WOOD RESEARCH doi.org/10.37763/wr.1336-4561/67.5.847865
e-ISSN 2729-8906
67(5): 2022 847-865 pp.

EVALUATION OF THE CHARACTERISTICS OF *EUCALYPTUS PELLITA* AND *ACACIA* HYBRID SUPERIOR CLONES SELECTED FROM BREEDING PROGRAM IN INDONESIA AS MATERIALS FOR PULP AND PAPERMAKING

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RECEIVED FEBRUARY 2022

ABSTRACT

This study evaluates the characteristics of superior clones of *Eucalyptus pellita* and *Acacia* hybrid (*Acacia mangium* × *A. auriculiformis*) aged six years selected from a breeding program in Indonesia as materials for pulp and papermaking. Height, diameter, and wood density differed significantly between species and among the clones, with respective mean values 21.6 m, 12.57 cm, and 657 kg$\cdot$m^{-3} for *E. pellita* and 19.5 m, 24.83 cm, and 567 kg$\cdot$m^{-3} for *Acacia* hybrid. Most fiber morphologies were significantly different between species. Cellulose and lignin differed significantly only among *Acacia* hybrid clones. The mean value of screened pulp yield *Acacia* hybrid (52.50%) was higher than that of *E. pellita* (50.31%). Kappa number and brightness were significantly different between species and among *E. pellita* clones. Some correlations of growth and wood properties showed a better relationship to pulp properties. Handsheet properties varied between species, and some clones showed an outstanding one.

KEYWORDS: *Acacia*, *Eucalyptus*, tree breeding, wood properties, pulp yield, handsheet properties.

INTRODUCTION

The pulp and paper industry dominates Indonesia's forest industries. *Acacia mangium* was the most recognised species for planting in dry-land to supply raw materials for these industries (Harwood and Nambiar 2013, Arisman and Hardiyanto 2006, Turnbull et al. 1997, Pinyopusarerk et al. 1993). After the second rotations of the plantations, however, severe problems occurred, particularly in the face of serious threats to *A. mangium* posed by two devastating diseases of *Ganoderma* and *Ceratocystis* (Brawner et al. 2015, Harwood and Nambiar 2014, Harwood et al. 2015, Tarigan et al. 2011). To maintain the plantation's high productivity, it is critical to look into other potential species.

Eucalyptus pellita is currently replacing *A. mangium* as the best alternative species as it has been identified as a species with good adaptation and productivity on mineral soils suitable for the plantation areas in Indonesia (Nambiar et al. 2018, Inail et al. 2019). Another promising species is *Acacia* hybrid, an inter-specific crossing between *A. mangium* and *A. auriculiformis*, that has been reported to have high yields in Vietnam (Le and Ha 2017) and Malaysia (Ibrahim and Awang 1991). Some studies had suggested *E. pellita* and *Acacia* hybrid as potential species tolerant to the current major diseases affecting the *A. mangium* plantations (Guimaraes et al. 2010, Trang et al. 2017, Nasution et al. 2019).

For the past two decades, a breeding program to improve the productivity of *E. pellita* in Indonesia has been carried out, mostly through the establishment of first-generation progeny trials (Kurinobu and Rimbawanto 2002). The improved seed from such breeding has been proven as having a stand volume improvement of 17% to 38% over the unimproved seed (Handayani et al. 2020). Some plus trees were selected based on the improved growth and vegetative propagated for further clonal testing using the genetic base available in the first-generation breeding population. Some superior clones have been reported to have a greater stand volume productivity of more than 96% over a control stand established using improved seed from first-generation breeding (Kartikaningtyas et al. 2020).

Following the success of developing *Acacia* hybrid in Vietnam (Le and Ha 2017), *Acacia* hybrids breeding program was undertaken in Indonesia (Sunarti et al. 2013). A controlled crossing between *A. mangium* and *A. auriculiformis* was used to initiate the breeding process. Some *Acacia* hybrid progenies have been identified and further propagated for testing in a clonal trial. Some hybrid clones were later reported to have a 17% higher stand volume yield than the improved pure parent species of *A. mangium* (Sunarti et al. 2013).

The breeding program of *E. pellita* and *Acacia hybrid* has selected some superior clones based on the growth, but its wood quality and pulping properties have not been reported. This study aimed to evaluate the characteristics of superior clones of *E. pellita* and *Acacia* hybrid (*A. mangium* × *A. auriculiformis*) at 6 years of age selected from the breeding program as materials for pulp and papermaking.

MATERIAL AND METHODS

Breeding and clone selection

The breeding program of *E. pellita* was started in 1994 by establishing first-generation progeny trials in several sites in Indonesia, such as Sumatra, Kalimantan, and Java (Kurinobu and Rimbawanto 2002). The genetic base for the progeny trial was explored from wide ranges of natural distribution in Papua New Guinea and Australia with 115 individual seedlots. In the progeny trials, a series of genetic selections involving within and between family selections were practised to convert into seedling seed orchards for genetically improved seed production. Nine top-ranking plus-trees in the orchard were selected based on their improved growth and clonally propagated for testing in a clonal trial in Central Java (Tab. 1). The clonal trial was established under two series of plot configurations: single tree-plot and squared tree-plot. It was reported that three out of the nine clones, namely Ep006, Ep007, and Ep014 were considered as consistent superior clones based on improved growth up to around 4 years of age after planting (Kartikaningtyas et al. 2020).

In the case of *Acacia* hybrid, co-improvement methods had become a basic strategy for *Acacia* hybrid breeding program. The improved hybrid progenies would be expected from a combined improvement of two parent species. A hybrid breeding garden consisting of *A. mangium* and *A.auriculiformis* had been established using selected trees based on improved growth and wood properties (Sunarti et al. 2013). Clonal development is the main target for deploying the superior *Acacia* hybrid into an operational plantation, and clonal testing is a pre-requisite for high vigorous hybrid progenies. Forty four *Acacia* hybrid clones derived from nine controlled-crosses combinations were tested in the clonal trial established adjacent to the clonal trial of *E. pellita* in Central Java (Tab. 1). The trial was laid out in randomised complete block design with a single tree-plot, 20 replications, and spacing of 3 × 3 m. After three years of age, it was reported that two out of the 44 clones, namely Ah025 and Ah044 were considered as consistent superior hybrid clones on improved growth with the stem volume productivity ranging 14% to 17% over the improved pure parent species of *A. mangium* (Sunarti et al. 2013).

Tab. 1: Site description of the clonal trial of E. pellita and Acacia hybrid *(Acacia mangium × A. auriculiformis) in Central Java (Sunarti et al. 2013).*

Site conditions	
Latitude (South)	7°32′ - 8°15′
Longitude (East)	110°41′ - 111°18′
Altitude (m a.s.l)	141
Climate (Schmidt & Ferguson)	C
Average of annual rainfall (mm)	1,878
Min-max temperature (°C)	22.0-33.6
Soil type	Vertisol

Sample trees, growth and wood properties assessment

For examining growth, wood, and pulp properties, sample trees were obtained from five superior clones selected on the improved growth in the clonal trials of *E. pellita* and *Acacia* hybrid described above: three clones from the *E. pellita* and two clones from the *Acacia* hybrid. Three trees at 6 years age from each of the five superior clones were used as wood samples. Before felling, diameter at breast height (DBH) was measured for each sample tree. After felling, total tree height was measured, followed by cutting off three stem discs from DBH upward at three cm intervals for wood properties assessment: wood density, fiber morphologies, and wood chemical contents. The wood properties analysis was conducted in the wood anatomy laboratory of Forest Products Research and Development Center, Bogor.

