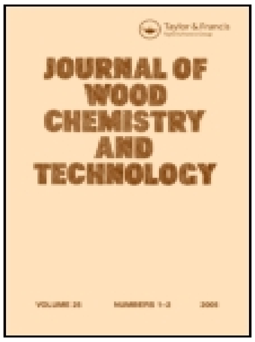

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Wood, Chemical, and Pulp Properties of Woods from Less-Utilized Fast-Growing Tree Species Found in Naturally Regenerated Secondary Forest in South Kalimantan, Indonesia

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WOOD, CHEMICAL, AND PULP PROPERTIES OF WOODS FROM LESS-UTILIZED FAST-GROWING TREE SPECIES FOUND IN NATURALLY REGENERATED SECONDARY FOREST IN SOUTH KALIMANTAN, INDONESIA

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This study aimed to identify fast-growing tree species suitable for pulpwood obtained from a secondary forest in South Kalimantan, Indonesia. Chemical and pulp properties were determined for terap (*Artocarpus elasticus* Reinw. ex Blume), medang (*Neolitsea latifolia* (Blume) S. Moore), and balik angin (*Alphitonia excelsa* (Fenzel) Reissek ex Benth). The mean values of ethanol-toluene extract and total lignin contents in terap, medang, and balik angin were 1.5 and 29.7, 2.1 and 25.0, and 3.0 and 24.6%, respectively. A significant negative correlation ($r = -0.573$) was obtained between lignin content and pulp yield, suggesting that low lignin content in these woods leads to high kraft pulp yields. On the basis of these results, it can be considered that medang and balik angin woods are promising raw materials for bleached pulp, whereas terap wood is suitable for unbleached pulp.

Keywords. Wood property, chemical component contents, pulp yield, Kappa number, fast-growing trees

INTRODUCTION

Indonesia has become one of the top 10 producers of pulp and paper worldwide,[1] and the industry has expanded rapidly at approximately 15% per year.[2] Pulp production capacity in Indonesia grew from 606,000 to 7.9 million metric tons per year between 1988 and 2010, whereas the processing capacity of the paper industry rose from 1.2 million to 12.2 million tons per year.[1]

Wood is widely used as a raw material for the pulp and paper industry in Indonesia. Therefore, fast-growing tree species play an important role in supplying raw material for the pulp industry. However, the common raw materials of pulpwood from fast-growing species, such as *Acacia mangium*, *Falcataria moluccana*, and others, are now used for lumber, plywood, and furniture, which have higher economic values. This condition has caused disparities between the demand and supply of wood for the pulp industry. To address these disparities, studies need to identify new wood resources as raw materials for pulp and paper.

To identify new or alternative pulpwood feedstocks, the wood and chemical properties should be evaluated. Wood properties, such as Runkel ratio, Luce's shape factor, flexibility

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coefficient, slenderness ratio, and solid factor, are calculated from measurements of anatomical characteristics, and these values are closely related to pulp yield, sheet density, burst factor, and breaking length of pulp.[3–5] In addition, the chemical components of wood influence the optimal pulping process, pulp yield, Kappa number, and paper quality.[6–12]

Terap (*Artocarpus elasticus* Reinw. ex Blume), medang (*Neolitsea latifolia* (Blume) S. Moore), and balik angin (*Alphitonia excelsa* (Fenzel) Reissek ex Benth) are less-utilized native tree species in South Kalimantan, Indonesia. These species are naturally distributed and are abundantly found in secondary forests in South Kalimantan. However, information on the wood, chemical, and pulp properties of these three species is limited. Studies of these properties are needed before these trees can be utilized as alternative pulp feedstocks.

The objective of this study was to characterize three native, fast-growing species—terap, medang, and balik angin—as potential new materials for the pulp and paper industry in Indonesia. For this purpose, wood, chemical, and pulp properties were determined for these three species.

EXPERIMENTAL

Wood Materials

Five trees of each species (terap, medang, and balik angin), grown in a naturally regenerated secondary forest in the Education Forest at Lambung Mangkurat University, Mandiangin, South Kalimantan, Indonesia (3°2′ to 3°45′S, 114°5′ to 115°10′E), were used.[13] Detailed information about the sampling site and sampled trees was presented previously.[13] The mean stem diameters of the harvested terap, medang, and balik angin trees were 19.4, 19.0, and 18.8 cm, respectively.[13] Disks of 10 cm in thickness were obtained 1 m above the ground from each tree.

