Wood properties related to pulp and paper quality in two Macaranga species

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Submission date: 15-Sep-2022 11:13PM (UTC-0400)
Submission ID: 1900998689
File name: Tropics.pdf (815.58K)
Word count: 5795
Character count: 29370

ISSN : 0917-415X DOI:10.3759/tropics.MS15-23

TROPICS Vol. 25 (3) 107–115 Issued December 1, 2016

ORIGINAL ARTICLE

Wood properties related to pulp and paper quality in two *Macaranga* species naturally regenerated in secondary forests, Central Kalimantan, Indonesia

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Received: February 24, 2016 Accepted: May 25, 2016 J-STAGE Advance published date: October 4, 2016

ABSTRACT The utilization of wood resources from unutilized fast-growing tree species found in secondary forests was investigated by studying the wood properties, including anatomical characteristics, of two *Macaranga* species—*M. bancana* and *M. pearsonii*—growing naturally in secondary forests in Central Kalimantan, Indonesia. Several wood properties related to pulp and paper quality were also evaluated, including the Runkel ratio, Luce's shape factor, flexibility coefficient, slenderness ratio, solid factor, and wall coverage ratio. The mean basic density of these two species ranged from 0.23 to 0.31 g cm^{-1}, while the mean values of vessel diameter, vessel element length, fiber diameter, fiber wall thickness, and fiber length ranged from 126 to 192 µm, 0.88 to 1.19 mm, 24.5 to 29.8 µm, 0.99 to 1.14 µm, and 1.42 to 1.69 mm, respectively. The lignin content of *M. bancana* and *M. pearsonii* wood was 27.2 and 28.0%, respectively. Almost all wood properties related to pulp quality showed better values than those reported for *Acacia* and *Eucalyptus* species, although sheet density of paper might be lower due to higher solids factor and possibility of occurrence of vessel picking was probably higher due to longer vessel element length and larger vessel diameter. Based on the results, the wood from these two *Macaranga* species can be used as pulpwood.

Key words: unutilized fast-growing tree species, basic density, fiber dimension, lignin content, pulp and paper quality

INTRODUCTION

The demand for wood and wood-based products, including pulp and paper, has increased in Indonesia. To supply this demand, fast-growing tree species, including *Acacia* and *Falcataria*, among others, have been planted in Indonesia for production of materials such as pulpwood and plywood (Wahyudi et al. 1999, Ishiguri et al. 2007, Makino et al. 2012). Other previously unutilized fast-growing tree species have also been planted to increase wood resources (Ishiguri et al. 2016).

The Southeast Asian region is home to many fast-growing tree species, typically found in secondary forests after shifting cultivation (Suzuki 1999ab, Adi et al. 2014, Istikowati et al. 2014, 2016). However, utilization of wood resources from these fast-growing tree species is limited because little information is available regarding the properties and anatomical characteristics of the wood (Adi et al. 2014, Istikowati et al. 2014, 2016). These wood characteristics and the corresponding pulp properties have recently been investigated for three unutilized fast-growing tree species—terap (*Artocarpus elasticus*), medang (*Neolitsea latifolia*), and balik angin (*Alphitonia excelsa*), which grow naturally in secondary forests in South Kalimantan—to exploit these potential wood resources as new alternative raw materials for pulp production (Istikowati et al. 2016). However, further research is needed to characterize the potential wood resources from other unutilized fast-growing tree species.

The pulp and paper qualities can be evaluated by wood properties including anatomical characteristics (Amidon 1981, Ona et al. 2001, Ohshima et al. 2005, Ashori and Nourbakhsh 2009, Yahya et al. 2010, Dutt and Tyagi 2011, Pirralho et al. 2014, Istikowati et al. 2016), although these qualities are also closely related to the chemical characteristics of wood. The pulp and paper quality, based on wood properties like anatomical characteristics, can be estimated using the following indices: Runkel ratio (Runkel

1949), Luce's shape factor (Luce 1970), flexibility coefficient (Malan and Gerischer 1987), slenderness ratio (Malan and Gerischer 1987), solids factor (Barefoot et al. 1964), and wall coverage ratio (Hudson et al. 1998). These indices have also been used for fast-growing tree species, such as *Acacia* species (Yahya et al. 2010) and *Eucalyptus* species (Hudson et al. 1998, Ona et al. 2001, Ohshima et al. 2005, Dutt and Tyagi 2011, Pirralho et al. 2014).