The wood density was determined as the oven dry matter weight (kg) per unit volume of green wood (m^3). For fiber morphologies, the fiber was macerated based on Franklin method as mentioned by Tesoro (1989) by sizing wood in 1 mm by 1 mm dimension with the length of 1 – 2 cm. Then, wood small sticks were soaked in acetic acid and hydrogen peroxide in ratio of 1:1. The mixture and wood samples were then slowly heated at 40 - 60ºC in a boiling water until it becomes pale and fibers are easily separated. The samples were then washed in aquadest for acid-free samples. The fibers were then embedded in the object-glass using transparent glue prior to fiber dimension measurement under the conventional microscope. For chemical contents, the cellulose was determined based on Norman and Jenkins Methods (1933), while the lignin was determined following the SNI 8429 (2017) Acid-insoluble lignin in wood and pulp.

Wood chipping and kraft pulping

The kraft pulping process was conducted in the pulping and bleaching laboratory of the Centre for Pulp and Paper, Bandung. Wood chips were prepared using the whole stem log taken from the base to the 5 cm top diameter which was cut into a specimen with 2 cm width, 2 cm length, and 2 mm thick. The wood chips from each sample tree were mixed to obtain each 1 kg of oven-dry weight chips for further kraft pulp processing. Pulping was done by the process of kraft and pulp bleaching using the elemental chlorine-free (ECF). Kraft pulping was done under conditions as shown in Tab. 2. Wood chips were cooked in rotary digesters with controlled hot air. The pulp is then washed thoroughly to remove black liquor from the pulp. The pulp obtained was then characterised by the screened pulp yield, screened reject, and total pulp yield. The kappa number was determined following SNI ISO 302 (2014).

Tab. 2: Kraft pulping conditions.

Parameter	Conditions
Temperature (°C)	165
Ratio	1 : 4
Active alkali as Na_2O (%)	18
Sulphidity (%)	25
Time (hours)	1 + 1.5

The unbleached pulps were further bleached by the ECF process with $D_0EpD_1D_2$ bleaching sequences (D_0- early chlorine dioxide; Ep- extraction with peroxide; D_1- first chlorine dioxide;

D_2- second chlorine dioxide). Details of pulp bleaching conditions are shown in Tab. 3. After the bleaching process, the pulp was washed until neutral and pressed to remove the water. Furthermore, the bleached pulp was characterized by bleached pulp yield. The bleaching performance was then evaluated by measuring the degree of brightness following SNI ISO 2470-1 (2016).

Tab. 3: Bleaching conditions.

Parameter	Stages			
	D_0	Ep	D_1	D_2
Consistency (%)	10	10	10	10
NaOH (%)	-	1	-	-
ClO_2 (%)	0.22 × KN*	-	1	0.5
Time (min)	120	60	180	180
Temperature (°C)	90	70	75	75
Peroxide (%)	-	1	-	-

*KN - kappa number.

Handsheet properties

Physical properties testing was carried out on a pulp handsheet in a PFI mill. Variations in milling degrees were determined based on the variation of grinding time measured using CSF (Canadian standard freeness tester) based on ISO 5267-2 (2001). The handsheet was further tested for its physical properties involving the freeness, bursting index, tearing index, and tensile index which were determined following ISO 5267-2 (2001), SNI ISO 2758 (2011), SNI ISO 1974 (2016) and SNI ISO 1924-2 (2010), respectively.

Observed parameter and data analysis

The experimental parameters for data analysis covered the growth: height and DBH, the wood physical: wood density, the wood chemical: cellulose and lignin, and the fiber morphologies: fiber length, fiber diameter, lumen diameter, wall thickness. While for the pulp and handsheet properties were kraft pulp yields, kappa number, brightness, freeness, bursting index, tearing index, and tensile index. Statistical analysis was made through analysis variance (ANOVA) of each parameter using all sample trees data to assess the differences between species and the differences between clones within each species. The ANOVA was calculated using SPSS software. Pearson's correlation coefficients were used to determine the significance of relationships among the observed parameters.

RESULTS AND DISCUSSION

Growth and wood density

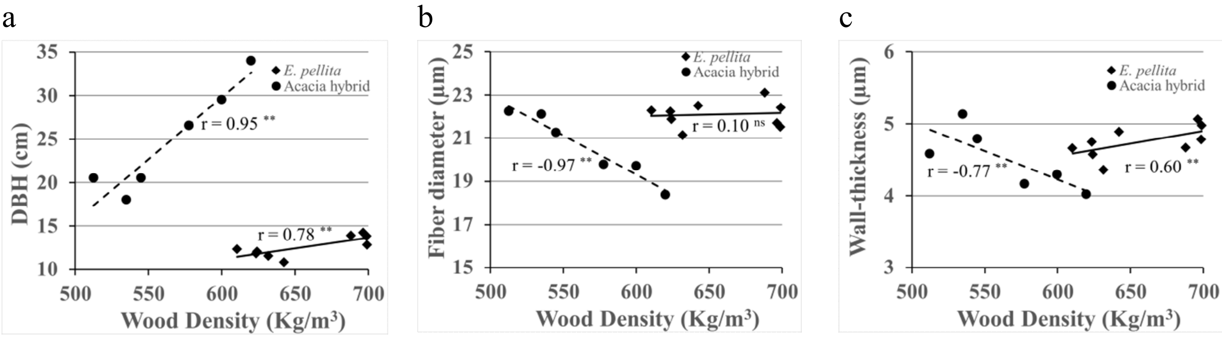
All trees from the two species used in this study were selected from the same age and had experienced the same site conditions because they were planted on adjacent trials. Tree height and DBH were significantly different ($p < 0.01$) between *E. pellita* and *Acacia* hybrid (Tab. 4). Similarly, the clones within each species differed significantly, with the exception of *Acacia* hybrid tree height. The two species differed in their superiority on the two observed growth traits at six years of age. The *E. pellita* performed better in tree height with mean value of 21.6 m. The *Acacia* hybrid, on the other hand performed better on DBH with mean value of 24.83 cm (Tab. 4).

Tab 4: Growth, wood density and fiber morphologies of clones from E. pellita and Acacia hybrid (Acacia mangium × A. auriculiformis).

Species	Clone	Growth		Wood density	Fiber morphologies			
		H (m)	DBH (cm)	$kg \cdot m^{-3}$	FL (mm)	FD (μm)	LD (μm)	WT (μm)
E. pellita	Ep006	20.2^{b}	11.37^{b}	632^{b}	1.086^{a}	21.973^{a}	12.692^{a}	4.666^{a}
	Ep007	21.3^{ab}	12.83^{ab}	643^{ab}	1.142^{a}	21.962^{a}	12.263^{a}	4.767^{a}
	Ep014	23.4^{a}	13.50^{a}	695^{a}	1.161^{a}	22.360^{a}	12.698^{a}	4.810^{a}
	Mean	**21.6**	**12.57**	**657**	**1.130**	**22.100**	**12.549**	**4.749**
Acacia hybrid	Ah25	18.9^{a}	19.67^{b}	531^{b}	1.426^{a}	21.870^{a}	12.286^{a}	4.835^{a}
	Ah44	20.1^{a}	30.00^{a}	599^{a}	1.410^{a}	19.290^{b}	10.970^{a}	4.160^{b}
	Mean	**19.5**	**24.83**	**567**	**1.418**	**20.580**	**11.630**	**4.495**
Significance of species		$p< 0.01$	$p< 0.01$	$p< 0.01$	$p< 0.01$	$p< 0.01$	$p< 0.05$	n.s

H - height; DBH - diameter at breast height; FL - fiber length; FD - fiber diameter; LD - lumen diameter; WT -wall thickness; n.s. - not significantly at the level of 5%. Mean followed by the same letter within the column for each species indicate not significantly different at the level of 5%.

