J. Korean Wood Sci. Technol. 2016, 44(4): 571~588 pISSN: 1017-0715 eISSN: 2233-7180
http://dx.doi.org/DOI:10.5658/WOOD.2016.44.4.571

Original Article

Chemical Properties and Fiber Dimension of *Eucalyptus pellita* from The 2nd Generation of Progeny Tests in Pelaihari, South Borneo, Indonesia[1]

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ABSTRACT

Eucalyptus pellita F. Muell is one of pulp woods that is being developed through breeding plantation programs in Indonesia. The research aimed at exploring the chemical and morphological characteristics of fiber, and to determine the rank of plus trees from 4 provenances based on the suitability for pulps. The materials included the plus trees of *E. pellita* (9 years) from the 2nd generation of progeny tests in Pelaihari, South Borneo. Wood properties under investigation included the chemical properties and morphological fiber characteristics (fiber dimensions and its derived properties). In the present study, data were analyzed using descriptive statistic, Analytic Hierarchy Process (AHP) and Pearson's correlation. Results showed that the chemical properties of *E. pellita, i.e.* the contents of ethanol-toluene extractives, hot water soluble extractives, holocellulose, alpha-celullose, and lignin were 3.08 ± 1.00%, 1.41 ± 0.38%, 75.26 ± 2.58%, 49.02 ± 2.88%, and 29.49 ± 1.86%, respectively. The average values of wood fiber morphology were 1.02 ± 0.08 mm (fiber length), 13.25 ± 1.64 μm (fiber diameter), of 6.94 ± 1.70 μm (lumen diameter), 3.15 ± 0.52 μm (fiber wall thickness), 0.97 ± 0.30 (Runkel ratio), 0.57 ± 0.10 (Luce's shape factor), 78.21 ± 10.34 (slenderness ratio) and 130.91 ± 33.77 × 10^3 μm^3 (solids factor). The AHP scoring rank indicated that the best individuals were 28.4.3.28 (Kiriwo Utara), 12.1.5.28 (North Kiriwo), 19.11.5.45 (Serisa Village), 3.8.4.9 (South Kiriwo), and 6.6.3.15 (South Kiriwo). Pearson correlation analysis showed significant correlations between the levels of fiber length with alpha-cellulose content (r = 0.39) as well as the fiber length with ethanol-toluene extractive contents (r = -0.41).

Keywords : *Eucalyptus pellita*, chemical properties, fiber morphology, Analytic Hierarchy Process, progeny test

1. INTRODUCTION

Eucalyptus has been recognized as an extensively-planted species for pulp production in numerous countries. In particular, *Eucalyptus pellita* has been posited as a primary raw material in Indonesia due to its fast growth. Besides, other desirable characteristics of *E. pellita* include a considerably good environmental adaptability, a straight stem growth, a single and

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high branchless stem, a high resistance to diseases and pests, and easy to cultivate (Harwood *et al*., 1997).

In fact, breeding objectives for pulp production systems for *E. pellita* have been developed by Japan International Cooperation Agency (JICA) and the Goverment of Indonesia through Centre for Forest Biotechnology and Tree Improvement Research (CBFTI). The programs were first initiated in 1994 by the establishment of the seed orchard for progeny trial in several sites. In 2003, the second progeny trials were conducted in Wonogiri (Central Java Province) and Pelaihari (South Borneo Province). During these programs, improved materials have been successfully produced by using classical breeding methods, which then results in a 18% increase of tree diameter, 15% of tree height, and 13% of stem volume (Leksono *et al*., 2008). An evaluation of tree increments indicated that the best source of seeds might have come from the progeny trial in Pelaihari site.

As aforementioned, the results of these tree improvement programs have been largely focused on the improvements of tree growth characteristics such as stem diameter, tree height and stem form. However, information about wood properties and pulp ability is still limited of the eucalyptus trees selected by breeding programs. The fiber length and specific gravity of the wood from the first progeny trial has been conducted by previous researches (Susilawati and Marsoem, 2006; Susilawati dan Fujisawa, 2002). There are many other wood properties that may act as selection criteria or influence that products have not been properly considered by current breeding objectives. As the priorities of national breeding programs have changed, a quite special attention has been put on wood quality. It is expected that the production of improved trees in the next future specifically will be targeted not only for growth characteristics, but also better quality of timber for pulp and paper.

Some chemical and anatomical properties are used by the pulping industry as indicators of wood quality for different industrial processes and final paper products. The purposes of this study included the evaluation on the degree of variation among 40 plus trees of *E. pellita* as a means to discover chemical and morphological wood characteristics and their relationship with growth characteristics. Another purpose put a focus on the rank among individuals as a raw material for pulp and paper by a multicriteria analysis i.e. analytic hierarchy process (AHP). Prior studies have shown that the method has been used in several timber applications (e.g. Kuzman and Grošelj, 2012; Myllyviita *et al*., 2013; Smith *et al*., 1995). Then, the best individuals are expected for being planted in future progeny trials (3rd generation).