Other fast-growing but unutilized tree species are members of the genus *Macaranga*, (family Euphorbiaceae) and are naturally distributed in Thailand, Malaysia, New Guinea, Singapore, and Indonesia (Sosef et al. 1998). Species such as *M. penangensis* and *M. lowii* are mainly found in primary forests with lower disturbance levels, but many other *Macaranga* species are pioneer species that grow in secondary forests with medium to high disturbance levels (Slik et al. 2003). For example, Slik et al. (2003) pointed out that burned forests are mainly populated by *Macaranga* species. In Indonesia, *Macaranga* trees are commonly found in secondary forests that have regenerated naturally after shifting cultivation. However, little information is available regarding the wood properties and anatomical characteristics for this genus (Killmann 1990, Sosef et al. 1998, Ogata et al. 2008).

The main objective of this study was to explore the potential utilization of the wood resources from unutilized fast-growing tree species found in secondary forests in Indonesia. In this paper, wood properties and anatomical characteristics were investigated for two *Macaranga* species (*M. bancana* (Miq.) Müll. Arg. and *M. pearsonii* Merr.) growing naturally in secondary forests in Central Kalimantan, Indonesia. The wood properties were also evaluated in terms of pulp and paper qualities to explore the possibility of using these wood resources as alternative raw materials for pulp and paper production.

MATERIALS AND METHODS

Materials

Wood samples were collected from six *Macaranga*

Table 1. Stem diameter at 1.3 m above the ground and the tree height of the sample trees.

Species	Tree No.	Stem diameter (cm)	Tree height (m)
Macaranga bancana	1	15.4	13.0
	2	9.3	10.0
	3	9.5	10.0
	Mean	11.4	11.0
	Standard deviation	3.5	1.7
Macaranga pearsonii	4	27.0	20.2
	5	13.3	16.8
	6	12.6	14.0
	Mean	17.6	17.0
	Standard deviation	8.1	3.1

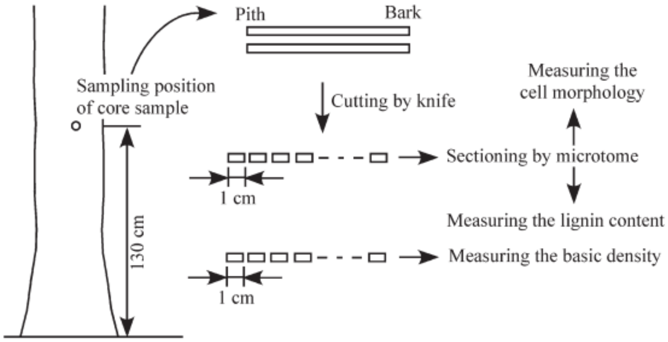

Fig. 1. Illustration of experimental procedures for determining anatomical characteristics, basic density, and lignin contents (Ishiguri et al. 2012, 2016).

trees naturally growing in secondary forests formed after shifting cultivation in the concession area of PT Sari Bumi Kusuma, Central Kalimantan, Indonesia (0°50'51"S, 112°19' 55"E). In this area, these trees are called "begarung". The botanical names of these six begarung trees were confirmed by the Indonesian Institute of Sciences as *M. bancana* and *M. pearsonii*. According to Slik et al. (2003), these two species are pioneer species found in secondary forests with medium to high disturbance levels.

Table 1 shows the stem diameter and tree height of the sample trees. Core samples (5 mm in diameter) for determining the basic density and anatomical characteristics were collected at breast height from each tree using an increment borer (Haglöf) (Fig. 1).

Basic density and anatomical characteristics

Core samples were cut into small segments at 1 cm intervals, from pith to bark, to determine the radial variations in basic density and anatomical characteristics (Fig. 1).

Basic density was determined by measuring the green volume of each 1 cm core segment by the water displacement method, and then oven-drying the segments at 105℃ to a constant weight, considered the oven-dry weight. Basic density was calculated by dividing the oven-dry weight by the green volume.

Transverse sections of the core samples, 20 µm in thickness, were prepared with a sliding microtome (ROM-380, Yamatokohki) and then stained with safranin, dehydrated in a graded ethanol series, cleared in xylene, and mounted on glass slides. Photomicrographs taken with a digital camera (E-P3, Olympus) mounted on a microscope (BX51, Olympus) were used for measuring vessel diameter, fiber diameter, and fiber wall thickness, and the images were examined using image analysis software (ImageJ, National Institute of Health) (Fig. 2). The vessel diameter was measured for 30 vessels, and fiber diameter and fiber wall thickness were measured for 50 fibers at each radial position.