Because of its strong link with other wood properties, wood density is considered one of the most essential parameters determining wood quality. Similar to DBH, wood density were significantly different between the two species or among the clones within species (Tab. 4). It was suggested that variation on DBH could further affect a significant difference in wood density. The high and positive correlation between DBH and wood density ($r \geq 0.78$) supported this hypothesis, indicating that the clone's DBH may be used as a good predictor of their wood density (Fig. 1a).



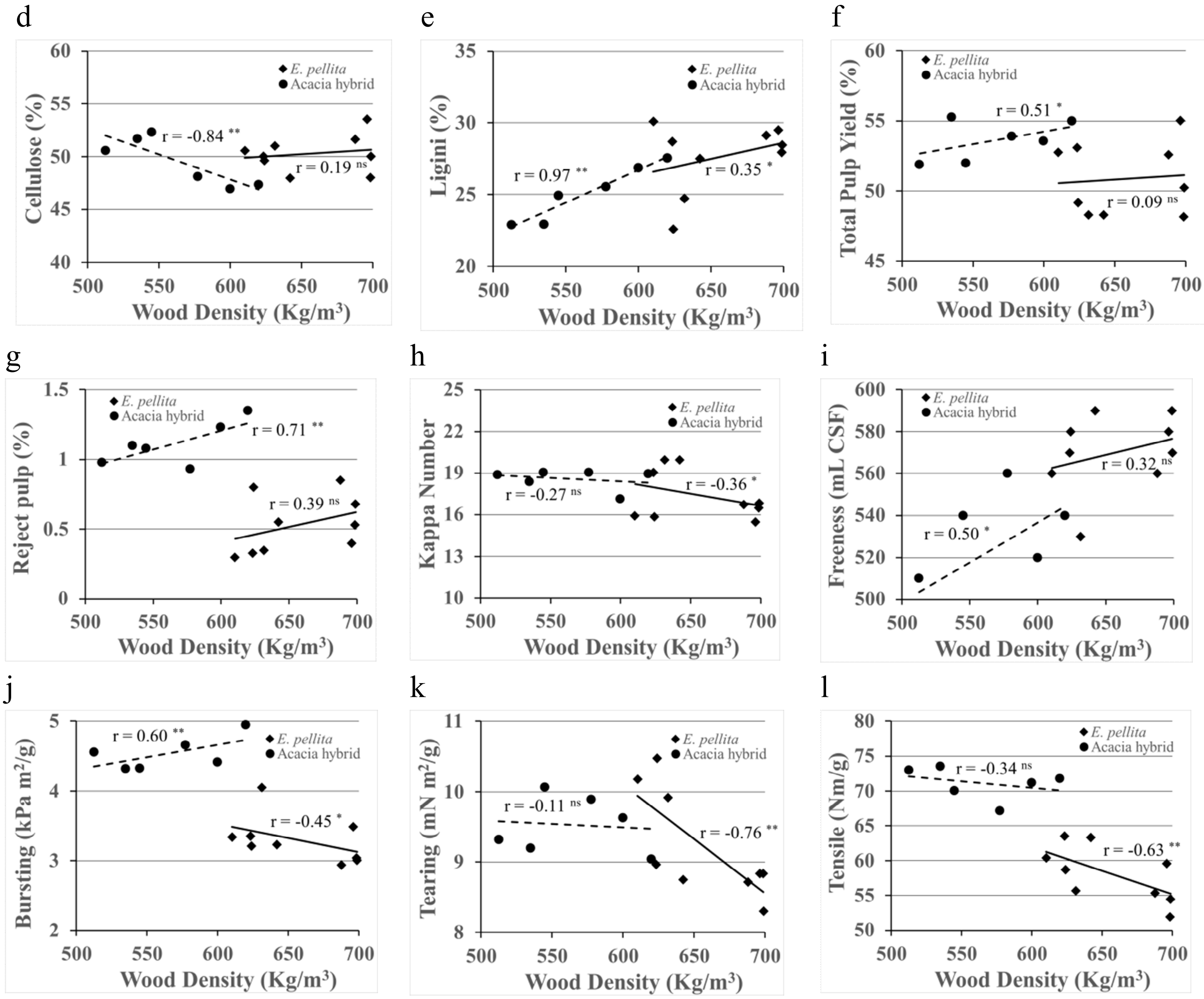


Fig. 1: Correlations between wood density and growths, fiber morphologies, chemical contents, pulp properties, handsheet properties of clones from Eucalyptus pellita and Acacia hybrid (Acacia mangium × A. auriculiformis).

For the five superior clones investigated in this study, the widely reported adverse correlation between diameter growth and wood density did not appear. As species- specific character, the wood density of *E. pellita*, however, was much higher than that of *Acacia* hybrid despite the fact that the DBH was smaller.

The mean values of wood density of the clones examined in this study was 657 $kg{\cdot}m^{-3}$ for *E. pellita* and 567 $kg{\cdot}m^{-3}$ for *Acacia* hybrid (Tab. 4). Clone Ep014 of *E. pellita* had the highest value (695 $kg{\cdot}m^{-3}$), while clone Ah044 of *Acacia* hybrid had the highest value (599 $kg{\cdot}m^{-3}$), and these two clones also had the biggest in DBH within species. The density of *E. pellita* found in this study were higher than in other Indonesian studies, ranging from 404.5 $kg{\cdot}m^{-3}$ to 558.7 $kg{\cdot}m^{-3}$ from four years old sample trees (Ramadan et al. 2018) and 590 $kg{\cdot}m^{-3}$ to 630 $kg{\cdot}m^{-3}$ from 10 years old trees (Yuniarti and Nirsatmanto 2018). But, it was comparable with 10 years old of *E. pellita* grown in Vietnam ranging from 657 $kg{\cdot}m^{-3}$ to 665 $kg{\cdot}m^{-3}$ (Hung et al. 2015). For the *Acacia* hybrid, the values were also higher than other studies that were reported ranging of 420

$kg·m^{-3}$ to 473 $kg·m^{-3}$ at 3.8-5 years age of *Acacia* hybrid in Vietnam (Kha et al. 2011, Viet et al. 2020) and around 470 $kg·m^{-3}$ of 6 years age in Malaysia (Ismail and Farawahida 2007).

The results as described in the preceding paragraphs confirmed that the breeding program for selecting superior clones of *E. pellita* and *Acacia* hybrid has improved the height and diameter growth. Selection based on growth traits has had positive impact for improving wood density of the clones. It appeared that clones selection as a breeding method in the two species was one of the practical ways to simultaneously improve growth and wood density. Furthermore, given the importance of wood density in affecting wood quality, the high correlation between DBH and wood density found in this study could be expected to be a useful tool not only for breeding selection but also for examining other wood properties and further end-product processing.