2. MATERIALS and METHODS

2.1. Progeny test site and sample preparation

Materials were obtained from a 2nd generation of half-sib progeny test. The progeny test consisted of 60 families from first generation of half-sib progeny test representing 4 provenances from Papua New Guinea and Muting-Indonesia. The open pollinated progeny test site was located at Pelaihari in South Borneo Province, Indonesia (3° 58' south latitude and 114° 37' east longitude, altitude 44 m above sea level), with an annual rainfall of 2,730 mm, minimum temperature of 23℃, and maximum temperature of 35℃. The trial was established in 2003 by the Centre for Forest Biotechnology and Tree Improvement Research and PT. INHUTANI III. At planting, the progeny test had a complete block design in six replicates. In each plot, five trees were planted linearly. The initial spacing was 4 m between rows and 2 m within rows.

In this present study, a total of 40 plus trees from 4 provenances of 9-year-old *E. pellita* were used (Table 1). The tree diameters were measured and the wood specimens were sampled at breast height by axing in a depth of 5-6 cm from the bark for wood chemical and morphology analysis. In a such depth, the heartwood part was also included in the specimens.

2.2. Chemical analysis

Lignin content, hot water, and alcohol-toluene soluble extracts were determined according to ASTM standard methods (2002). The extractions by ethanol-toluene (ASTM D1107 - 96), and hot-water (ASTM D1110 - 84) were conducted in succession. Then, alpha-cellulose and holocellulose content were determined according to Wise's chlorite method (Browning, 1967).

Table 1. Individuals of *E. pellita* in Pelaihari, South Borneo

Provenance	Number of plus trees
Bupul Muting, Irian Jaya	1
Desa Serisa, West Papua	16
Kiriwo Selatan, West Papua	11
Kiriwo Utara, West Papua	12

2.3. Fiber morphology

Transverse sections of 12-μm in thickness were cut from the wood blocks on a sliding microtome (American Optical Corp., New York, USA). Sections were stained with a 0.1% solution of safranine (WAKO Pure Chemical Industries, Osaka, Japan), dehydrated with graded ethanol series, mounted on the glass slides, fixed in resin (Entellan new; Merck, Darmstadt, Germany) and covered with cover slips (Nugroho *et al.*, 2012). Images were recorded under a light microscope (Olympus BX 51; Olympus Coorporation; Japan) with a digital camera (Olympus DP 70; Olympus Coorporation; Japan). Digital images of transverse sections were recorded for measurements of fiber diameter, fiber lumen diameter, and fiber wall thickness according to IAWA (1989).

For the measurements of wood fiber length, small pieces were removed each block of samples. The pieces of wood were macerated with Franklin solution. Images of wood fibers were recorded under a light microscope (Olympus BX 51; Olympus Coorporation; Japan) with a digital camera (Olympus DP 70;

Olympus Coorporation; Japan). Lengths of wood fibers were measured with image-analysis software (Image pro Plus). A hundred wood fibers in each sample were measured at random according to IAWA (1989).

The derived fiber properties are defined as follows (Oshima *et al.*, 2005 and the literatures cited therein):

Runkel ratio = double fiber cell wall thickness / fiber lumen diameter ········ (1)

Luce's shape factor = (fiber diameter^2 − fiber lumen diameter^2) / (fiber diameter^2 + fiber lumen diameter^2) ········ (2)

Slenderness ratio = fiber length / fiber diameter ········ (3)

Solids factor = (fiber diameter^2 − fiber lumen diameter^2) × fiber length ········ (4)

2.4. Analytic Hierarchy Process (AHP)

AHP, first developed by Saaty (1980), refers to a multi-criteria decision analysis methodology that provides a comprehensive and rational framework for structuring a problem, for representing and quantifying its elements, for relating those elements to overall goals, and for evaluating alternative solution. It allows objective and subjective factors of a decision making. The first step is formulating the decision problem in a hierarchical structure. The top level presents the general objective of the decision problem. The elements affecting the decision are represented in intermediate levels. The lowest level comprises the decision options.

The goal/principle in this study aimed at determining the rank of individuals (plus trees) being tested by evaluating their suitable properties as raw material for pulps and papers, particularly a printing paper. In particular, developing a rank for discovering requires specific evaluation criteria.

Based on a literature study, the evaluation criteria were simplified into 2 goups, i.e. chemical properties and fiber morphology. Fig. 1 exhibits citeria taken in this study.

- Chemical properties criterion contains cell wall components (holocellulose, alpha-cellulose, lignin contents) and extractives (ethanol-toluene and hot-water soluble extracts).
- Fiber morphology criterion contains fiber dimension (fiber length, cell wall thickness, fiber and lumen diameter) and derived fiber properties (Runkel ratio, Luce's shape factor, slenderness ratio, solids factor).

The second step was to determine the variable in the criterion and indicator. Criterion used in the AHP were chemical properties and fiber derived values. Fiber dimension indicators were eliminated in this phase as their values were, theoretically, auto-correlated with derived fiber properties values. The colinearity test by Pearson's analysis among the variables in the chemical properties and derived fiber properties criterion then was performed on the basis of the obtained data.