Small wood blocks (1 × 1 × 5 mm) were prepared for measuring vessel element length and fiber length and were macerated with Schulze's solution (6 g potassium chlorate in 100 mL 35% nitric acid). At each radial position, 30 vessels and 50 fibers were measured using a microprojector (V12, Nikon) and a digital caliper (CD-30C, Mitutoyo).

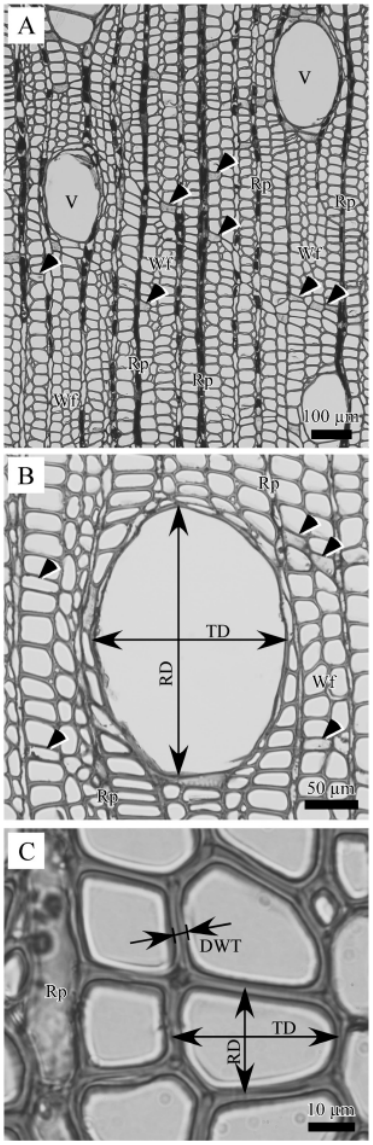

Fig. 2. Photomicrographs of transverse sections of *Macaranga pearsonii*. The photomicrographs were taken at 7 cm from pith of the sample No. 4. The secondary xylem of *M. pearsonii* was consisted of vessel (V), wood fiber (Wf), ray parenchyma (Rp), and axial parenchyma cells (arrow heads) (Fig. 2A). Cell diameter was determined by averaging the radial diameter (RD) and tangential diameter (TD) (Figs. 2B and 2C). Cell wall thickness of wood fiber was defined as half values of double wall thickness (DWT) including compound middle lamella (Fig. 2C).

Table 2. Calculation formula of wood properties related to pulp and paper quality.

Property	Related pulp and paper properties	Formula	Reference
Runkel ratio	Pulp yield (positively) and digestability (negatively)	$(2 \times FWT)/FLD$	Runkel (1949)
Luce's shape factor	Resistance to beating (positively)	$(FD^2 - FLD^2)/(FD^2 + FLD^2)$	Luce (1970)
Flexibility coefficient	Tearing and tensile streingth (positively)	FLD/FD	Malan and Gerisher (1987)
Slenderness ratio	Tearing strength (positively)	FL/FD	Malan and Gerisher (1987); Ona et al. (2001)
Solids factor	Sheet density (negatively)	$(FD^2 - FLD^2) \times FL$	Barefoot et al. (1964); Ona et al. (2001)
Wall coverage ratio	Bending resistance (negatively)	$(2 \times FWT)/FD$	Hudson et al. (1998)

Note: FWT; fiber wall thickness, FLD; fiber lumen diameter, FD; fiber diameter, FL; fiber length.

Wood properties related to pulp quality

The pulp and paper properties were evaluated by calculating the following wood properties related to pulp quality: Runkel ratio (Runkel 1949), Luce's shape factor (Luce 1970), flexibility coefficient (Malan and Gerischer 1987), slenderness ratio (Malan and Gerischer 1987), solids factor (Barefoot et al. 1964), and wall coverage ratio (Hudson et al. 1998). These properties were calculated from the fiber morphologies determined by the method described above. The calculation formulas are listed in Table 2.

