity: 0.47) and 16% active alkali concentration, which yielded 52.84%, the pulp yield for the three clones with 15% alkali concentration is still relatively low. However, these results are not far from the screened pulp yield found by Anggraeny & Marsoem (2013), with alkali concentrations of 14% and 16% and a specific gravity of 0.64, yielding 31.78% and 40.91%, respectively. This could be due to the lower specific gravity of the three *E. pellita* clones compared to the one used in Anggraeny & Marsoem (2013).

3.3 Alkali consumption and kappa number

The alkali consumption for the three clones of *E. pellita* ranges from 12.09% to 14.35%. This indicates that the chemicals used were not fully effective in the pulping process, as they did not reach the target alkali concentrations of 13% and 15%. According to Lukmandaru (2018), higher alkali absorption suggests that more alkali is being used to degrade lignin. To assess the remaining lignin content in the pulp, the kappa number was calculated.

The average kappa number for the pulping process with 13% and 15% active alkali concentrations were 18.61 and 10.01, respectively. According to Sixta (2006), the target kappa number for good sulfate pulp cooking is between 15-20 for hardwoods. The results with 13% active alkali meet the target, but those with 15% do not, suggesting that delignification may have been too high at this concentration, which could degrade pulp quality. Further examination of sulfidity, cooking ratio, temperature, and cooking time is needed to explain this discrepancy.

Compared to the kappa numbers reported by Anggraeny & Marsoem (2013) for *E. pellita* with active alkali concentrations of 14% and 16% (30.07 and 22.57, respectively), the delignification level for the three clones is already better. Darmawan et al. (2020) also found a kappa number of 16.69 at 16% active alkali concentration and 25-28% sulfidity, supporting the lower kappa number and lower lignin content for the three clones compared to Darmawan et al. (2020), where the lignin content was 28.09%.

3.4 Physical properties of pulp from three clones of Eucalyptus pellita F. Muell

The physical properties tested for the pulp sheets from the three clones of *E. pellita* include burst index, tear index, and tensile index. Grammage values were used for the calculations, with a target of 80 gsm and a refining degree between 200-300 CSF. Below is a comparison table for the physical properties of the pulp and fiber dimensions of the three

clones of *E. pellita.* Based on the results, it can be observed that the pulp from the three clones exhibited reasonable quality in terms of burst index, tear index, and tensile index, with values close to the standard specifications.

Table 3. Comparison of physical properties of pulp from three clones of *Eucalyptus pellita*

Criteria	*E. pellita*			*E. pellita*(b)	*E. globulus*(c)	SNI 6107:2015
	CEP06	CEP13	CGP32			
Tear index (mN.m^2/g)	6.35	5.20	5.11	1.13	7,8	5.5
Tear index (kPa.m^2/g)	3.55	2.11	2.64	1.91	5,6	2.5
Tensile index (Nm/g)	37.60	24.59	39.11	44.43	90	45

Notes: *: Class and Fiber Dimension Derivatives (Directorate General of Forestry, 1976), b: (Anggraeny & Marsoem, 2013), c: (Roliadi et al., 2010)

Based on Table 3, the tear index for clone CEP06 meets the SNI 6107:2015 standard, which is 5.5 mN·m^2/g, but the tear index for clones CEP13 and CGP32 does not meet this standard. The tear index of the three *E. pellita* clones is higher than that of *E. pellita* in the study by Anggraeny & Marsoem (2013). According to Syafii & Siregar (2006), a high tear index is influenced by high tensile strength, but the three clones have lower tensile strength compared to *E. pellita* in Anggraeny & Marsoem's study. It is suspected that the tear index value is influenced by the fiber morphology, particularly the fiber length (Biermann, 1996). Additionally, flexibility correlates positively with burst and tear strength (Takeuchi et al., 2016). The fibers of the three clones are longer and more flexible compared to *E. pellita* in the study by Anggraeny & Marsoem (2013).

From Table 3, it can be seen that the burst index of clones CEP06 and CGP32 meets the SNI 6107:2015 standard of 2.5 kPa·m^2/g. Compared to the *E. pellita* study by Anggraeny & Marsoem (2013), the burst index of the three clones is higher. This is suspected to be because the Runkel ratio of clones CEP06 and CGP32 is lower, except for clone CEP13, which is almost similar to the previous study. A lower Runkel ratio indicates thinner fiber walls, wider lumen diameters, easy fiber flattening, and higher burst strength in pulp sheet formation (Syafii & Siregar, 2006). Flexibility correlates positively with burst strength (Takeuchi et al., 2016), and the three clones have higher flexibility values than those in Anggraeny & Marsoem's study. The acceptable flexibility value for pulp and paper production is above 0.5 (Anthonio & Antwi-Boasiako, 2017), and all three clones have values above 0.5.