The next step was to determine the relative importance of the element in each level of the

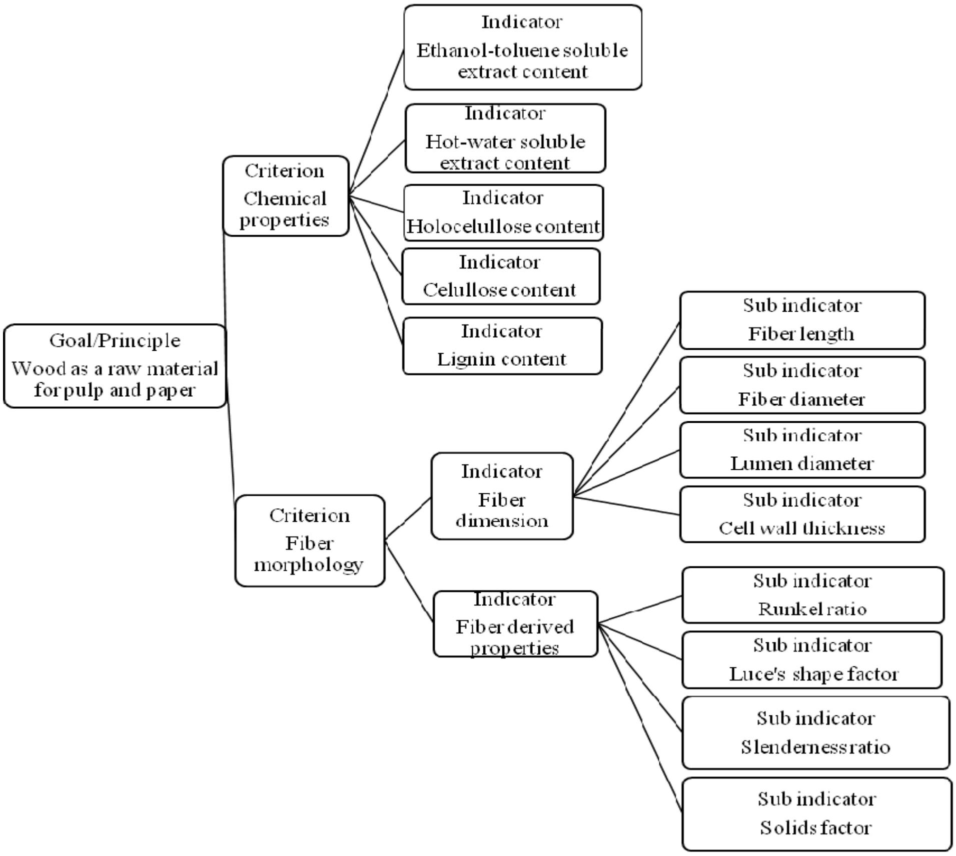

Fig. 1. The hierarchy tree for the evaluation of plus trees of *E. pellita*.

hierarchy. Elements in each level are pairwise compared with respect to their importance in making the decision under consideration. The evaluation of criteria weights was based on a subjective pairwise comparison of the criteria in a standard 1-9 AHP measurement scale (Saaty, 1980). This scale defines the intensity of importance of one criterion upon another, as shown in Table 2.

Determination of weighting percentage and consistency ratio was further performed. It was considered that, for printing paper purposes,

Table 2. Standard 1-9 Analytic Hierarchy Process measurement scale

Intensity of Importance	Definition
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Extreme importance
2, 4, 6, 8	Used for compromised judgments when necessary

between chemical properties and fiber derived values were equal importance (50 : 50). The

Table 3. Chemical properties of *E. pellita* wood in Pelaihari progeny trial, South Borneo

Chemical properties	Minimum	Maximum	Average (sd)	Coefficient of variation (%)
ETSE (%)	1.57	5.86	3.08 ± 1.00	32.6
HWS (%)	0.53	2.04	1.41 ± 0.38	26.7
Holocellulose (%)	71.07	79.33	75.26 ± 2.58	3.42
Alpha-cellulose (%)	43.79	53.31	49.02 ± 2.88	5.86
Lignin (%)	25.50	33.19	29.49 ± 1.86	6.30

Note: ETSE: ethanol-toluene soluble extractives, HWS: hot-water soluble extractives

degree of consistency achieved in the pair-wise comparison was measured by a consistency ratio (CR) which both checks the reliability of the analysis and reduces the chance of making a procedural mistake (Saaty, 1980).

After forming the comparison matrices above mentioned, the process moves to the phase of data normalisation and scoring. Normalization values were calculated by dividing the actual value by the maximum value in all samples of each indicator. Apparently, the indicators with a positive correlation were alpha-cellulose contents and slenderness ratio. It means that a higher value of those indicators would produce a better pulp quality and *vice-versa*. In contrast, ones with a negative correlation included ethanol-toluene soluble extract, hot-water soluble extract, lignin content, Runkel ratio, and solid factor.

Then, scoring is useful to express the preferences of a decision maker. In the current study, score for each indicator was obtained by multiplying normalized score and its weighting percentage. A total score was then calculated by summing the whole scores of indicators. The best ranks were samples with the highest score.

2.5. Pearson's correlation analysis

Relationships between the independent variables were investigated through a Pearson's correlation analysis. The corellation of some parameters, e.g. hollocellulose-lignin contents, fiber diameter-lumen diameter values, fiber dimension-derived fiber dimension values, and RR - LSF values, were not calculated to avoid auto-correlation.