Fiber morphologies

Except for wall thickness, all observed fiber morphologies showed a significant variation between the two species (Tab. 4). Except for the fiber length, *E. pellita* fiber morphological values were higher than *Acacia* hybrid. For *E. pellita*, the mean values of fiber length, fiber diameter, lumen diameter, and wall thickness were at 1.130 mm, 22.100 µm, 12.549 µm, and 4.749 µm, respectively, and for *Acacia* hybrid, 1.418 mm, 20.580 µm, 11.630 µm and 4.495 µm, resp. For within species, the clones showed similar values, except for fiber diameter and wall thickness of *Acacia* hybrid in which the fiber of clone Ah25 was significantly wider and thicker. The values of fiber morphology of *E. pellita* clones in this study were higher than a study reported by Lukmandaru et al. (2016) using materials from nine years old plus trees in the second-generation progeny trial in South Kalimantan, Indonesia. The previous study reported averages of around 1.02 mm, 13.25 µm, 6.94 µm, and 3.15 µm for fiber length, fiber diameter, lumen diameter, and wall thickness, respectively. Except for lumen diameter, the mean values for the *Acacia* hybrid clones in this study were also higher compared to another study for three *Acacia* species at eight years old reported by Yahya et al. (2010) that ranged from 0.877 to 1.000 mm (fiber length), 16.76 to 19.39 µm (fiber diameter), 11.13 to 14.29 µm (lumen diameter), and 2.51 to 2.81 µm (wall thickness).

Concerning the wood density, there was a correlation pattern in which the fibers diameter and wall thickness were a high and negative correlation ($r = -0.77$ to $r = -0.97$) with the wood density for the *Acacia* hybrid clones. Still, it was a weak-moderate and positive correlation ($r = 0.10$ to $r = 0.60$) for the *E. pellita* (Figs. 1b,c). It appeared that differences in the proportion of the cell wall thickness and diameter of the fibers were related to variations in wood density in *Acacia* hybrids. Panshin and de Zeeuw (1980) stated that cell wall thickness and cell dimensions are major factors in the variation of wood density.

The fiber morphologies of clones from the *E. pellita* and *Acacia* hybrid indicated the suitability of the wood as raw materials for pulp and papermaking. The fiber wall thickness and lumen diameter values (Tab. 4) derived Runkel ratio (Valkomies 1969) at low values of around 0.70 for all clones. The fiber length and fiber diameter derived slenderness ratio at high values of more than 50 for all clones. The low Runkel and high Slenderness ratio from the clones of *E. pellita* and *Acacia* hybrid in this study indicated that the wood from those clones is favorable as raw materials for pulp and paper. These results are comparable with a study in *Acacia* hybrid reported by Jusoh et al. (2014) that the Runkel and Slenderness ratio were at around 0.35 and 57, resp. According to du Plooy (1980) and Bamber (1985), a lower Runkel ratio (<1.00) indicates a favorable fiber strength in pulp production. In addition, Xu et al. (2006), reported that a higher Slenderness ratio (>33) indicates good fiber in papermaking.

Chemical contents

Cellulose and lignin were not significantly different between species and among *E. pellita* clones, but differed significantly between *Acacia* hybrid clones (Tab. 5). Clones from the two species had 47.49% to 51.54% cellulose and 23.59% to 28.50% lignin. For *E. pellita*, the cellulose was comparable to a study reported by Lukmandaru et al. (2016), but the lignin was 2% lower. In the case of *Acacia* hybrid, the chemical contents were higher for the cellulose, but slightly lower for the lignin as compared to the study reported by Yamada et al. (1991).

Tab. 5: Wood chemical, unbleached pulp yield, Kappa number and bleached pulp yield of clones from E. pellita and Acacia hybrid (A. mangium × A. auriculiformis).

Species	Clone	Wood chemical		Unbleached pulp				Bleached pulp		
		Cellulose (%)	Lignin (%)	Screened (%)	Reject (%)	Total (%)	Kappa number	Yield[1] (%)	Yield[2] (%)	Brightness (% ISO)
E. pellita	Ep006	49.70[a]	26.98[a]	49.48[a]	0.41[a]	49.89[a]	19.67[a]	48.16[a]	97.31[a]	85.60[b]
	Ep007	51.26[a]	27.40[a]	51.81[a]	0.50[a]	52.31[a]	15.75[c]	49.25[a]	95.03[a]	87.81[a]
	Ep014	49.91[a]	28.50[a]	49.64[a]	0.69[a]	50.33[a]	16.68[b]	46.80[a]	96.20[a]	85.71[b]
	Mean	**50.29**	**27.63**	**50.31**	**0.53**	**50.84**	**17.37**	**48.07**	**96.18**	**86.37**
Acacia hybrid	Ah25	51.54[a]	23.59[b]	51.99[a]	1.05[a]	53.05[a]	18.76[a]	48.92[a]	94.18[a]	88.60[a]
	Ah44	47.49[b]	26.65[a]	52.99[a]	1.17[a]	54.16[a]	18.38[a]	49.38[a]	93.17[a]	88.83[a]
	Mean	**49.51**	**25.12**	**52.50**	**1.11**	**53.60**	**18.57**	**49.15**	**93.67**	**88.71**
Significance of species		n.s.	n.s.	n.s.	$p<0.01$	$p<0.01$	$p<0.01$	n.s.	n.s.	$p<0.01$

n.s. - not significantly at the level of 5%. [1] bleached pulp yield (%) on wood; [2] bleached pulp yield (%) on screened yield. Mean followed by the same letter within the column for each species indicate not significantly different at the level of 5%.

The correlation between cellulose and lignin was weak and positive for *E. pellita* ($r = 0.27$), but a high negative correlation ($r = -0.79$) was observed for *Acacia* hybrids (Fig. 2a). The negative correlation for *Acacia* hybrid was also reflected in its correlation with wood density: a high and negative ($r = -0.84$) for cellulose, but a high and positive ($r = 0.97$) for lignin (Figs. 1d,e). It was observed that the wood density could be used as a good predictor of cellulose and lignin content in *Acacia* hybrid clones. The clones with greater wood density tend to produce wood with a higher lignin content and a lower cellulose content. These findings suggested that as the male parent, *A. auriculiformis*, had a greater influence on the lignin concentration of *Acacia* hybrid progenies. The lignin content of *A. auriculiformis* had been reported to be high (Yamada et al. 1991, Haque et al. 2019).

a b

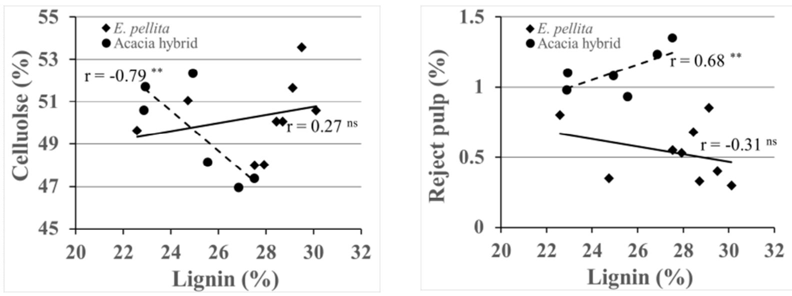


Fig. 2: Correlations of lignin with cellulose and reject pulp of clones from E. pellita and Acacia hybrid (A. mangium × A. auriculiformis).