The tensile index of the three clones, does not meet the SNI 6107:2015 standard of 45 Nm/g. The tensile index of the three clones is also lower than that of *E. pellita* in the study by Anggraeny & Marsoem (2013). The tensile index is influenced by the wood morphology, particularly fiber length and wall thickness (Horn, 1978), with clone CEP13 having thicker fiber walls. This result is also supported by Shmulsky & Jones (2019), who noted that thicker fiber walls result in paper with lower burst and tensile strengths but higher tear strength. When comparing the Muhlsteph ratio, the values of the three clones are lower than those of *E. pellita* in Anggraeny & Marsoem's study. The Muhlsteph ratio depends on fiber wall thickness and affects tear, tensile, and pulp density (Sumardi et al., 2020). A low Muhlsteph ratio leads to better pulp sheet density and strength (Syafii & Siregar, 2006), which increases the burst and tear strength of the three *E. pellita* clones. However, their tensile indices are lower than those of *E. pellita* in Anggraeny & Marsoem's study. When compared to the study by Ramirez et al. (2009) with 25.4% lignin content, the pulp from E. globulus exhibited better physical properties than the three *E. pellita* clones, with a tear index of 7.8 mN·m^2/g, burst index of 5.6 kPa·m^2/g, and tensile index of 90 Nm/g.

3.5 Variability of test parameters in Eucalyptus pellita F. Muell Clones

The results of the study showed significant differences among the three *E. pellita* clones for fiber dimensions, fiber dimension derivatives, specific gravity, and lignin content. This is consistent with the findings of Sharma et al. (2015), Kim et al. (2008), Veenin et al. (2005),

and Kardiansyah & Marsoem (2018). Clone CEP06 has the longest fibers, thin fiber walls, low specific gravity, and superior tensile strength. Clone CGP32 has the lowest lignin content and excels in Runkel ratio, Muhlsteph ratio, stiffness coefficient, and flexibility.

Variance analysis did not show significant differences in active alkali consumption and tear index among the three *E. pellita* clones. The filtered yield showed significant differences between the clones, and the interaction between clone and active alkali concentration significantly affected filtered yield and kappa number. This is similar to the findings, variability in filtered yield among clones. Clone CEP13 with 13% active alkali concentration achieved the highest filtered yield. Clone CEP13 with 13% active alkali concentration showed the lowest kappa number. This suggests that clone CEP13 is more mature than the other two clones. Clones CEP13 and CGP32 show higher filtered yields of 38.34% and 38.26%, respectively, compared to clone CEP06 at 32.95%. Then, that the highest kappa number was obtained from clone CEP06 with 13% active alkali concentration (37.11), while the lowest kappa number was obtained from clone CEP13 with 13% active alkali concentration (6.57). According to Sixta (2006), the kappa number for hardwood is 15-20. It is suspected that excessive delignification caused a decrease in the kappa number, deviating from the target. It is increasing the active alkali concentration reduces the kappa number, but clone CEP13 with 15% active alkali concentration had a higher kappa number than with 13%, possibly due to its higher specific gravity and thicker fiber walls, which make chemical solutions harder to penetrate and diffuse into the fibers. Shmulsky and Jones (2019) suggested that woods with thick fiber walls and small lumen diameters are indicative of tension wood compared to normal wood. Clone CEP13 exhibits similar characteristics compared to the other two clones. However, it has higher lignin content, which contradicts Shmulsky & Jones (2019), who stated that lignin content in tension wood is lower than in normal wood. The findings by Aiso et al. (2013) report that increased lignin content in Gardenia jasminoides wood tends to form tension wood, which may explain similar phenomena in clone CEP13. Furthermore, the extractive content of the clones in Appendix 11 is higher than the other two clones, possibly inhibiting the cooking process at 15% active alkali concentration. Further exploration is needed to understand the impact of extractive components on clone CEP13.