Wood Properties

To determine the fiber length, small blocks were collected from the disks at 1 cm intervals from pith and macerated with Schulz's solution. Fifty fibers in each sample were measured under a microprojector (V-12B, Nikon, Japan) with a digital caliper (CD-15CX, Mitutoyo, Japan).

Blocks (ca. 1 × 1 × 1 cm) collected from the disks at every 1 cm from pith to bark were used for determining cell morphology. Wood blocks were softened with 25% glycerin at 90°C for 50, 6, and 33 hours for terap, medang, and balik angin, respectively. Transverse sections (15 − 30 μm) were prepared, stained with safranin, dehydrated, and mounted in Bioleit (Koken Co. Ltd., Japan). Transverse-sectional images were captured by computer and analyzed with ImageJ software (National Institutes of Health, USA). The following fiber morphologies were measured: radial and tangential diameters, lumen radial and tangential diameters, cell area, lumen area, cell perimeter, and lumen perimeter. Tangential and radial diameters were determined from 50 fiber measurements in each 1 cm segment. Fiber diameter, fiber lumen diameter, and fiber wall thickness were calculated as follows:

$$\text{Fiber diameter } (\mu\text{m}) = \frac{\text{Radial diameter} + \text{tangential diameter}}{2}$$

$$\text{Fiber lumen diameter } (\mu\text{m}) = \frac{\text{Radial lumen diamater} + \text{tangential lumen diameter}}{2}$$

$$\text{Fiber wall thickness } (\mu\text{m}) = \frac{2 \times (\text{Cell area} - \text{lumen area})}{(\text{Cell perimeter} + \text{lumen perimeter})}$$

Runkel ratio,[14] slenderness ratio,[15] coefficient of rigidity,[3] Luce's shape factor,[16] solids factor,[4] and flexibility coefficient[15] were calculated by the following equations:

$$\text{Runkel ratio} = \frac{\text{Fiber wall thickness} \times 2}{\text{Fiber lumen diameter}}$$

$$\text{Slenderness ratio} = \frac{\text{Fiber length}}{\text{Fiber diameter}}$$

$$\text{Coefficient of rigidity} = \frac{\text{Fiber wall thickness}}{\text{Fiber diameter}}$$

$$\text{Flexibility coefficient} = \frac{\text{Fiber lumen diameter}}{\text{Fiber diameter}}$$

$$\text{Luce's shape factor} = \frac{[(\text{Fiber diameter})^2 - (\text{fiber lumen diameter})^2]}{[(\text{Fiber diameter})^2 + (\text{fiber lumen diameter})^2]}$$

$$\text{Solids factor} = [(\text{Fiber diameter})^2 - (\text{Fiber lumen diameter})^2] \times \text{Fiber length}$$

Chemical Analysis

The following chemical components were determined by standard methods[17–19]: 1% sodium hydroxide, hot water, and organic solvent extracts; holocellulose; α-, β-, and γ-cellulose; Klason lignin; acid-soluble lignin; and ash. Before chemical analysis, the samples from the whole discs of wood were ground with a rotary speed mill (P-14, Fritsch, Germany) and then sieved to collect the 42–82 mesh size.

Pulp Properties

Wood sticks (ca. 1 × 1 × 20 mm) were cut from the whole disks of wood to determine pulp properties. Five grams of wood sticks was pulped by the following kraft cooking conditions: active alkali charge = 16% (as NaOH); sulfidity index = 25%; liquor/wood ratio = 4/1; time to cooking temperature = 90 min; time for cooking at 170°C = 90 min. After cooking, pulp yield was determined as the ratio of oven-dry weight of the residue after pulping to oven-dry weight of wood sticks. Kappa number was determined according to ES ISO 302:2012 (E).