3. RESULTS and DISCUSSION

3.1. Chemical properties

In the future, tree selection in breeding program on the basis of pulp yield and alpha-cellulose, lignin and extractives contents are possible to be economically relevant for the paper industries. In the current study, the chemical properties were assessed from the contents of extractives and cell wall components. Table 3 summarizes the detemination of chemical properties of *E. pellita* in the 2nd generation of progeny tests. Ethanol-toluene soluble extracts (ETSE), hot-water soluble extracts (HWS), holocellulose, alpha-celullose, and lignin were 3.08

± 1.00%, 1.41 ± 0.38%, 75.26 ± 2.58%, 49.02 ± 2.88%, and 29.49 ± 1.86%, respectively. In general, a high level of coefficent variation (CV > 20%) was measured in terms of ETSE and HWS. In contrast, cell wall components gave lower CV values in all parameters.

By successive extraction, ETSE gave higher values than those of HWS indicating a lower of sugar contents in the *E. pellita* wood. In terms of cell wall components, *E. pellita* wood showed comparatively high lignin contents (25-33%). The values obtained here showed a higher holocellulose and extractive content levels but lignin contents are comparable to the values of *E. pellita* grown in Brazil (Olieveira *et al*., 2010) and Pinar Del Rio (Igarza *et al*., 2006). Among other eucalyptus species, *E. pellita*, therefore, has higher extractive, holocellulose, and lignin contents than those of *E. grandis, E. alba, E. tretecornis* (Dutt and Tyagi, 2011), *E. globulus*, and *E. urograndis* (Evtuguin and Netto, 2007).

The best chemical properties for pulp and paper were observed in individuals from different provenances. In particular, the lowest of ETSE levels were found in individuals from Kiriwo Utara (a sample code of 24/12.1.5.28) provenance while for the HWS, and lignin content values (a sample code of 11/5.5.5.42 and 13/6.10.2.34) were from Desa Serisa provenances. Further, the highest levels of holocellulose and alpha-cellulose contents were measured in trees from Desa Serisa (23/11.17.1.35) and Kiriwo Utara (34/22.17.2.23) provenances.

Apparently, a fiber separation occurs as lignin that cements the cells together is dissolved (Shmulsky and Jones, 2011). Cellulose composes ca. 40-50% of the dry weight of wood and is the major component (74-86% by weight) of kraft pulp (Sjöström, 1992). In this experiment, a comparatively high average of alpha-cellulose content may have occured probably due to the sampling position, which is near the bark (5-7 cm). The variation of cellulose content increase from the pith toward the bark (Tsoumis, 1991). The high amounts of cellulose and hemicellulose are necessary as they may produce a high yield of pulp (Kien *et al*., 2009; Copur *et al*., 2005).

Compared to *Acacia mangium* (Haroen and Dimyati, 2006), which is a major pulpwood in Indonesia, *E. pellita* had lower cellulose content and higher lignin and extractive contents. In this context, *A. mangium* is considered as having a better raw material for pulp than *E. pellita*. However, it should be noted that *A. mangium* is not as resistance particularly against Ganoderma fungi (Irianto *et al*., 2006).

3.2. Fiber morphology

Beside chemical properties, the physical properties of sheets manufactured from hardwood pulp fibers are affected by the characteristics of the fibers (Nugroho *et al*., 2012). The characters of fiber morphology could be determined from the fiber dimension and its derived fiber properties. Table 4 shows a summary of fiber morphology values for *E. pellita* in the 2nd

Table 4. Fiber morphology of *E. pellita* wood in Pelaihari progeny trial, South Borneo

Fiber morphology	Minimum	Maximum	Average (sd)	Coefficient of variation (%)
Fiber length (mm)	0.86	1.17	1.02 ± 0.08	8.3
Cell wall thickness (μm)	2.19	4.03	3.15 ± 0.52	16.6
Fiber diameter (μm)	10.82	17.03	13.25 ± 1.64	12.3
Lumen diameter (μm)	4.22	11.98	6.94 ± 1.70	24.4
Runkel ratio	0.42	1.64	0.97 ± 0.30	30.5
Luce's shape factor	0.34	0.75	0.57 ± 0.10	17.8
Slenderness ratio	53.67	103.29	78.21 ± 10.34	13.2
Solids factor (× 10^3 μm^3)	78.25	205.97	130.91 ± 33.77 × 10^3	25.8

generation of progeny test. In details, the average values of wood fiber morphology were 1.02 ± 0.08 mm (fiber length), 13.25 ± 1.64 μm (fiber diameter), 6.94 ± 1.70 μm (lumen diameter), 3.15 ± 0.52 μm (fiber wall thickness), 0.97 ± 0.30 (Runkel ratio/RR), 0.57 ± 0.10 (Luce's shape factor/LSF), 78.21 ± 10.34 (slenderness ratio/SR) and 130.91 ± 33.77 × 10^3 μm^3 (solid factor/SF). The low CV values were observed in terms of fiber length, fiber diameter, cell wall thickness, SR, and LSF parameter. On the other hand, RR and SF showed comparatively high CV values. Similar to the chemical property variables, the high CV values indicate high variations within the population.

In case of fiber length, the values of this experiment (0.78-1.17 mm) were within the range of first generation of progeny test (1.00-1.10 mm), which was measured at near of the bark (Susilawati and Marsoem, 2006). In addition, fibers from Pelaihari site were thinner compared to *E. pellita* grown in Merauke site in terms of fiber and lumen diameters (Marsoem *et al*., 2012).