Significant differences were observed among the three *E. pellita* clones for burst and tensile indices, but there was no significant interaction between active alkali concentration and clones. Labosky et al. (1982) reported significant differences among clones for tensile and tear strength, and Ramirez et al. (2009) also reported significant differences in anatomy, wood chemical components, and paper strength properties, which is consistent with the findings for the three clones. Regarding burst index, the average cooking results for clone CEP06 were the highest at 3.55 kPa·m^2/g, followed by CGP32 at 2.64 kPa·m^2/g, and CEP13 at 2.11 kPa·m^2/g. For the tensile index, the average cooking results for clones CEP06 and CGP32 were nearly the same, 37.60 Nm/g and 39.11 Nm/g, respectively, followed by clone CEP13 at 24.59 Nm/g. The lower burst and tensile indices of clone CEP13 are due to its higher Runkel ratio, Muhlsteph ratio, and stiffness coefficient compared to the other two clones. A higher Runkel ratio indicates stiffer, less flexible fibers and creates paper with lower fiber bonding areas, leading to lower burst and tensile strength (Shmulsky and Jones, 2019). A high Muhlsteph ratio indicates smaller fiber surfaces, resulting in fewer fiber-to-fiber bonds and lower burst and tensile strength. A higher stiffness coefficient leads to lower tensile strength (Aprianis & Rahmayanti, 2009). Clone CEP13 has thicker fiber walls than the other two clones, and thicker fiber walls result in paper with lower tensile strength (Shmulsky & Jones, 2019). According to Casey (1966), thicker fibers are difficult to flatten and retain their round shape during sheet formation, complicating the grinding process. Additionally, the high lignin content, as noted by Biermann (1996), can reduce paper strength, affecting the tensile strength of clone CEP13. This is supported by the kappa number data, which shows significant differences in alkali concentration and clone, along with lower active alkali consumption.

3.6 Variability of test parameters in active alkali concentration

The variance analysis shows significant differences between active alkali concentrations of 13% and 15% for filtered yield, reject, active alkali consumption, and kappa number. The filtered yields of the three clones ranged from 26.22% to 44.46%. That increasing the active alkali concentration resulted in increased filtered yield, but at 15% active alkali concentration, the filtered yield was lower than at 13%. This indicates that the fiber properties of the clones have reached their maximum efficiency for cooking with 13% active alkali concentration. The reject content increased with increasing active alkali concentration, and the consumption of active alkali increased with higher alkali concentration. The kappa number decreased with increasing active alkali concentration, with the lowest kappa number obtained from clone CEP13 at 13%. However, the kappa number increased when the active alkali concentration was raised to 15%, especially for clones CEP06 and CGP32.

4. Conclusions

The study on pulp yield and physical properties from three clones of *Eucalyptus pellita* at two alkali concentrations showed significant differences. The average yield of screened pulp was highest for clone CEP13 (38.34%) and CGP32 (38.26%), compared to CEP06 (32.95%). In terms of physical properties, clone CGP32 had the highest tensile index (39.11 Nm/g), while CEP06 exhibited the best tear index (6.35 $mN.m^2/g$) and burst index (3.55 $kPa.m^2/g$). Overall, CEP13 and CGP32 had higher yields, while CEP06 and CGP32 showed superior physical properties.

The interaction between clones and alkali concentration also resulted in significant differences in kappa number and various fiber characteristics, including dimensions, specific gravity, and lignin content. Significant variations in alkali consumption, screened yield, and reject were observed. These findings suggest that both clone selection and alkali concentration play key roles in optimizing pulp quality.

Acknowledgement
The authors expresses gratitude for the support and assistance provided during the completion of this research.

Author Contribution
All of authors was contribute equally and solely responsible for all aspects of this research, including conceptualization, data collection, analysis, and manuscript preparation.

Funding
This research received no external funding.

Ethical Review Board Statement
Not available.

Informed Consent Statement
Not available.

Data Availability Statement
Not available.

Conflicts of Interest
The authors declare no conflict of interest.

References

Aiso, H., Hiraiwa, T., Ishiguri, F., Iizuka, K., Yokota, S., & Yoshizawa, N. (2013). Anatomy and lignin distribution of "compression-wood-like reaction wood" in Gardenia jasminoides. *IAWA Journal, 34*(3), 262–272. https://doi.org/10.1163/22941932-00000032

Anggraeny, T., & Marsoem, S. N. (2013). Pengaruh konsentrasi alkali aktif terhadap rendemen dan sifat fisik pulp sulfat pada kayu teras dan gubal eukaliptus pelita (*Eucalyptus pellita*). *Thesis.* Universitas Gadjah Mada.