Kraft pulp properties

Kraft pulp yields and Kappa number of the individual sample trees from the three superior clones *E. pellita* and the two superior clones *Acacia* hybrid are presented in Tab. 5. Unbleached total pulp yields were different between the two species. Although having lower wood density (Tab. 4) and cellulose (Tab. 5), the mean value of total pulp yield of *Acacia* hybrid (53.60%) was significantly higher than that of *E. pellita* (50.84%). However, the *Acacia* hybrid had a significantly higher reject pulp (1.11%) compared to *E. pellita* (0.53%). As a result, the screened pulp yield for the *Acacia* hybrid was not significantly different to the *E. pellita*, although it was numerically still greater. In the case of clonal variation within species, the total pulp yields were similar among the clones ranging from 53.05% to 54.16% for *Acacia* hybrid, and from 49.89% to 52.31% for *E. pellita*.

The high and positive correlation (r = 0.68) between lignin and reject pulp (Fig. 2b) was suggested to be one of the main contributors in increasing reject pulp for the *Acacia* hybrid clones (Tab. 5). In addition, the yield of pulping process was not affected by the variation of wood density of clones. It could be observed in the *Acacia* hybrid that the denser wood contained higher lignin and lower cellulose (Tab. 5), which under given pulping conditions (Tab. 1) tended to impact a greater difficulty in a delignification and a decrease in the selectivity of the pulping process. It was also confirmed on the correlation values in which the wood density was stronger and positively correlated with rejected pulp (r = 0.71) rather than its correlation with the total pulp yield (r = 0.51) (Figs. 1f,g). Aguayo et al. (2015) reported a study in *E. globulus* that a higher pulp yield was obtained from the wood sample containing lower original lignin content than higher lignin. In addition, they concluded that the structure of lignin in genotypes of a single species should be considered an important parameter on the selection and improvement of the species in commercial plantations for pulp production.

The insignificant difference in screened pulp yield between the two species (Tab. 5) was also influenced by the level of delignification process of the pulp as identified by the kappa number. In the same active alkali content of 18% and sulfidity 25 %, the mean value of kappa number was significantly different between species: 17.37 for *E. pellita* and 18.57 for *Acacia* hybrid (Tab. 5), and indicated that the wood of *E. pellita* pulped easier than the *Acacia* hybrid. Interestingly, there was a tendency for the decreases of kappa number with the increases of wood density (Fig. 1h). In general, the kappa number among *E. pellita* clones was more varied than the

Acacia hybrid. A significant difference ($p < 0.05$) was found among *E. pellita* clones, but not for the *Acacia* hybrid. For *E. pellita*, the significantly lower Kappa number for the Clone Ep007 (15.75) produced, numerically but not significantly, greater pulp yields (> 52%), followed by the Clone Ep014 and Ep006. While for the *Acacia* hybrid, the two clones were similar on the kappa number and pulp yields, although numerically the mean screened and total pulp yield of the clone Ah044 were around 2% over the clone Ah25. The same active alkali content (18%) resulted in less variation in the pulp yields, even if the kappa number varied significantly, such as in *E. pellita*. It indicated that the given pulping conditions tended to cause the weak-moderate and negative correlation between the kappa number and the pulp yields for the clones of *E. pellita* ($r = -0.43$) and *Acacia* hybrid ($r = -0.16$) (Fig.3a). These results are similar to a study on the effect of active alkali on *A. mangium* and *E. pellita* reported by Ardina et al. (2018) that using active alkali content of 17% - 20% resulted in kappa number by ≤ 18% and screened pulp yields by 50% to 53%.

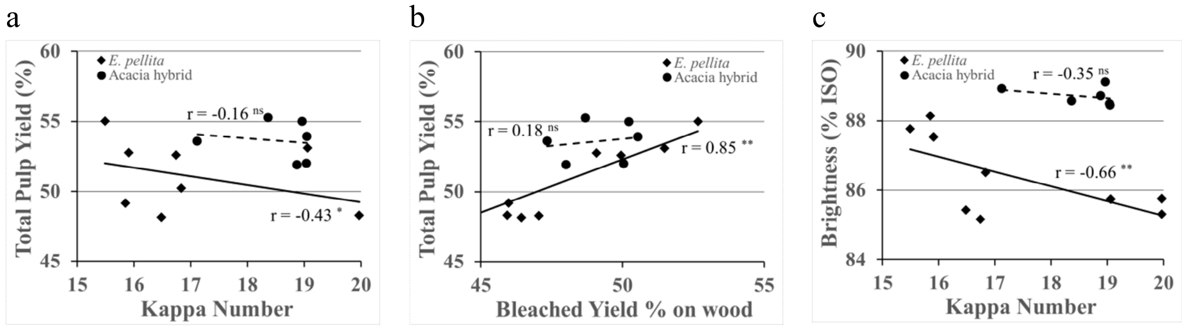


Fig. 3: Correlation of kappa number with total pulp yield and brightness, and between bleached pulp yield on wood and total pulp yield of clones from E. pellita and Acacia hybrid (A. mangium × A. auriculiformis).

In contrast to the unbleached pulps, there was no significant difference in pulp yield after bleaching between the two species (Tab. 5). The mean value of bleached pulp yield (%) on wood was 48.07% for *E. pellita*, and 49.15% for the *Acacia* hybrid. A weak correlation ($r = 0.18$) between the bleached pulp yield (%) on wood and the unbleached total pulp yield was found on *Acacia* hybrid clones, but a high correlation ($r = 0.85$) was found on the *E. pellita* (Fig. 3b). It indicated that the bleaching process seemed to cause a higher shrinkage of the pulp yields on the *Acacia* hybrid clones compared to the *E. pellita*. However, the bleached pulp yield (%) on screened yield was still considerably high in both species (> 93%). It indicated that the cellulose degradation during the bleaching process was relatively small for the two species.

The bleaching process resulted in a significantly higher brightness on the *Acacia* hybrid (88.71% ISO) as compared to the *E. pellita* (86.37% ISO) (Tab. 5). The brightness was found to vary among the *E. pellita* clones more than the *Acacia* hybrid clones. A significant difference in the kappa number among the clones of *E. pellita* had influenced the brightness variation. As shown in Fig. 3c, the significantly different brightness among *E. pellita* clones showed a high and negative correlation with the kappa number ($r = -0.66$), which indicated that a lower kappa number produced a higher brightness. Although most of the wood quality was not a statistically significant difference among the clones of *E. pellita* (Tabs. 4 and 5), the varies in brightness stability might indicate that the impact of wood quality variation among and within clones are still significant (Oliveira et al. 2016).

Freeness and handsheet properties

A significant difference between species was found on the freeness and two out of the three observed handsheet properties: bursting and tensile index (Tab. 6). While among the clones the significant difference was found only on the tensile index in *E. pellita*. The values of freeness, bursting, tearing, and tensile indexes of *Acacia* hybrid were ≥ 507 mL CSF, ≥ 4.403 kPa·m^2·g^{-1}, ≥ 9.520 mN·m^2·g^{-1}, and ≥ 70.05 Nm·g^{-1}, resp. While *E. pellita* were ≥ 563 mL CSF, ≥ 2.997 kPa·m^2·g^{-1}, ≥ 8.620 mN·m^2·g^{-1}, and ≥ 53.93 Nm·g^{-1}, resp. Except for freeness, the higher minimum values indicated that in general the clones of *Acacia* hybrid showed better handsheet properties than *E. pellita*. The tendency of better handsheet properties of the *Acacia* as compared to *Eucalyptus* species was also reported by Mohlin and Hornatowska (2006).