To evaluate the relationships between basic density (BD) and chemical or pulp properties, small blocks (from pith at 1 cm intervals, 2 cm in width and 1 cm in thickness) were collected from the disks. BD was calculated as the ratio of oven-dry weight to green volume determined by the water displacement method.[20]

RESULTS AND DISCUSSION

Wood Properties

Table 1 shows the wood properties of the three species investigated. Ashori and Nourbakhsh[7] pointed out that the most important and primary observation determining the suitability of any raw material for pulp and paper manufacturing is the Runkel ratio. In general, a fiber with a high Runkel ratio produces stiff, less flexible, and bulky paper.[5,7] The standard value of the Runkel ratio is 1, and favorable pulp strength properties are usually obtained when the Runkel ratio lies below this value.[7,21] In the present study, the Runkel ratios of terap, medang, and balik angin were 0.16 ± 0.05, 0.45 ± 0.05, and 0.14 ± 0.01, respectively (Table 1). Medang showed the highest Runkel ratio among the three species examined here. The Runkel ratios of *Eucalyptus camaldulensis* and *E. globulus* were 0.42 and 0.40, respectively.[5] Yahya et al.[8] reported that the Runkel ratios in *Acacia* hybrid, *A. mangium*, and *A. auriculiformis* were 0.37, 0.37, and 0.55, respectively. The Runkel ratio in medang was similar to those in *Eucalyptus* spp. and *Acacia* spp.[5,8] The lower Runkel ratio of terap, medang, and balik angin indicates that the fibers of these three species are easily collapsed to form paper with good strength properties.

The slenderness ratio is the ratio of the fiber length to fiber width. A high value of this ratio corresponds to better-formed and well-bounded paper.[7] In general, the acceptable slenderness ratio for papermaking is greater than 33.[21] The slenderness ratios of terap, medang, and balik angin were 66.2 ± 10.7, 68.6 ± 6.7, and 67.0 ± 3.7, respectively (Table 1). For comparison, the values of *E. camaldulensis* and *E. globulus* are 57.4 and 65.0, respectively,[5] while those of *A.* hybrid, *A. mangium*, and *A. auriculiformis* are 57.4, 51.3, and 52.7, respectively.[8] The slenderness ratios of terap, medang, and balik angin were higher than those of *Eucalyptus* spp. and *Acacia* spp.[5,8] On the basis of these results, terap, medang, and balik angin are suitable for making good-forming and well-bounded paper.

The coefficient of rigidity is the ratio of fiber wall thickness to fiber diameter. Thin-walled fibers with large diameter collapse to flattened ribbons in the process of sheet formation and provide high burst and tensile strength.[3] Thus, fibers with a low coefficient of rigidity produce paper with high burst and tensile strength.

TABLE 1. Wood properties of three species.

Property	Terap (n = 5) Mean	SD	Sig.	Medang (n = 5) Mean	SD	Sig.	Balik angin (n = 5) Mean	SD	Sig.	Significance among species
Runkel ratio	0.16	0.05	**	0.45	0.05	ns	0.14	0.01	ns	**
Slenderness ratio	66.2	10.7	*	68.6	6.7	**	67.0	3.7	ns	ns
Coefficient of rigidity	0.07	0.02	**	0.15	0.01	*	0.06	0.01	ns	**
Flexibility coefficient	0.86	0.04	**	0.67	0.03	*	0.87	0.02	ns	**
Luce's shape factor	0.15	0.05	**	0.38	0.04	*	0.14	0.02	ns	**
Solid factor x 10^3 (μm^3)	219.5	38.0	**	208.9	37.3	**	84.3	17.6	*	**

Note: n, sample number; SD, standard deviation; sig. significance among trees; *, significant difference at 5% level; **, significant difference at 1% level; ns, no significant.

Yahya et al.[8] reported that the coefficients of rigidity of *A.* hybrid, *A. mangium*, and *A. auriculiformis* as 0.13, 0.13, and 0.17, respectively. In the present study, the coefficients of rigidity of terap, medang, and balik angin were 0.07 ± 0.02, 0.15 ± 0.01, and 0.06 ± 0.01, respectively (Table 1). From these results, medang has a coefficient of rigidity similar to those of *Acacia* spp., whereas terap and balik angin have lower, more favorable values.[8]