Anthonio, F., & Antwi-Boasiako, C. (2017). The characteristics of fibres within coppiced and non-coppiced rosewood (Pterocarpus erinaceus Poir.) and their aptness for wood- and paper-based products. *Pro Ligno, 13*(2), 27–39.. https://www.proligno.ro/en/articles/2017/201702.htm

Aprianis, Y., & Rahmayanti, S. (2009). Dimensi serat dan nilai turunan seratnya dari tujuh jenis kayu asal Provinsi Jambi. *Jurnal Penelitian Hasil Hutan, 29*(1), 11–20. https://doi.org/10.20886/jphh.2009.27.1.11-20

Bajpai, P. (2012). *Biotechnology for pulp and paper processing*. Springer Science & Business Media.

Biermann, C. J. (1996). *Handbook of pulping and papermaking* (2nd ed.). Academic Press.

Casey, J. P. (1980). *Pulp and paper: Chemistry and chemical technology* (Vol. 1: Pulping and bleaching, 3rd ed.). Wiley-Interscience.

Darmawan, A., Irawan, B., Ni'mah, H., Roesyadi, A., & Kurniawansyah, F. (2020). Delignification of abaca fiber (Musa textilis) as potential substitute for Eucalyptus pellita. *IOP Conference Series: Materials Science and Engineering, 857*, 1–8. https://doi.org/10.1088/1757-899X/857/1/012021

Directorate General of Forestry. (1976). Indonesian forestry vademecum. Directorate General of Forestry, Ministry of Agriculture

Guimarães, L. M. S., Titon, M., Lau, D., Rosse, L. N., Oliveira, L. S. S., Rosado, C. C. G., Christo, G. G. O., & Alfenas, A. C. (2010). Eucalyptus pellita as a source of resistance to rust, ceratocystis wilt and leaf blight. *Crop Breeding and Applied Biotechnology, 10*, 124–131. http://dx.doi.org/10.12702/1984-7033.v10n02a04

Harwood, C. E. (1998). *Eucalyptus pellita: An annotated bibliography*. CSIRO Forestry and Forest Products.

Horn, R. A. (1978). Morphology of pulp fiber from hardwood and influence on paper strength. U.S. Department of Agriculture.

Kardiansyah, T., & Marsoem, S. N. (2018). Dissolving pulp tiga klon akasia hibrida (*Acacia mangium* x *Acacia auriculiformis*) dari Wonogiri, Jawa Tengah. *Thesis*. Gadjah Mada, Yogyakarta.

Kartikaningtyas, D., Nirsatmanto, A., Sunarti, S., Setyaji, T., Handayani, B. R., & Surip. (2020). Trends of genetic parameters and stand volume productivity of selected clones of Eucalyptus pellita observed in clonal trials in Wonogiri, Central Java. *IOP Conference Series: Earth and Environmental Science,* 522. https://doi.org/10.1088/1755-1315/522/1/012005

Kim, N. T., Ochiishi, M., Matsumura, J., & Oda, K. (2008). Variation in wood properties of six natural acacia hybrid clones in Northern Vietnam. *Journal of Wood Science, 54*, 436–442. https://doi.org/10.1007/s10086-008-0970-3

Labosky, P., Bowersox, T. W., & Blankenhorn, P. R. (1983). Kraft pulp yields and paper properties obtained from first and second rotations of three hybrid poplar clones. *Wood and Fiber Science, 15*(1), 81–89. https://wfs.swst.org/index.php/wfs/article/view/132.

Lukmandaru, G., Marsoem, S. N., & Siagian, R. M. (2002). Kualitas kayu nilotika (*Acacia nilotica*) sebagai bahan baku pulp. *Prosiding Seminar Nasional V MAPEKI,* 397–402. [Unpublished Paper]

Lukmandaru, G. (2018). Pengaruh penambahan antrakinon terhadap sifat pulp dan lindi hitam proses sulfat pada kayu karet*. Prosiding Seminar Nasional Masyarakat Peneliti Kayu Indonesia XX*, 226–233. [Unpublished Paper]

Marsoem, S. N. (2012). *Buku Ajar Pulp dan Kertas*. Fakultas Kehutanan Universitas Gadjah Mada.