Lignin content

The lignin content was determined by the acetyl bromide method (Iiyama and Wallis 1988). Small wood samples were prepared from the core samples with a sliding microtome. Each small wood sample (5 mg oven-dry weight) was extracted with a 95% ethanol-toluene mixture (1 : 2, v/v) in a Soxhlet extractor for 6 hours. The extracted samples were put into 15 mL test tubes containing 5 mL 25% acetyl bromide in acetic acid and 0.2 mL 70% perchloric acid and heated at 70℃ for 30 min in a block heater (MG-2200, EYELA). This reaction mixture was added to a mixture of 10 mL 2M aqueous NaOH and 20 mL acetic acid, and the volume was adjusted to 100 mL with acetic acid. The absorbance at 280 nm was measured with a spectrophotometer (V-650, JASCO). The lignin content was calculated by the following equation:

$$\text{Lignin content (\%)} = 100 \cdot (As - Ab) \cdot V \cdot (20.091\,W)^{-1}$$

where As and Ab are the absorbances at 280 nm for the sample and blank, respectively, V is the volume of the measurement solution, and W is oven-dry weight of the sample.

RESULTS AND DISCUSSION

Basic density

The mean values for the basic density of *M. bancana* and *M. pearsonii* wood ranged from 0.29 to 0.31 g cm^{-3} and from 0.23 to 0.31 g cm^{-3}, respectively (Table 3). The previously reported range of basic densities of wood from *Macaranga* species was about 0.30 to 0.45 g cm^{-3} (Killmann 1990, Suzuki 1999a, Ogata et al. 2008, Chin et al. 2013). Killmann (1990) reported a basic density for *M. hosei* wood of 0.27 to 0.34 g cm^{-3}. Our results for the mean basic density for the two *Macaranga* species studied here were therefore similar to those reported for the other *Macaranga* species.

Basic density is closely related to pulp properties: wood with a low basic density produces paper with high sheet density; tensile, bursting and folding strengths; and lower resistance to beating; but with low pulp yield and tearing strength (Yahya et al. 2010, Santos et al. 2012). The mean values for the basic density of *Acacia* wood were 0.42 and 0.45 g cm^{-3} for 5- and 7-year-old *A. mangium* trees, respectively (Makino et al. 2012), 0.52 g cm^{-3} for 40-year-old *A. melanoxylon* (Santos et al. 2012), and 0.57 g cm^{-3} for 11-year-old *A. auriculiformis* (Chowdhury et al. 2009). The mean value for the basic density of a *Eucalyptus* species was 0.79 g cm^{-3} for 10-year-old *E. tereticornis* trees (Sharma et al. 2005). The mean values found for the basic density of *M. bancana* and *M. pearsonii* wood in the present study

Table 3. Mean values of basic density and anatomical characteristics.

Species	Tree No.	n*	BD (g cm^{-3})	n**	VD (μm)	VEL (mm)	FD (μm)	FWT (μm)	FL (mm)
M. bancana	1	6	0.29 (0.02)	6	149 (13)	1.15 (0.06)	28.9 (0.5)	0.99 (0.03)	1.67 (0.11)
	2	5	0.31 (0.02)	4	126 (13)	1.19 (0.07)	24.9 (0.5)	1.02 (0.03)	1.69 (0.09)
	3	5	0.31 (0.01)	5	130 (33)	0.99 (0.04)	27.0 (0.9)	0.99 (0.02)	1.43 (0.16)
	Mean	16	0.30 (0.02)	15	137 (23)	1.11 (0.10)	27.2 (1.8)	1.00 (0.03)	1.59 (0.17)
M. pearsonii	4	13	0.31 (0.04)	12	192 (54)	0.88 (0.16)	24.5 (4.3)	1.14 (0.03)	1.69 (0.27)
	5	6	0.23 (0.02)	5	168 (51)	0.92 (0.13)	29.8 (2.3)	1.01 (0.04)	1.42 (0.17)
	6	6	0.25 (0.05)	6	181 (40)	1.02 (0.07)	29.8 (2.8)	1.04 (0.03)	1.60 (0.17)
	Mean	25	0.28 (0.05)	23	184 (49)	0.93 (0.14)	27.0 (4.4)	1.08 (0.06)	1.61 (0.25)
Significance difference between species			ns		*	ns	ns	ns	ns

Note: n*; number of core segments in a tree for measuring basic density, n**; number of core segments in a tree for measuring anatomical characteristics, BD; basic density, VD; vessel diameter, VEL; vessel element length, FD; fiber diameter, FWT; fiber wall thickness, FL; fiber length, *; significant at 5% level, ns; no significant, Values in parenthesis are standard deviation.