The flexibility coefficient is the ratio of lumen width to fiber width. It indicates the potential of fiber collapse during beating, which provides more bonding area, resulting in stronger papers.[7,8] For example, significant positive correlations were found between the flexibility coefficient and sheet density, burst factor, breaking length, and folding endurance in *E. camaldulensis*.[5] Ona et al.[5] reported that the mean values of the flexibility coefficient from *E. camaldulensis* and *E. globulus* were 0.70 ± 0.04 and 0.72 ± 0.06, respectively. Those from *A.* hybrid, *A. mangium*, and *A. auriculiformis* were 0.73, 0.73, and 0.67, respectively.[8] In the present study, the mean values of the flexibility coefficient in terap, medang, and balik angin were 0.86 ± 0.04, 0.67 ± 0.03, and 0.87 ± 0.02, respectively. Thus, terap, medang, and balik angin have flexibility coefficients similar to or slightly higher than *Eucalyptus* spp. and *Acacia* spp.[5,8]

The mean values of Luce's shape factor in terap, medang, and balik angin were 0.15 ± 0.05, 0.38 ± 0.04, and 0.14 ± 0.02, respectively (Table 1). The Luce's shape factors in *E. camaldulensis* and *E. globulus* were 0.34 ± 0.05 and 0.32 ± 0.07, respectively.[5] The Luce's shape factor of medang was similar to those of *Eucalyptus* spp., whereas terap and balik angin showed lower values.[5] Luce's shape factor is significantly negatively correlated with breaking length of paper,[5,8] with a lower Luce's shape factor corresponding to a higher breaking length. Thus, terap and balik angin can produce paper with higher breaking length than medang.

The mean values of solid factor in terap, medang, and balik angin were 219.5 ± 38.0, 208.9 ± 37.3, and 84.3 ± 17.6 × 10^3 μm^3, respectively. Ona et al.[5] reported the solid factors of *E. camaldulensis* and *E. globulus* as 45.8 and 91.2 × 10^3 μm^3, respectively. A highly negative relationship between the solids factor and the breaking length of paper was reported in *E. camaldulensis*.[5] These results suggest that terap and medang have lower breaking length than balik angin.

Radial variation of wood properties is shown in Figure 1. Although the values were different among species, the trends of wood properties in the radial direction were similar for all three species. Runkel ratio, slenderness ratio, coefficient of rigidity, Luce's shape factor, and solid factor of the three species investigated gradually increased when measured from pith to bark. Similar trends have been reported in *E. camaldulensis* and *E. globulus* for radial profiles of Runkel ratio, slenderness ratio, Luce's shape factor, and solid factor.[15,22] In contrast, radial variation of flexibility coefficient in terap, medang, and balik angin gradually decreased