Menucelli, J. R., Amorim, E. P., Freitas, M. L. M., Zanata, M., Cambuim, J., de Moraes, M. L. T., Yamaji, F. M., Júnior, F. G. S., & Longui, E. L. (2019). Potential of Hevea brasiliensis clones, Eucalyptus pellita, and Eucalyptus tereticornis wood as raw materials for bioenergy based on higher heating value. *BioEnergy Research, 12*, 992–999. https://doi.org/10.1007/s12155-019-10040-9

Ramirez, M., Rodriguez, J., Balocchi, C., Peredo, M., Elissetche, J. P., Mendonça, R., & Valenzuela, S. (2009). Chemical composition and wood anatomy of *Eucalyptus globulus* clones: Variations and relationships with pulpability and handsheet properties. *Journal of Wood Chemistry and Technology, 29*(1), 43–58. https://doi.org/10.1080/02773810802626944

Roliadi, H., Dulsalam, & Anggraini, D. (2010). Penentu daur teknis optimal dan faktor eksploitasi kayu hutan tanaman jenis *Eucalyptus* hybrid sebagai bahan baku pulp. *Jurnal Penelitian Hasil Hutan, 28*(4), 332–357. https://doi.org/10.20886/jphh.2010.28.4.332-357

Sixta, H. (2006). *Handbook of pulp*. Wiley-VCH Verlag.

Sharma, S. K., Shukla, S. R., Shashikala, S., & Poornima, V. S. (2015). Axial variations in anatomical properties and basic density of Eucalyptus urograndis hybrid (E. grandis × E. urophylla) clones. *Journal of Forestry Research, 26*(3), 739–744. https://doi.org/10.1007/s11676-015-0091-8

Shmulsky, R., & Jones, P. D. (2019). *Forest products and wood science: An introduction* (7th ed.). Wiley-Blackwell.

Sumardi, I., Hadiyane, A., Rumidatul, A., & Melani, L. (2020). Characteristics of empty palm bunch fibers as alternative pulp material*. American Journal of Applied Sciences*, 17, 129–134. https://doi.org/10.3844/ajassp.2020.129.134

Syafii, W., & Siregar, I. Z. (2006). Sifat kimia dan dimensi serat kayu mangium (Acacia mangium Willd.) dari tiga provenans. *Journal Tropical Wood Science & Technology, 4(*1). https://doi.org/10.51850/jitkt.v4i1.286

Takeuchi, R., Wahyudi, I., Aiso, H., Ishiguri, F., Istikowati, W. T., Ohkubo, T., Ohshima, J., Iizuka, K., & Yokota, S. (2016). Wood properties related to pulp and paper quality in two Macaranga species naturally regenerated in secondary forests, Central Kalimantan, Indonesia. *TROPICS, 25*(3), 107–115. https://doi.org/10.1007/s10457-017-0171-9

TAPPI T404 OM-92. (1992). *TAPPI test methods: Tensile breaking strength and elongation of paper and paperboard (using pendulum type tester).* TAPPI Press.

Veenin, T., Fujita, M., Nobuchi, T., & Siripatanadilok, S. (2005). Radial variations of anatomical characteristics and specific gravity in Eucalyptus camaldulensis clones*. IAWA Journal, 26*(3), 353–361. https://doi.org/10.1163/22941932-90000116

Biography of Authors

Rian Palimirno Adi, Faculty of Forestry, Universitas Gadjah Mada, Sleman, Special Region of Yogyakarta, 10430, Indonesia.

- Email: rian.palimirmo.ac@gmail.com
- ORCID: N/A
- Web of Science ResearcherID: N/A
- Scopus Author ID: N/A
- Homepage: N/A

Sri Nugroho Marsoem, Faculty of Forestry, Universitas Gadjah Mada, Sleman, Special Region of Yogyakarta, 10430, Indonesia.

- Email: snmarsoem@ugm.ac.id
- ORCID: 0000-0002-0108-9372
- Web of Science ResearcherID: N/A
- Scopus Author ID: 35293122100
- Homepage: https://sinta.kemdikbud.go.id/authors/profile/6002244
-

Ganis Lukmandaru, Faculty of Forestry, Universitas Gadjah Mada, Sleman, Special Region of Yogyakarta, 10430, Indonesia.

- Email: ganisarema@lycos.com
- ORCID: 0000-0003-2203-4247
- Web of Science ResearcherID: N/A
- Scopus Author ID: 25629277200
- Homepage: https://sinta.kemdikbud.go.id/authors/profile/6001580