Tab. 6: Freeness and handsheet properties of clones from E. pellita and Acacia hybrid (Acacia mangium × A. auriculiformis).

Species	Clone	Freeness (mL CSF)	Bursting (kPa m^2 g^{-1})	Tearing (mN m^2 g^{-1})	Tensile (Nm g^{-1})
E. pellita	Ep006	573^a	3.543^a	9.213^a	60.84^a
	Ep007	573^a	3.347^a	9.833^a	59.60^{ab}
	Ep014	563^a	2.997^a	8.620^a	53.93^b
	Mean	**570**	**3.296**	**9.222**	**58.12**
Acacia hybrid	Ah25	507^a	4.403^a	9.530^a	72.20^a
	Ah44	540^a	4.677^a	9.520^a	70.05^a
	Mean	**523**	**4.540**	**9.525**	**71.13**
Significance of species		$p < 0.01$	$p < 0.01$	n.s	$p < 0.01$

n.s. - not significantly at the level of 5%; mean followed by the same letter within column for each species indicate not significantly different at the level of 5%.

A varied trend of correlations of the freeness and the three handsheet properties either with wood density or fiber morphologies was found between *E. pellita* and *Acacia* hybrid clones. Some of the trends were in the opposite direction. A moderate and positive correlation was found between freeness and wood density for the *Acacia* hybrid (r = 0.50), but it was a weak correlation for *E. pellita* (r = 0.32) (Fig. 1i). For the *E. pellita*, the three observed handsheet properties showed a moderate-strong and negative correlation with wood density (r = −0.45 to −0.76) (Figs. 1j-l). It is similar to a study in *E. grandis* reported by du Plooy (1980) that wood density is negatively correlated to tensile, burst and tear indexes, which then indicated a good predictor for the handsheet properties. While for the *Acacia* hybrid, the correlation was weak (r = −0.11 and −0.34), except for bursting that showed a moderate and positive correlation (r = 0.60). For practical purposes, it suggested that wood density could be a good indicator for the handsheet quality in *E. pellita* clones and the freeness in the *Acacia* hybrid.

Concerning the fiber, bursting index was negatively correlated with two of the observed fiber morphologies in the two species. For *Acacia* hybrid, fiber diameter and wall thickness were good indicators for bursting (*r* = −0.72 to −0.81), while for *E. pellita* it was found only on fiber diameter (r = −0.70) (Figs. 4a-b).

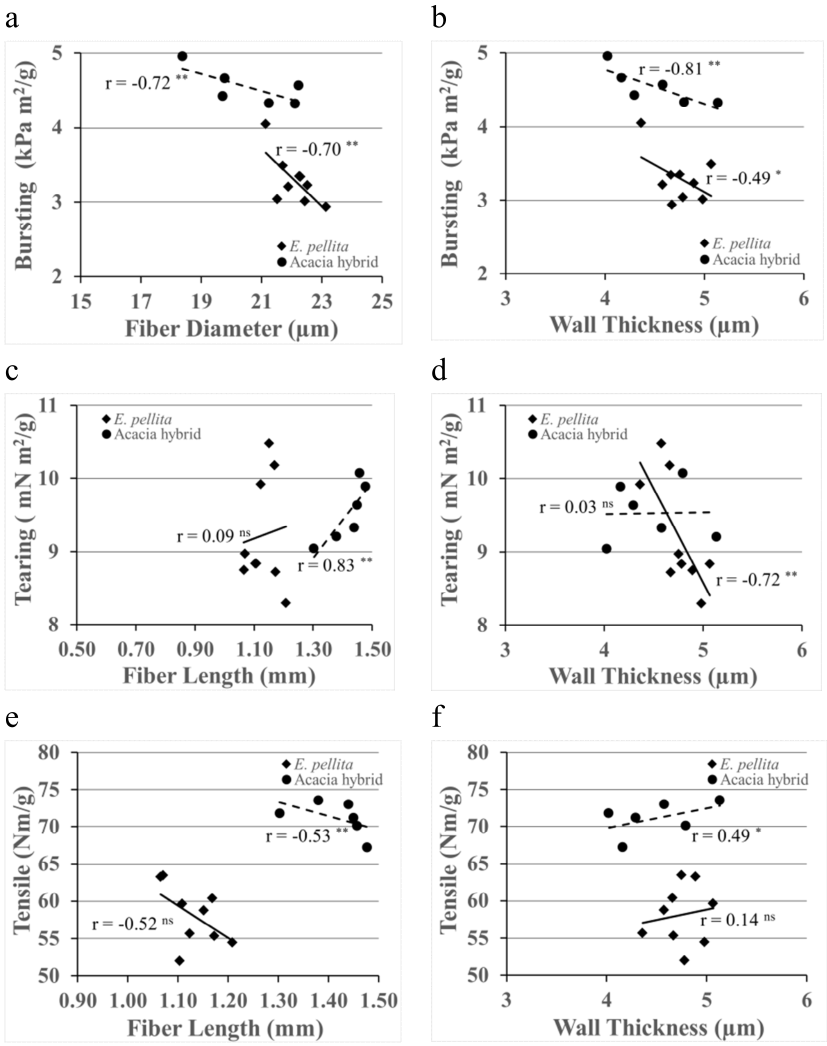


Fig. 4: Correlations between fiber morphologies and handsheet properties of clones from E. pellita and Acacia hybrid (A. mangium × A. auriculiformis).

The tearing index showed a different trend direction of the correlation between the two species. For *E. pellita*, tearing showed a weak correlation with fiber length *(r* = 0.09), but it was a strong and negative correlation with wall thickness (*r* = −0.72) (Figs. 4c,d). On the contrary, *Acacia* hybrid's tearing was a strong and positive correlation with fiber length (*r* = 0.83), but a weak correlation with wall thickness (*r* = 0.03). It indicated that although the absolute mean value of tearing between the species was not significantly different (Tab. 6), variation among the clones within species for fiber morphologies could influence the strength and trend of the relationship of tearing. Another study reported by du Plooy (1980) indicated a strong correlation between the fiber length and tearing index.

In the case of a tensile index, the fiber length showed a better indicator as shown by the same moderate negative correlation with around *r* = −0.50 for the two species (Figs. 4e,f). It seemed that the influence of fiber length for the tensile index was stable, although the fiber length was significantly different between the species (Tab. 4). On the contrary, the correlation between the tensile index and wall thickness were positive for the two species. Although a non-significant difference in wall thickness was found between the two species (Tab. 4), its strength of correlation to the tensile was different: a moderate correlation (r = 0.49) for the *Acacia* hybrid, and a low correlation (r = 0.14) for the *E. pellita*.

Comparisons of freeness, brightness, and the three observed handsheet properties between this study and other reported studies on common tropical *Acacia* species planted in Indonesia are presented in Tab.7.

Tab. 7: Comparisons of freeness, brightness, and handsheet properties between this study and other common tropical Acacia species planted in Indonesia, and the threshold of the SNI 6107 (2015).