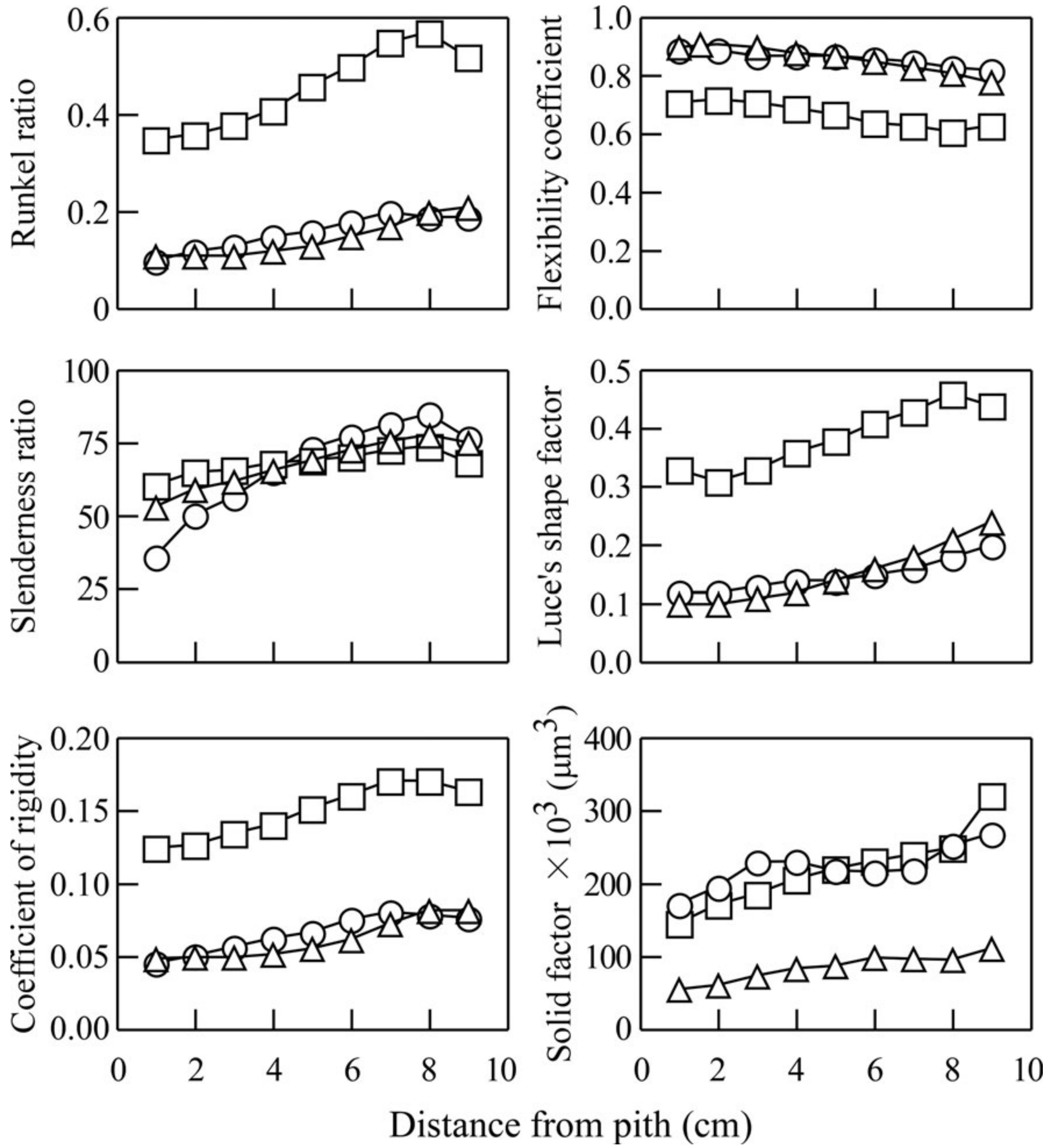

FIGURE 1. Radial variation in mean values of wood properties in three species. Circles, squares, and triangles indicate data of terap, medang, and balik angin, respectively.

slightly when measured from pith to bark. *E. grandis*, grown in South Africa, shows a similar pattern of flexibility coefficient when measured from pith to bark.[15]

Significant differences in wood properties among trees and among species are shown in Table 1. Almost all wood properties values, except for Runkel ratio in medang, showed significant differences among trees in terap and medang. In contrast, the only difference in solid factor significant at the 5% level was found in balik angin. These results suggest that wood properties of terap and medang can be improved by tree breeding programs.

Chemical Properties

Table 2 shows the chemical properties of the three species investigated in the present study. The mean values of ethanol-toluene extract contents in terap, medang, and balik angin were 1.5, 2.1, and 3.0%, respectively. The ethanol-toluene extract contents in the three species examined were lower than those in *Eucalyptus* spp. and *Acacia* spp.[8,10,23] Wood with low extractive content is preferable for pulpwood, because extractives in wood affect the pulp and paper end-products by producing color substances[5,6,9] and consuming pulp chemicals. In general, the presence of extraneous materials in wood reduces pulp yield, and the substances require cooking chemicals for their removal.[6,7,10,24,25] On the basis of the results obtained in this study, terap, medang, and balik angin could consume fewer cooking chemicals during the pulping process than *Eucalyptus* spp. and *Acacia* spp.