These samples also had shorter fiber length and thinner cell wall thickness than those of *E. pellita* grown in Portugal (Poubel *et al*., 2011) and China (ITTO, 2006). Compared to other eucalyptus species, *E. pellita*, has in fact a longer fiber length than *E. grandis, E. tretecornis, E. torelliana, E. urophylla*, (Dutt and Tyagi, 2011) and *E. globulus* (Wimmer, 2002); however, it has a thinner cell wall thickness than *E. globulus, E. alba, E. tretecornis, E. torelliana, E. europhylla, E. caldulensis* (Aguayo, 2012; Dutt and Tyagi, 2011).

Next, regarding derived fiber properties, *E. pellita* in the current showed lower RR and higher SR values than *E. pellita* grown in India (Moorthy, 1985). Compared to other eucalyptus species, higher values of derived fiber properties were observed in these *E. pellita* samples compared to *E. camaldulensis* and *E. globulus* (Ona *et al*., 2001; Oshima *et al*., 2005). Further, the samples had lower RR, LSF, and SF values but a higher SR value compared to *E. tereticornis* and *E. grandis* (Sharma *et al*., 2011).

In term of fiber morphology, the samples indicated that the best characteristics were also distributed to different provenances. The longest fiber values were measured in the samples from Desa Serisa, but the thinnest cell wall and lowest LSF and RR values were found in the samples from Kiriwo Selatan provenances. Further, the highest SR and lowest SF values were revealed in the samples from Kiriwo Utara provenances.

A previous study by Bamber (1985) has found that RR value less than 1.0 is favourable to produce a good conformability and an inter-fiber contact in manufacturing paper using hardwoods. It was noted that the average RR values of *E. pellita* was 0.97 or near 1.0. The value is considered as high as RR negatively related to pulp digestibility and positively related to pulp yield (Ona *et al*., 2001). In general, *E. pellita* is hence predicted to produce a good yield but a low digestibility for making pulp. Further, the RR and SR values of *E. pellita* is higher than that of *A. mangium* (RR = 0.45; SR = 66.98) reported by Haroen and Dimyati (2006).

3.3. Analytic Hierarchy Process (AHP)

The evaluation for pulp quality is known as a difficult and complicated approach, which has to deal with wood anatomical, physical, and chemical aspects. The AHP is a method for conducting a decision making with which one may a decision based on several attributes, or known as a multi-criteria decision. It may reduce a set of complex decisions to a series of pairwise comparisons and then synthesizes new results. In particular, the goal in this study was to rank plus trees under observation in terms of their suitability to produce printing paper. Practically, the criteria were simplified into chemical properties and fiber morphology (Fig. 1). Some other common properties, e.g. wood density and cells proportion, were not included in this experiment.

Basically, printing paper requires a higher proportion of chemical pulps i.e. bleached kraft pulp from both hardwoods and softwoods. Thus, chemical properties of initial pulp woods would surely affect pulps being manufactured. Beside chemical properties, selection criteria based on intrinsic wood characteristics such as fiber dimension to produce pulp was a routine in genus eucalypt (e.g. Ramirez *et al*., 2009; Wimmer *et al*., 2002; Wimmer *et al*., 2008; Apiolaza *et al*., 2005).

Prior to performing colinearity test, some sub indicator variables were eliminated due to auto-correlations. Fiber dimension parameters were excluded in this phase, which was then replaced by derived fiber properties. For instance, fiber length variable was represented by SR (fiber length/fiber diameter) while cell wall thickness was represented by RR (double fiber cell wall thickness/fiber lumen diameter).

Apparently, a colinearity test showed that there was no strong correlation among the chemical properties; however, a strong correlation was found between LSF and RR (r = 0.98) in derived fiber properties (Table 5 and 6). Therefore, one variable should be eliminated as it indicated an auto-corellation. The auto-corre

Table 5. Colinearity test among the criterion of chemical properties

Parameters	ETSE	HWS	Alpha-cellulose
HWS	0.24		
Alpha-cellulose	0.27	0.26	
Lignin	0.19	0.32	0.49

Note: ETSE = ethanol-toluene soluble extractives, HWS = hot-water soluble extractives

Table 6. Colinearity test among the criterion of derived fiber properties

Parameters	RR	LSF	SR
LSF	0.98		
SR	0.47	0.52	
SF	0.22	0.21	0.31

Note: RR = Runkel ratio, LSF = Luce's shape factor, SR = slenderness ratio, SF = solids factor.

lation between sub indicator RR and LSF may be related to wall thickness as fiber diameter and fiber lumen diameter are used to obtain the cross-sectional fiber wall area in both equations. RR value was selected for the sub indicator of criterion in the next phase. RR was selected as it has more frequently been taken than LSF to evaluate pulp quality in many prior studies than LSF. Among all chemical properties, holocellulose content was eliminated as it auto-correlates with lignin content, while also partly represented by alpha-cellulose content.

The next step of AHP is suitable criteria for decision making are compared with each other and their value-weighted index is determined. The pairwise comparison of these criteria with respect to goal is presented in Table 7 and 8. Looking at chemical properties, alpha-cellulose content had a very strong importance, strong, and equal upon the ethanol-toluene soluble extractives (ETSE), hot-water soluble extractives (HWS), and lignin contents, respectively. Furthermore, lignin content criterion favoured strongly importance upon ETSE criterion and extreme important upon HWS criterion. Finally, ETSE criterion had a moderate importance upon the HWS criterion. On the basis of fiber derived properties, SR criterion had a a moderate importance upon RR and very strong importance upon SF. Then, RR criterion has an extreme importance upon SF.