(Table 3) were lower than those reported for *A. mangium* and *Eucalyptus* species used for pulpwood production. Therefore, paper produced from *M. bancana* and *M. pearsonii* woods may have some advantages in terms of strength and sheet density compared to that from *Acacia* and *Eucalyptus* woods. However, the overall pulp yield might be lower.

Anatomical characteristics

The mean values for the anatomical characteristics of the two *Macaranga* species studied here are listed in Table 3. The mean values were similar for all anatomical characteristics except vessel diameter and vessel element length in both species. The vessel diameter was smaller and the vessel element length was longer in *M. bancana* than in *M. pearsoni*. Information about the anatomical characteristics of *Macaranga* species is very limited, although Ogata et al. (2008) reported vessel diameters of 100 to 180 µm and fiber lengths of 1.0 to 2.0 mm in *Macaranga* species. The vessel diameters and fiber lengths reported in the present study for *M. bancana* and *M. pearsoni* were therefore similar to those reported by Ogata et al. (2008).

Wood with long and large diameter vessel elements produces paper showing vessel picking which vessel elements are picked from the surface of paper during the printing process and are deposited on the printing surface (Hudson et al. 1998, Drew and Pammenter 2006). Therefore, wood with short vessel elements with small diameters is preferable for paper production. The reported mean vessel diameters were 136 µm for *A. mangium* (Nugroho et al. 2012), 120 µm for *E. camaldulensis*, 157 µm for *E. globulus* (Ona et al. 2001), and 156 µm for *E. tereticornis* (Sharma et al. 2005), while the mean vessel element lengths were 0.24 mm for *A. auriculiformis* (Chowdhury et al. 2009), 0.31 mm for *E. tereticornis* (Sharma et al. 2005), 0.22 mm for *E. camaldulensis*, and 0.19 mm for *E. maculata* (Pirralho et al. 2014). As shown in Table 3, the vessel diameters and vessel element lengths of the two *Macaranga* species studied here were relatively larger and longer than those reported for *Acacia* and *Eucalyptus* species. These vessel morphology results indicate the possibility of a relatively higher occurrence of vessel picking in paper made from the two *Macaranga* species when compared to paper made from *Acacia* and *Eucalyptus* species.

Lignin content

Table 4 shows that the mean values for the lignin content were similar for both *Macaranga* species, ranging from 26.9 to 27.5% in *M. bancana* and from 27.6 to 28.5% in *M. pearsonii*. A previous study on *Macaranga* species by Chin et al. (2013) reported a lignin content for *Macaranga* species of 28.2%, which is similar to the values reported here.

Pulpwood requires a low lignin content, because lignin content is negatively correlated with pulp yield and fiber strength (Amidon 1981, Dutt and Tyagi 2011). Previous studies on *Acacia* and *Eucalyptus* species have reported total lignin contents of 34.1% for *A. auriculiformis*, 31.3% for *A. mangium* (Yahya et al. 2010), 26.0% for *A. melanoxylon* (Santos et al. 2012), 31.0% for an *Acacia* hybrid (Yahya et al. 2010), 29.3 % for *E. grandis* (Dutt and Tyagi 2011), 27.5% for *E. regnans* (Iiyama and Wallis 1988), and 33.2 % for *E. urophylla* (Dutt and Tyagi 2011), for an average lignin content of commercial pulpwood from fast-growing trees ranging from about 25 to 30%. As shown in Table 4, the lignin content of the two *Macaranga* species studied here was similar or somewhat lower values than previously reported for other fast-growing tree species used for pulpwood production. The lignin content therefore indicates that the wood from *M. bancana* and *M. pearsonii* has similar characteristics for pulpwood production to those of fast-growing *Acacia* and *Eucalyptus* species currently used commercially.

Wood properties related to pulp quality

The Runkel ratio is related to the suitability of papermaking: fibers with a Runkel ratio less than 1.0 are suitable for use as pulp (Runkel 1949). Fibers with high Runkel ratio are stiffer and form bulkier paper with lower bonded area when compared to low Runkel ratio fibers (Ashori and Nourbakhsh 2009). A lower Runkel ratio also indicates that the fibers easily collapse to form paper with good strength properties (Istikowati et al. 2016). The mean Runkel ratios in two species studied here were less than 0.1 (Table 5), suggesting that the fibers from both species would produce a good quality paper.