Higher contents of holocellulose and α-cellulose in wood result in higher pulp yield.[6,7,11,25,26] The holocellulose and α-cellulose contents of terap, medang, and balik angin were 78.0 and 50.7, 81.0 and 55.2, and 80.8 and 50.8%, respectively (Table 2). The mean holocellulose contents in these three species were similar to those in *Eucalyptus* spp. and *Acacia* spp.[8,11,23,24] Their α-cellulose contents were higher than those of *Acacia* spp.[8,11,27]

The mean values of total lignin content in terap, medang, and balik angin were 29.7, 25.0, and 24.6%, respectively. Total lignin contents of medang and balik angin were lower than those of *Acacia* spp.[8,10,11,27] Wood with low lignin content is more desirable for pulpwood because it affects pulp yield as well as bleaching, with higher lignin in wood leading to lower pulp yield and paper strength.[9,11]

The analysis of variance for the chemical components of terap, medang, and balik angin is shown in Table 2. Significant differences among the three species were found for all components except hot water extract, β-, and γ-cellulose. The chemical components of wood influence pulp properties.[5–7,9,24–26] These results suggest that the chemical contents of individual trees could be used as selection indices for quality breeding.

Pulp Properties

The mean pulp yields in terap, medang, and balik angin were 50.3, 53.6, and 54.1%, respectively (Table 2). The yield of reject content was almost 0%, owing possibly to the small size of chips used in this study. The highest pulp yield

TABLE 2. The mean values of amounts of basic density, chemical components, and pulp properties of terap, medang, and balik angin.

Property	Terap (n = 5)		Medang (n = 5)		Balik angin (n = 5)		Significance among species
	Mean	SD	Mean	SD	Mean	SD	
BD (g/cm^3)	0.37	0.06	0.57	0.04	0.39	0.03	**
Hot water extract (%)	3.2	0.9	3.1	1.4	3.2	0.3	ns
1% NaOH extract (%)	14.6	2.1	11.2	2.0	15.7	3.1	*
Ethanol-toluene extract (%)	1.5	0.3	2.1	0.6	3.0	1.2	*
Holocellulose (%)	78.0	0.4	81.0	0.7	80.8	0.7	**
α-Cellulose (%)	50.7	1.2	55.2	2.0	50.8	1.6	**
β-Cellulose (%)	4.2	2.5	4.8	1.7	5.5	1.4	ns
γ-Cellulose (%)	22.4	3.0	19.8	2.0	22.9	1.1	ns
Klason lignin (%)	28.7	1.1	21.7	2.3	20.8	2.7	**
Acid-soluble lignin (%)	1.0	0.1	3.3	1.0	3.8	0.6	**
Total lignin (%)	29.7	1.1	25.0	2.6	24.6	3.2	*
Ash (%)	1.5	0.2	0.3	0.1	0.3	0.1	**
Pulp yield (%)	50.3	2.8	53.6	0.8	54.1	1.0	*
Kappa number	38.1	2.2	14.6	2.4	22.0	4.0	**

Note: n, sample number; SD, standard deviation; BD, basic density; ns, no significance; **, significant difference at 1% level; * significant difference at 5% level.

TABLE 3. Relationships between chemical properties and pulp yield.

	BD (g/cm^3)	Ethanol-toluene extract (%)	Holo-cellulose (%)	α-Cellulose (%)	Klason lignin (%)	ASL (%)	Total lignin (%)	Pulp yield (%)	Kappa number
BD (g/cm^3)		ns	ns	**	ns	ns	ns	ns	**
Eth-toluene extract (%)	0.053		ns	ns	ns	ns	ns	ns	ns
Holocellulose (%)	0.411	− 0.009		*	**	*	*	*	**
α-Cellulose (%)	0.702	− 0.303	0.577		*	*	ns	ns	*
Klason lignin (%)	−0.311	− 0.345	−0.845	−0.537		**	**	**	**
ASL (%)	0.394	0.603	0.644	0.216	−0.713		**	**	**
Total lignin (%)	−0.222	− 0.175	−0.787	−0.583	0.953	−0.467		*	*
Pulp yield (%)	0.482	− 0.280	0.667	0.378	−0.657	0.593	−0.573		**
Kappa number	−0.725	− 0.296	−0.735	−0.622	0.750	−0.785	0.607	−0.702	

Note: number sample = 15; BD, basic density; ASL, acid-soluble lignin; **, significant at 1% level, *, significant at 5% level.