Table 7. Pair wise comparison of criteria on chemical properties of *E. pellita* wood with respect to goal

Chemical properties	ETSE	HWS	Cellulose	Lignin
ETSE	1	3	$\frac{1}{7}$	$\frac{1}{6}$
HWS		1	$\frac{1}{9}$	$\frac{1}{8}$
Cellulose			1	2
Lignin				1

Note: ETSE: ethanol-toluene soluble extractives, HWS: hot-water soluble extractives

Table 8. Pair wise comparison of criteria on fiber derived properties of *E. pellita* wood with respect to goal

Fiber derived properties	RR	SR	SF
RR	1	$\frac{1}{2}$	7
SR		1	9
SF			1

Note: RR = Runkel ratio, SR = slenderness ratio, SF = solids factor.

It is unsure whether one between chemical properties and fiber morphology has a stronger effect on the pulp quality of *E. pellita*. In the current study, an equal proportion was assumed between these two (50 : 50). The results of de-

Table 9. Weighting percentage and consistency ratio

Types of criterion	Indicators	Weighting percentage	Consistency ratio
Chemical properties	ETSE	5	6.67%
	HWS	2	
	Alpha-cellulose	26	
	Lignin	17	
Derived fiber properties	Runkel ratio	17	1.55%
	Slenderness ratio	30	
	Solid factor	3	
	Total	100	

Note: ETSE: ethanol-toluene soluble extractives, HWS: hot-water soluble extractives

termination of weighting percentage and consistency ratio are presented in Table 9. On the basis of chemical properties, cellulose content was ranked first, having the highest weighting factor (26%), which is followed by lignin content (17%). The SR was ranked first (30%) followed by RR (17%), within the fiber derived values.

The content of alpha-cellulose is associated with the stability and longevity of paper, whereas the non-cellulosic components may cause the degradation of these materials (Markussen *et al*., 2002). Besides, pulp cooking is not possible until all lignin has been dissolved, causing detrimental effects on both yield and pulp strength. Then, high amounts of wood extractives may cause operational and quality problems during pulp and paper production due to the formation of spots, specks, and other product defects.

In terms of chemical parameters, alpha-cellulose content was set as the most important indicators followed by lignin content (Table 7 and 9). In earlier reports, alpha-cellulose content is strongly correlated with whole tree kraft pulp yield of *E. globulus* and *E. nitens* (Apiolaza *et al*., 2005; Kube and Raymond, 2002; Wallis *et al*., 1996). Alpha-cellulose content is under strong genetic control and is useful to rank trees, which is based on pulp yields, over in *E. urophylla* plantations (Kien *et al*., 2009). In fact, a higher pulp yield may reduce in the wood requirement per ton of pulp being produced, and consequently wood costs. Thus, the alpha-cellulose was strongly preferred in this regard.

Within fiber dimension sub indicators, fibre length has a direct effect on the tear index of *E. globulus* (Wimmer *et al*., 2002). Further, the thickness of the fiber wall is associated with tearing strength (Nugroho *et al*., 2012). In this study, parameters of fiber dimension were represented by derived fiber properties. In a prior work, Oshima *et al*. (2005) summarized that RR is related to paper conformability as well as pulp yield, whereas LSF and SR may affect paper sheet density and to pulp digestability, respectively. LSF and SF associated in a negative way with the breaking length of paper among eucalyptus species.

Shmulsky and Jones (2011) have described the critical position of tear strength for a printing paper; however, other factors have also been contributing, e.g. ink absorbency, brightness, permanent whiteness, surface smoothness, and opacity. From a point of view as such, SR, as a derived fiber properties, is determined to be a mainly prioritized sub indicators (Table 8 and 9) as it includes fiber lenght within its formula. SR has also been reported as affecting folding endurance, tensile, burst, and tearing strength (Oshima *et al*., 2005; Horn, 1978).

The AHP allows some small inconsistencies in some degrees during a judgment, because human is not always consistent. In order to produce compatible judgments, it is necessary to maintain the inconsistence rate of matrices at equal to or below 0.1. If the rate is higher than 0.1, it is necessary to revise the expert's judgment for making matrices compatible. Besides, the geometrical mean of cells of matrices is obtained from comparative matrices (Saaty, 2000). The value obtained values for two sub-criteria were lower than 10% so that the judgment could be justified (Table 9). It was calculated that CR values of chemical properties was higher than that of derived fiber properties (Table 9).

Finally, AHP suggest a synthesizing process over all judgments into a general conclusion, in which alternatives are clearly classified from best to worst. After determination of weighting percentage and consistency ratio, the values were normalized and scored. The rank of top 20 out of 40 individuals is listed in Table 10. From the list, the sample codes in the top 5 ranks were 38/28.4.3.28 (Kiriwo Utara), 24/12.1.5.28 (Kiriwo Utara), 32/19.11.5.45 (Desa Serisa), 7/3.8.4.9 (Kiriwo Selatan), and 12/6.6.3.15 (Kiriwo Selatan). In other words, these 5 and other best individuals are predicted to produce pulp with a better quality for a printing paper. Consequently, those highly-scored individuals are the candidates for the 3rd generation for progeny tests in the future.