Parameter	Clones		Other common species		SNI 6107:2015[c]
	E. pellita (6 years)	*Acacia* hybrid (6 years)	*A. crassicarpa* (6 years)[a]	*A. mangium* (5 years)[b]	
Freeness (mL CSF)	570	523	580-600	590	≥ 430
Brightness (% ISO)	86.37	88.71	87.69-88.60	87.06	≥ 85
Bursting index (kPa m^2g^{-1})[d]	3.296	4.540	4.50-4.70	5.73	≥ 2.5
Tearing index(mN m^2 g^{-1})[d]	9.220	9.525	5.60-5.80	8.330	≥ 5.5
Tensile index (Nm g^{-1})[d]	58.12	71.13	57-63	85.70	≥ 45

[a] Sugesty et al. (2015), [b] Kardiansyah and Sugesty (2020), [c] The SNI, Standar Nasional Indonesia (*Indonesian National Standard*), [d] Measurement under freeness 300 (mL CSF).

In general, the comparisons varied among the observed values. There were some outstanding values from *E. pellita* and *Acacia* hybrid clones used in this study compared to other species referred, such as on tearing index in which almost all clones showed values more than 9.000 $mN{\cdot}m^2{\cdot}g^{-1}$. All *Acacia* hybrid clones could therefore be expected to be somewhat also higher on brightness (≥ 88.60% ISO) than that of the female parent species of *A. mangium* as well as *A. crassicarpa*. On the other hand, there were some lower values, particularly on bursting index and freeness. However, it should be noted here that the comparisons might be confounded mainly with differences among the sites of the sample trees grown, different ages, as well as the differences in the pulping process. All of the parameters from clones examined in this study showed a better value on the threshold of SNI 6107 (2015).

CONCLUSIONS

The results suggested that the superior clones of *E. pellita* and *Acacia* hybrid (*A. mangium* × *A. auriculiformis*) evaluated in this study showed good growth and wood properties characteristics, which provided a better effect on kraft pulp yield and handsheet properties. In general, *Acacia* hybrid clones showed higher pulp yields and better handsheet properties than *E. pellita* clones. Some observed wood properties from the clones showed a good relationship and were considered a good predictor of the quality of pulp and handsheet, such as wood density, lignin content, fiber diameter, and wall thickness. Some of the relationships showed an opposite direction and influenced the specific characteristics between the species. All clones also showed a better value on the threshold of the Indonesian National Standard (SNI). Therefore, the five superior clones could be considered promising materials for planting to maintain supplying raw materials for pulp and papermaking in Indonesia. However, some further studies are still required to ensure the adaptability of the clones in other sites representative for plantation.

ACKNOWLEDGMENTS

This research was funded by the Ministry of Research and Technology/National Agency for Research and Innovation under Centre of Excellence for Science and Technology (Pusat Unggulan IPTEK/PUI) in the financial year of 2017–2019. Special thanks to Priyo Kusumedi and Jaka Suryanta for management process coordination, to Dwi S Yuliastuti, Sumaryana, Didik Indriatmoko for data providing and sample collection and to Anto Rimbawanto for his comments and editing the manuscript.

REFERENCES

1. Aguayo, M.G., Ruiz, J., Norambuena, M., Mendonça, RT., 2015: Structural features of dioxane lignin from *Eucalyptus globulus* and their relationship with the pulp yield of contrasting genotypes. Maderas-Ciencia y Tecnologia 17(3): 625−636.
2. Ardina, V., Irawan, B., Prajitno, D.H., Roesyadi, A., 2018: Active alkali charge effect on kraft pulping process of *Acacia mangium* and *Eucalyptus pellita*. Pp 1-6, Proceeding of International Conference of Science and Applied Science (ICSAS).
3. Arisman, H., Hardiyanto, E.B., 2006: *Acacia mangium* - a historical perspective on its cultivation. Pp 9-11, Proceedings of a workshop: Heart rot and root rot in tropical *Acacia* plantations.
4. Bamber, R. K., 1985: The wood anatomy of eucalypts and papermaking. Appita Journal 38: 210−216.
5. Brawner, J.T., Japarudin, Y., Lapammu, M., Rauf, R., Boden, D., Wingfield, M.J., 2015: Evaluating the inheritance of *Ceratocystis acaciivora* symptom expression in a diverse *Acacia mangium* breeding population. Southern Forests: a Journal of Forest Science 77: 83−90.
6. du Plooy, A.B.J., 1980: The relationship between wood and pulp properties of *Eucalyptus grandis* (Hill ex-Maiden) grown in South Africa. Appita Journal 33: 257−264.
7. Guimaraes, 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.
8. Handayani, B.R., Sunarti, S., Nirsatmanto, A., Setyaji, T., Kartikaningtyas, D., Surip., 2020: Impact of within family variation on growth superiority of improved seeds of *Eucalyptus pellita* observed in genetic gain trial. Pp 1-7, Proceeding of International conference on managing forest genetic resources in changing environment and landscaping.

9. Haque, M., Nanjiba, M., Jahan, M.S., Quaiyyum, M.A., Alam, M.Z., Nayeem, J., 2019: Pre-bleaching of kraft *Acacia* pulp. Nordic Pulp Paper Research Journal 34(2): 165−172.
10. Harwood, C.E., Hardiyanto, E.B., Wong, C.Y., 2015: Genetic improvement of tropical *Acacia*s: achievements and challenges. Southern Forests: a Journal of Forest Science 77: 11–18.
11. Harwood, C.E., Nambiar, E.K.S., 2013: Sustainable plantation forestry in South East Asia. Client report EP14685 to Australian Centre for International Agricultural Research. Sustainable Agriculture Flagship and CSIRO Ecosystem Sciences. Australia, 105 pp.
12. Harwood, C.E., Nambiar, E.K.S., 2014: Productivity of *Acacia* and eucalypt plantations in Southeast Asia. 2. Trends and variations. International Forestry Review 16: 249–260
13. Hung, T.D., Brawner, J.T., Meder, R., Lee, D.J., Southerton, S., Thinh, H.H., Dieters, M.J., 2015: Estimates of genetic parameters for growth and wood properties in *Eucalyptus pellita* F. Muell. to support tree breeding in Vietnam. Annals of Forest Science 72: 205-217.
14. Ibrahim, Z., Awang, K., 1991: Flowering and fruiting phenology of *Acacia mangium* and *Acacia auriculiformis* in Peninsular Malaysia. Pp 45-48, Breeding Technologies for Tropical *Acacia*s. Australian Centre for International Agricultural Research. Australia.
15. Inail, M.A., Hardiyanto, E.B., Mendham, D.S., 2019: Growth Responses of *Eucalyptus pellita* F. Muell plantations in South Sumatra to macronutrient fertilisers following several rotations of *Acacia mangium* Willd. Forests 10(12): 1054.
16. ISO 5267-2, 2001: Pulps-determination of drain ability. Part 2: Canadian standard freeness method.
17. Ismail, J., Farawahida, A.Z., 2007: Physical and mechanical properties of *Acacia mangium* × *Acacia auriculiformis* hybrid (*Acacia* hybrid) and *Acacia mangium* super bulk planted in Sarawak. Pp 270-278, Proceedings of the Conference on Forestry & Forest Products Research.
18. Jusoh, I., Zaharin, F.A., Adam, N.S., 2014: Wood quality of *Acacia* hybrid and second-generation *Acacia mangium*. Bioresources 9: 150–160.
19. Kardiansyah, T., Sugesty, S., 2020: Pengaruh alkali aktif terhadap karakteristik pulp kraft putih *Acacia mangium* dan *Eucalyptus pellita*. Jurnal Selulosa 10(1): 9−20.
20. Kartikaningtyas, D., Nirsatmanto, A., Sunarti, S., Seytaji, 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. Pp 1-12, Proceeding of international conference on managing forest genetic resources in changing environment and landscaping.
21. Kha, L.D., Harwood, C.E., Kien, N.D., Baltunis, B.S., Hai, N.D., Thinh, H.H., 2011: Growth and wood basic density of *Acacia* hybrid clones at three locations in Vietnam. New Forest 43(1): 13−29.
22. Kurinobu, S., Rimbawanto, A., 2002: Genetic improvement of plantation species in Indonesia–summary of project achievement (JICA forest tree improvement phase II). Pp 158-163, Proceedings of international conference on advances in genetic improvement of tropical tree species.