The mean values of Luce's shape factor were 0.08 and 0.09 for the two species studied here (Table 5). Luce's shape factor is an index for the resistance to beating in the pulp, so that a low value for Luce's shape factor indicates a decreased resistance to beating in paper making (Luce 1970). Pirralho (2014) reported that Luce's shape factor ranged from 0.39 to 0.74 in several *Eucalyptus* species. Ohshima et al. (2005) also reported mean values of Luce's shape factor of 0.37 for *E. camaldulensis* and 0.42 for *E. globulus*. The values for Luce's shape factor in *M. bancana* and *M. pearsonii* were therefore relatively lower than those reported for *Eucalyptus* species.

The flexibility coefficient is related to paper strength (Malan and Gerischer 1987, Ashori and Nourbakhsh 2009, Yahya et al. 2010, Pirralho et al. 2014). Ashori and Nourbakhsh (2009) reported that the flexibility coefficient expresses the potential of the fiber to collapse during beating or during drying of the paper web. The collapsed fibers then provide a greater bonding area and therefore a stronger paper. In addition, Moriya (1967) reported that flexibility coefficient was positively related with paper strength, such as burst factor and tear factor. The reported values for the flexibility coefficient ranged from 0.37 to 0.65 in several *Eucalyptus* species (Pirralho et al. 2014) and were 0.70 and 0.72 in *E. camaldulensis* and *E. globulus*,

Table 4. Mean value of lignin content.

Species	Tree No.	n	Lignin content (%)
M. bancana	1	3	26.9 (0.5)
	2	3	27.5 (2.0)
	3	3	27.2 (2.8)
	Mean	9	27.2 (1.7)
M. pearsonii	4	3	28.5 (2.2)
	5	3	28.1 (1.0)
	6	3	27.6 (1.4)
	Mean	9	28.0 (1.4)
Significant difference between species			ns

Note: n; number of samples, ns; no significant; Values in parenthesis are standard deviation.

Table 5. Mean values of wood properties related to pulp quality.

Species	Tree No.	n	Runkel ratio	Luce's shape factor	Flexibility coefficient	Slenderness ratio	Solids factor ($\times 10^3 \mu m^3$)	Wall coverage ratio
M. bancana	1	6	0.07 (0.01)	0.07 (0.01)	0.93 (0.01)	57.7 (4.0)	184 (18)	0.07 (0.01)
	2	4	0.09 (0.01)	0.09 (0.01)	0.92 (0.01)	67.8 (2.5)	164 (15)	0.08 (0.01)
	3	5	0.08 (0.01)	0.08 (0.01)	0.93 (0.01)	52.7 (4.4)	148 (24)	0.07 (0.01)
	Mean	15	0.08 (0.01)	0.08 (0.01)	0.93 (0.01)	58.7 (6.9)	167 (24)	0.07 (0.01)
M. pearsonii	4	12	0.11 (0.03)	0.10 (0.02)	0.90 (0.02)	70.0 (6.7)	184 (55)	0.10 (0.02)
	5	5	0.07 (0.01)	0.07 (0.01)	0.93 (0.01)	47.4 (3.0)	167 (38)	0.07 (0.01)
	6	6	0.08 (0.01)	0.07 (0.01)	0.93 (0.01)	53.9 (5.5)	192 (37)	0.07 (0.01)
	Mean	23	0.09 (0.02)	0.09 (0.02)	0.92 (0.02)	60.8 (11.3)	182 (46)	0.08 (0.02)
Significant difference between species			ns	ns	ns	ns	ns	ns

Note: n; number of core segments in a tree for calculating wood properties related to pulp and paper qualities, ns; no significant, Values in parenthesis are standard deviation.

respectively (Ona et al. 2001). In the present study, the mean values for the flexibility coefficient were 0.93 for *M. bancana* and 0.92 for *M. pearsonii* (Table 5).

The mean values for the slenderness ratio were 58.7 in *M. bancana* and 60.8 in *M. pearsonii* (Table 5). The slenderness ratio is related to the tearing strength and folding endurance of paper (Malan and Gerischer 1987, Yahya et al. 2010): a high ratio indicates a better formed and well-bonded paper (Ashori and Nourbakhsh 2009). Previously, Pirralho et al. (2014) reported values for the slenderness ratio ranging from 39.4 to 48.4 for several *Eucalyptus* species. Ohshima et al. (2005) also reported a ratio of 50.5 to 56.5 and 57.7 to 59.9 in 14-year-old *E. camaldulensis* and *E. globulus*, respectively. The values for the two *Macaranga* species studied here were similar or slightly higher than these previously reported values.