By a close examination, the top 5 individuals were evaluated for each indicator (Table 11). The table showed that the highest rank individuals did not necessarily deliver the best characteristics in all parameters under observation. For example, a first rank individual (the sample code 38/28.4.3.28, originated from Kiriwo Utara) has been ranked the 2nd, 18th, 20th, 11th, 2nd, 36th and 30th best within all samples for ETSE, HWS, alpha-cellulose, lignin contents, RR, SR, and SF parameters, respectively. It may have delivered the highest total score, although it has never reached the best for each parameter. Furthermore, the high CV values may have also been affecting the rank of the tested samples as the resulted test scores indicated a wide margin among the individuals.

Paper quality may be approached by strength, optical properties, softness or proper ink receptivity. It may possibly expected with proper knowledge of the complexity presented in woods, by which various quality requirements could be anticipated with a better accuracy. It should be noted that anatomical factors, which

Table 10. The rank of 20 individuals of *E. pellita* in Pelaihari progeny trial, South Borneo

Individual number	Sample Code	Provenance	Total score	Rank
38	28.4.3.28	Kiriwo Utara, Papua Barat	146.7	1
24	12.1.5.28	Kiriwo Utara, Papua Barat	142.7	2
32	19.11.5.45	Desa Serisa, Papua Barat	139.8	3
7	3.8.4.9	Kiriwo Selatan, Papua Barat	135.3	4
12	6.6.3.15	Kiriwo Selatan, Papua Barat	135.0	5
22	10.9.4.27	Kiriwo Utara, Papua Barat	129.4	6
35	23.13.5.12	Kiriwo Selatan, Papua Barat	127.8	7
34	22.17.2.23	Kiriwo Utara, Papua Barat	124.3	8
20	8.13.4.20	Kiriwo Utara, Papua Barat	123.6	9
28	14.2.4.37	Desa Serisa, Papua Barat	123.0	10
13	6.10.2.34	Desa Serisa, Papua Barat	122.0	11
10	4.5.5.6	Bupul-Muting, Irian Jaya	121.4	12
19	8.11.1.47	Desa Serisa, Papua Barat	121.0	13
33	21.16.5.1	Kiriwo Selatan, Papua Barat	116.9	14
36	25.15.2.19	Kiriwo Utara, Papua Barat	116.9	15
11	5.5.5.42	Desa Serisa, Papua Barat	116.5	16
37	27.2.2.20	Kiriwo Utara, Papua Barat	116.2	17
29	16.10.2.3	Kiriwo Selatan, Papua Barat	115.2	18
15	6.15.1.38	Desa Serisa, Papua Barat	114.6	19
21	10.4.3.38	Desa Serisa, Papua Barat	113.4	20

Table 11. Top 5 ranks for individual of *E. pellita* in progeny trials at Pelaihari, South Borneo, Indonesia, based on Analytic Hierarchy Process analysis

Properties	**Rank**									
	I		**II**		**III**		**IV**		**V**	
	R	**S**	**R**	**S**	**R**	**S**	**R**	**S**	**R**	**S**
ETSE (%)	2	1.76	1	1.57	20	2.74	36	4.57	30	3.46
HWS (%)	18	1.37	2	0.62	8	1.09	33	1.84	22	1.43
Alpha-cellulose (%)	20	49.75	12	51.17	7	52.29	37	44.95	38	44.60
Lignin content (%)	11	28.47	4	26.20	10	28.42	26	30.25	22	30.00
Runkel ratio	2	0.46	10	0.79	4	0.49	1	0.42	3	0.47
Slenderness ratio	36	65.8	1	103.29	34	66.85	40	53.66	39	57.96
Solids factor ($\times$ 10^3 μm^3)	30	156.23	12	101.08	19	130.46	22	133.92	2	78.34
Individual number	**38**		**24**		**32**		**7**		**12**	
Sample code	**28.4.3.28**		**12.1.5.28**		**19.11.5.45**		**3.8.4.9**		**6.6.3.15**	
Provenance	**Kiriwo Utara**		**Kiriwo Utara**		**Desa Serisa**		**Kiriwo Selatan**		**Kiriwo Selatan**	

Note: R = rank within the samples; N = score of evaluation; ETSE: ethanol-toluene soluble extractives, HWS: hot-water soluble extractives

Table 12. Pearson's correlation coefficients among the chemical properties and fiber morphology values of *E. pellita*

Parameters	TD	ETSE	HWS	HOL	AC	LG	FL	FD	LD	CT	RR	LSF	SR
ETSE	-0.19												
HWS	-0.12	0.23											
HOL	-0.09	-0.06	0.09										
AC	-0.06	-0.27	-0.26	0.08									
LG	0.13	0.19	0.32*		-0.49**								
FL	0.04	-0.41**	-0.16	0.07	0.39*	-0.20							
FD	-0.32*	-0.09	-0.24	-0.18	0.00	-0.15	0.14						
LD	-0.29	0.01	-0.21	-0.17	-0.18	-0.16	-0.15						
CT	-0.02	-0.17	-0.02	-0.00	0.30	0.02	0.48**		-0.36*				
RR	0.13	-0.11	0.24	0.05	0.27	0.11							
LSF	0.19	-0.11	0.16	0.10	0.28	0.12					0.98**		
SR	0.31*	-0.17	0.12	0.18	0.23	-0.01					0.48**	0.52**	
SF	-0.17	-0.27	-0.21	-0.06	0.25	-0.11					0.22	0.21	-0.31