23. Le, D.K., Ha, H.T., 2017: Research and development of *Acacia* hybrids for commercial planting in Vietnam. Life Journal of Science, Technology and Engineering 59(1): 36−42.
24. Lukmandaru, G., Zumaini, U.F., Soeprijadi, D., Nugroho, W.D., Susanto, M., 2016: Chemical properties and fiber dimension of *Eucalyptus pellita* from the 2nd generation of progeny tests in Pelaihari, South Borneo, Indonesia. Journal of the Korean Wood Science and Technology 44(4): 571−588.
25. Mohlin, B., Hornatowska, J,. 2006: Fibre and sheet properties of *Acacia* and eucalyptus. Appita Journal 59(3): 225−230.
26. Nambiar, E.K.S., Harwood, C.E., Mendham, D.S., 2018: Paths to sustainable wood supply to the pulp and paper industry in Indonesia after diseases have forced a change of species from *Acacia* to eucalypts. Australian Forests 81:148−161.
27. Nasution, A., Glen, M., Beadle, C., Mohammed, C., 2019: *Ceratocystis* wilt and canker – a disease that compromises the growing of commercial *Acacia*-based plantations in the tropics. Australian Forest 82: 80−93.
28. Norman, A.G., Jenkins, S.H., 1933: A new method for the determination of cellulose, based upon observations on removal of lignin and other encrusting materials. Biochemical Journal 27(3): 818-831.
29. Oliveira, R.L., Colodette, J.L., Eiras, K.M.M., Ventorim, G., 2006: The effect of wood supply and bleaching process on pulp brightness stability. Revista Árvore 30(3): 439−450.
30. Panshin, A.J., de Zeeuw, C., 1980: Textbook of wood technology. McGraw-Hill: New York, 687 pp.
31. Pinyopusarerk, K., Liang, S.B., Gunn, B.V., 1993: Taxonomy, distribution, biology, and use as an exotic. In: *Acacia mangium* growing and utilization (eds. Awang K, Taylor D). Pp 1−18, Winrock International & FAO. Thailand.
32. Ramadan, A., Indrioko, S., Hardiyanto, E.B., 2018: Parameter genetik sifat pertumbuhan dan kerapatan kayu klon *Eucalyptus pellita* F. Muell. di dua tapak yang berbeda di Kalimantan Timur. Jurnal Pemuliaan Tanaman Hutan 12(2):115−125.
33. SNI ISO 302, 2014: Pulp-Cara uji bilangan kappa (Pulps-determination of Kappa number).
34. SNI ISO 1924-2, 2010: Kertas dan karton: Cara uji sifat tarik, Bagian 2: Metode kecepatan elongasi tetap (Paper and paperboard: Determination of tensile properties – Part 2: Constant rate of elongation method).
35. SNI ISO 1974, 2016: Kertas: Cara uji ketahanan retak (Paper: Determination of tearing resistance).
36. SNI 6107, 2015: Pulp kraft putih kayudaun (Leaf bleached kraft pulp).
37. SNI 8429, 2017: Lignin tidak larut asam dalam kayu dan pulp (Acid insoluble lignin in wood and pulp).
38. SNI 2470-1, 2016: Kertas, karton, dan pulp – Cara uji faktor pantulan baur biru-Bagian 1: Kondisi siang hari di dalam ruangan (Paper, board and pulps-measurement of diffuse blue reflectance factor – Part 1: Indoor daylight conditions).
39. SNI ISO 2758, 2011: Kertas: Cara uji ketahanan retak (Paper: Determination of bursting.)
40. Sugesty, S., Kardiansyah, T., Pratiwi, W., 2015: Potensi *Acacia crassicarpa* sebagai bahan baku pulp kertas untuk hutan tanaman industri. Jurnal Selulosa 4(1): 21−32.

41. Sunarti, S., Na'iem, M., Hardiyanto, E.B., Indrioko, S., 2013: Breeding strategy of *Acacia* hybrid (*A. mangium* × A. *auriculiformis*) to increase forest plantation productivity in Indonesia. Jurnal Manajemen Hutan Tropis 19(2): 128−137.
42. Tarigan, M., Roux, J., van Wyk, M., Tjahjono B., Wingfield, M.J., 2011: A new wilt and die-back disease of *Acacia mangium* associated with *Ceratocystis manginecans* and *C. acaciivora* sp nov. in Indonesia. South African Journal of Botany 77: 292−304.
43. Tesoro, F., 1989: Wood structure and quality: bases for improvement utilization of timbers. International Association of Wood Anatomists Bulletin 10(3): 333-334.
44. Trang, T.T., Eyles, A., Davies, N., Glen, M., Ratkowsky, D., Mohammed, C., 2017: Screening for host responses in *Acacia* to a canker and wilt pathogen, *Ceratocystis manginecans*. Forest Pathology 48(1).
45. Turnbull, J.W., Midgley, S.J., Cossalter, C., 1997: Tropical *Acacia*s planted in Asia: an overview of recent developments in *Acacia*s planting. Pp 14-28, Proceeding of an international workshop.
46. Valkomies, P. J., 1969: Wood raw materials for pulp paper in tropical countries. Unasylva 94(23): 3.
47. Viet, D.D., Ma, T., Inagaki, T., Kim, N.T., Chi, N.Q., Tsuchikawa, S., 2020: Physical and mechanical properties of fast growing polyploid *Acacia* hybrids (*A. auriculiformis* × *A. mangium*) from Vietnam. Forests 11:717.
48. Xu, F., Zhong, X. C., Sun, R. C., and Lu, Q., 2006: Anatomy, ultrastructure, and lignin distribution in cell wall of *Caragana korshinskii*. Industrial Crops and Products 24: 186−193.
49. Yahya, R., Sugiyama, J., Silsia, D., Gril, J., 2010: Some anatomical features of an *Acacia* hybrid, *A. mangium* and *A. auriculiformis* grown in Indonesia with regard to pulp yield and paper strength. Journal of Tropical Forest Science 22(3): 343−351.
50. Yamada, N., Khoo, K.C., Yusoff, M.N.M., 1991: Sulphate pulping characteristics of *Acacia* hybrid, *Acacia mangium* and *Acacia auriculiformis* from Sabah. Journal of Tropical Forest Science 4: 206−214.
51. Yuniarti, K., Nirsatmanto, A., 2018: Several physical properties of *Eucalyptus pellita* F. Muell from different provenances and sampling position on tree. Jurnal Penelitian Kehutanan Wallacea 7(2): 151−163.

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