Ona et al. (2001) reported values for the solids factor of 46 × 10^3 µm^3 and 91.2 × 10^3 µm^3 for 14-year-old *E. camaldulensis* and *E. globulus*, respectively. In addition, they found significant negative relationship between solids factor and sheet density. The mean values for the solids factor were 167 × 10^3 µm^3 for *M. bancana* and 182 × 10^3 µm^3 for *M. pearsonii* (Table 5), suggesting that sheet density of paper produced from these *Macaranga* species might be lower than that produced from *Eucalyptus* species.

Wall coverage ratio is an index for bending resistance (Hudson et al. 1998) and is related to fiber flexibility (Amidon 1981). A material with a wall coverage ratio value less than 0.4 is considered to be good pulpwood (Kami parupu gijutsu kyokai 1969). In the present study, the mean values for the wall coverage ratios for *M. bancana* and *M. pearsonii* ranged from 0.07 to 0.08 and from 0.07 to 0.10, respectively (Table 5).

CONCLUDING REMARKS

The basic density, anatomical characteristics, and lignin content were investigated for wood from *Macaranga bancana* and *M. pearsonii* trees growing naturally in secondary forests of Central Kalimantan, Indonesia in order to determine the usefulness of these trees as wood resources for pulpwood production. The mean values for basic density, anatomical characteristics, and lignin content were within ranges of previously reported values for other *Macaranga* species. Compared to the wood properties related to pulp quality with those of *Acacia* and *Eucalyptus* species currently used for commercial pulpwood, both *M. bancana* and *M. pearsonii* showed better properties (Table 6), although these *Macaranga* species has lower basic density, longer vessel elements length, larger vessel diameter, and higher solids factor. Therefore, the wood from these two *Macaranga* species could produce paper with higher strength properties, but lower pulp yield, higher possibility of occurrence of vessel picking and lower sheet density, compared with currently commercialized papers made from the fast-growing trees. In addition, for kraft pulp production, mixing these *Macaranga* woods with other commercial pulpwood could compensate the low pulp yield from these *Macaranga* wood.

ACKNOWLEDGEMENTS The authors express their thanks to Professor Mamoru Kanzaki, Graduate School of Agriculture, Kyoto University, and Associate Professor Masayuki Yanagisawa, Center for Integrated Area Studies, Kyoto University for their information about the field survey. The authors also thank the Sari Bumi Kusuma Co., Ltd. for conducting the field survey and sampling. This

Table 6. Wood properties related to pulp quality in two *Macaranga* species and commercial fast-growing plantation tree species.

Species	Age (year)	Runkel ratio	Luce's shape factor	Flexibility coefficient	Slenderness ratio	Solids factor (× 10^3 µm^3)	Wall coverage ratio	References
Macaranga bancana	—	0.08	0.08	0.93	58.7	167	0.07	This study
Macaranga pearsonii	—	0.09	0.09	0.92	60.8	182	0.08	This study
Acacia auriculiformis	7	0.55	—	0.67	52.7	—	—	Yahya et al. (2010)
Acacia mangium	7	0.37	—	0.73	51.3	—	—	Yahya et al. (2010)
Eucalyptus camaldulensis	4	0.79	0.51	0.56	39.4	—	—	Pirralho et al. (2014)
Eucalyptus camaldulensis	14	0.50	0.37	—	50.5–56.6	48.6–51.2	—	Ohshima et al. (2005)
Eucalyptus globulus	—	0.85	—	—	—	—	0.46	Hudson et al. (1998)
Eucalyptus globulus	14	0.54–0.67	0.39–0.44	—	57.7–59.9	96.3–97.6	—	Ohshima et al. (2005)

Note: Runkel ratio and wall coverage ratio less than 1.0 and 0.4 are suitable for use as pulpwood, respectively. Values of Luce's shape factor, flexibility coefficient, and slenderness ratio are positively correlated with resistance to beating, tearing and tensile strength, and tearing strength, respectively. Values of solid factor is negatively correlated with sheet density.

study was financially supported by Strategic Funds for the Promotion of Science and Technology of the Japan Science and Technology Agency (project title; Creation of a Paradigm for the Sustainable Use of Tropical Rainforest with Intensive Forest Management and Advanced Utilization of Forest Resources).

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