was found in balik angin. Pulp yield values of the common pulpwoods by the kraft process have been reported.[12,14,21–23,25] The pulp yields of *E. camaldulensis* and *E. globulus* planted in Western Australia were 37.3 and 49.6%, respectively,[5] and those of *E. globulus* planted in Portugal were 49.0–58.7%.[25] The pulp yield of *A. melanoxylon* planted in Portugal was 47.9–55.0%[10] and those in *A. mangium*, *A. crassicarpa*, and *A. aulacocarpa* planted in Thailand were 48.6–53.8, 50.3–53.9, and 47.5–52.5%, respectively.[27] Jahan et al.[9] reported the pulp yield of *Hevea brasiliensis* as 44.7–49.3%. The pulp yields of medang and balik angin obtained in the present study were similar to those of *Eucalyptus* spp. and *Acacia* spp.,[10,12,25,27] and the pulp yield of terap was similar to that of *H. brasiliensis*.[9] Medang and balik angin produced higher pulp yield than terap, likely due to a lower lignin content, which logically results in higher pulp yield.[9,10,25]

The mean values of the Kappa numbers for terap, medang, and balik angin pulp were 38.1, 14.6, and 22.0, respectively. The preferred Kappa number for bleachable pulp is 15 to 25,[27] although Santos et al.[10] reported that the pulps were well-delignified at Kappa number between 10.9 and 18.4. According to previous studies, the preferred Kappa number in this study was 10.9 to 25.[10,27] Medang showed the lowest and terap the highest Kappa number. The higher Kappa number in terap is in accord with its higher lignin content. These results indicate that medang and balik angin are more readily delignified, owing to their lower lignin content, and that those values achieved the preferred Kappa number.

Correlations between Properties

The BD values of terap, medang, and balik angin were 0.37, 0.57, and 0.39 g/cm^3, respectively (Table 2). The BD of wood has a strong correlation with the strength of pulp and paper, and expresses as tear strength, tensile strength, and burst strength,[11,25,26] as well as with chemical and pulp properties.[10,23,27] The relationships among BD, chemical component contents, and pulp yield in terap, medang, and balik angin are presented in Table 3. BD in the three species was not significantly correlated with holocellulose content ($r = 0.411$), although it was significantly positively correlated with α-cellulose content ($r = 0.702$). Similar results have been reported in *E. globulus*.[23] No significant correlations were found between BD and pulp yield in the three species. This is also true for *A. melanoxylon*.[10] A significant negative correlation was found between pulp yield and total lignin content ($r = -0.573$). Other researchers have reported similar results.[10,26] Thus, the lower the lignin content in wood, the higher the yield of kraft pulp.[10] In contrast, Amidon[26] reported that the holocellulose content in hardwoods was positively correlated with pulp yield. In the present study, a significant positive correlation ($r = 0.667$) was found between holocellulose and pulp yield. A significant negative correlation ($r = -0.702$) was observed between pulp yield and Kappa number, suggesting that the samples with higher pulp yield have lower Kappa number. In general, positive correlation was found between pulp yield and Kappa number.[9,28] However, several researchers have been reported negative correlation between them.[10,11,29] Santos et al.[10] reported that higher pulp yields were associated with lower Kappa number in kraft pulping of *A. melanoxylon*. Our result was in accordance with the results of the previous studies.[10,11,29]

CONCLUSION

Wood, chemical, and pulp properties were determined for three less-used, fast-growing tree species—terap, medang, and balik angin. The mean values of the Runkel ratio in terap, medang, and balik angin were 0.16, 0.45, and 0.14, respectively. The wood properties investigated in the present study were similar to those of other fast-growing trees already used as raw materials for pulp and paper production. Radial variations of Runkel ratio, slenderness ratio, coefficient of rigidity, Luce's shape factor, and solids factor increased when measured from pith to bark. In contrast, radial variation in flexibility coefficient decreased when measured from pith to bark. The mean values of ethanol-toluene extracts in terap, medang, and balik angin were 1.5, 2.1, and 3.0%, respectively. The extractive contents in these three species were lower than those in *Acacia* spp. and *Eucalyptus* spp. The mean values of pulp yield in terap, medang, and balik angin were 50.3, 53.6, and 54.1%, respectively. Medang and balik angin were characterized as woods with lower lignin and higher holocellulose and α-cellulose contents than terap. Medang and balik angin had higher pulp yield and lower Kappa number than terap. On the basis of these results, medang and balik angin are suitable raw materials for bleached chemical pulp, whereas terap is suitable for unbleached chemical pulp.

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