Note: TD = tree diameter, ETSE: ethanol-toluene soluble extractives, HWS: hot-water soluble extractives, HOL = holocellulose, AC = alpha-cellulose, LG = lignin, FL = fiber length, FD = fiber diameter, LD = lumen diameter, CT = cell wall thickness, RR = Runkel ratio, LSF = Luce's shape factor, SR = slenderness ratio, SF = solids factor.

will affect pulp quality such as cell wall percentage and cell proportion were not included in this model as well as wood density and microfibril angle. The addition of these parameters may further help tree breeders during tree selection in future programs.

3.4. Relationship between tree diameter, chemical properties, and fiber morphology of *E. pellita* wood

Enhancing of wood properties through breeding is valuable only if there are significant relationships between wood properties and end-product properties. These relationships are expected to reduce costs and optimize paper quality to match consumer requirements of the wooden industries. Correlation analysis between tree diameter and wood properties is shown in Table 12. There was a negative and significant relationship between tree diameter and fiber diameter (r = -0.32). A similar finding also occurs between tree diameter and SR (r = 0.31). Despite having weak degrees, a smaller fiber diameter and a higher SR may occur for trees with a bigger diameter. A high SR value indicates a long and thin fiber (Sharma *et al.*, 2013). As a high SR value is expected to enhance pulp quality, a bigger tree diameter is clearly an advantage.

Among the wood properties, a moderate degree correlation was discovered between lignin and alpha-cellulose contents (r = -0.49), which is followed by between fiber length and cell wall thickness (r = 0.48). Further, among derived fiber properties, the highest correlation coefficient was observed between the LSF and SR (r = 0.52). In terms of a relationship between chemical and fiber properties, a significant correlation was measured between alpha-cellulose content and fiber length value (r = 0.39).

A moderate negative correlation (r = -0.49) between alpha-cellulose and lignin content may probably occur due to the hemicellulose parts in the holocellulose. The significant positive correlation between fiber length and cell wall thickness indicates the increase of cell length and cell wall thickness goes hand in hand during wood formation. However, it does not occur between lumen diameter and cell wall thickness as shown by a negative correlation (r = -0.36). A previous report by Kiaei (2012) on Maple wood has discovered that the increase of fiber and lumen diameters but the decrease in cell wall thickness occur alongside the increase of cambial age.

Furthermore, a positive correlation (r = 0.48) between RR and SR values is undesirable for enhancing pulp quality. SR have been recognized as being positively correlated with the folding endurance in a paper (Oshima *et al*., 2005), while RR is expected to have a low value (RR < 1) (Sharma *et al*., 2013). A similar has also been observed between LSF and SR (r = 0.52). Technically, LSF affects the density of paper (Sharma *et al*., 2013); however, LSF is negatively correlated with pulp quality (Ona *et al*., 2001).

Moreover, in terms of chemical properties and fiber morphology, there is a positive correlation between fiber length and alpha-cellulose (r = 0.39), while the length has a negative correlation with ETSE values (r = -0.41). These results may have been interpreted as during fiber formation, alpha-cellulose is also intensively formed; however, it has not always been followed by formation extractives in the lumen. Then, there is in fact no significant correlation discovered between lumen diameter and extractive contents.

4. CONCLUSION

The study has investigated differences in terms of the chemical composition and fibre morphology of *Eucalyptus pellita* planted in progeny trials at Pelaihari site, South Borneo, Indonesia. These properties are important for the quality breeding of pulpwoods. Sampling was conducted over 40 plus trees, which have aged years old, from 4 provenances. Judging by coefficient of variation values, extractive contents are considerably more varied than the cell wall components. Investigations on fiber morphology have revealed that high coefficent of variation levels were observed in lumen diameter, Runkel ratio, and solids factor. The methodology based on AHP was suggested in this study to select a suitable material among plus trees for a printing paper. Quantitative requirements in the optimal selection model for plus trees were distinguished into two parts, the required chemical properties and fiber morphology. The former consisted of holocellulose, alpha-cellulose, lignin, and extractives from ethanol-toluene and hot-water. The latter covered Runkel ratio, slenderness ratio, and solids factor. As results, the rank for 40 plus trees was obtained, which will later be prioritized for the next progeny test. Then, moderate significant correlations between the levels of fiber length and alpha-cellulose content as well as between the fiber length with ethanol toluene extractive contents have been measured by utilizing Pearson's analysis. The minimal performance criteria taken in this study may be further be updated in order to achieve more accurate information.

ACKNOWLEDGEMENTS

We wish to thank Centre for Forest Biotechnology and Tree Improvement Research (CFBTI) for funding support. The assistance of Suzumu Kurinobu, expert from JICA for the progeny test of *E. pellita* in South Kalimantan, M. Anis Fauzi (CFBTI), Soleh Nurochman and Amrin (INHUTANI III) who helped to collect the wood samples in South Kalimantan is greatly appreciated.

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