Physical and Mechanical Properties of Woods from Three Native Fast-Growing Species in a Secondary Forest in South Kalimantan, Indonesia

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Abstract

Growth characteristics and basic wood properties of three native fast-growing species, terap (*Artocarpus elasticus* Reinw. ex Blume), medang (*Neolitsea latifolia* (Blume) S. Moore), and balik angin (*Alphitonia excelsa* (Fenzel) Reissek ex Benth), were investigated. All three species are grown in a secondary forest in South Kalimantan, Indonesia. No significant correlations between growth characteristics (stem diameter and tree height) and stress-wave velocity of the stems were found. The mean basic density (BD) for whole trees of terap, medang, and balik angin were 0.34, 0.55, and 0.39 g cm^{-3}, respectively. The BD in medang wood was similar in both radial and longitudinal directions. On the other hand, the BD gradually increased from pith to bark, decreased from 1 to 3 m above the ground, and then gradually increased to the top of the tree in terap and balik angin. Significant positive correlations between radial and tangential shrinkages and BD were found. Compressive strength parallel to grain and air-dry density also showed high positive correlations for all species. Analysis of variance showed significant differences in wood properties among the five sample trees in each species.

The increase in population in Indonesia has resulted in a steady increase in the consumption of wood and wood-based products. In addition, the production of wood resources has tended to decrease due to the reduction of natural forest areas. This situation has resulted in disparities between demand for and supply of wood resources in Indonesia. To resolve the disparities, fast-growing tree species, such as *Acacia mangium, A. auriculiformis, Anthocephalus cadamba,* and *Falcataria moluccana*, have become major plantation species in Indonesia. Growing these species can be an efficient way of producing timber and pulpwood, and a plantation of fast-growing species can be a profitable investment both for the companies involved and for society as a whole (Cossalter and Pye-Smith 2003). Many researchers have studied the wood properties of fast-growing species planted in Indonesia (Wahyudi et al. 1999, Ishiguri et al. 2007, Kojima et al. 2009, Carrillo et al. 2011, Makino et al. 2012, Nugroho et al. 2012). Unutilized native fast-growing species can be found in secondary forests that were formed after the logging of natural forests and for other reasons, such as shifting cultivation and forest fire. It is important, therefore, to find alternative fast-growing species from these secondary forests that are suitable for raw materials in the wood industry sector. Terap (*Artocarpus elasticus* Reinw. ex Blume), medang (*Neolitsea latifolia* (Blume) S. Moore), and balik angin (*Alphitonia excelsa* (Fenzel) Reissek ex Benth) are native fast-growing species

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in South Kalimantan, Indonesia. These species are naturally distributed and found abundantly in the secondary forest in South Kalimantan. However, information on the wood properties of these three species is still very limited. Gathering information on the wood properties is necessary in order to utilize these fast-growing species to help alleviate the disparities between demand for and supply of wood resources in Indonesia.

Improvement of wood quality should be part of tree breeding programs (Zobel and van Buijtenen 1989). Some tropical fast-growing species, such as *A. auriculiformis* and *F. moluccana,* have been investigated to clarify tree variation for establishing tree breeding programs in Southeast Asian countries. Breeding for wood quality has strong potential and is important for updating the breeding strategy in these species (Ishiguri et al. 2007, Hai et al. 2008, Susanto et al. 2008).

The objective of this study was to determine the growth characteristic and basic wood properties of three native fast-growing species, terap, medang, and balik angin, grown in South Kalimantan, Indonesia, to allow rational utilization of their wood.

Materials and Methods

Three native fast-growing species, terap, medang, and balik angin, were examined, with 15 trees, 5 trees per species, randomly selected from a secondary forest. The trees were obtained from an experimental site located in Lambung Mangkurat University Education Forest, Mandiangin, South Kalimantan, Indonesia (3°2′ to 3°45′S, 114°5′ to 115°10′E). This educational forest is part of Sultan Adam National Forest Park, but some trees are cut down by local people for logging or shifting cultivation. The secondary forests were naturally regenerated. To obtain the basic information about the three species in a secondary forest, blocks (10 by 10 m) were set near the sampling location for determining the stem diameter (D), tree height (H), and density of trees per hectare. Trees 7 m or taller were measured for D and H, and the total number of trees was counted in that location.

D and stress-wave velocity (SWV) were measured before trees were harvested. D at 1.3 m above the ground was measured by calipers (Haglöf). Stem SWV was measured using a commercial handheld stress-wave timer (Fakopp Microsecond Timer; Fakopp Enterprise) in accordance with our previous report (Ishiguri et al. 2007). The start and stop sensors were set at 150 and 50 cm, respectively, above the ground level. The stress-wave propagation time was measured 10 times for each tree by hitting the start sensor with a small hammer. SWV for each tree was calculated as the distance between sensors (100 cm) divided by the average value of the 10 stress-wave propagation times. H was also measured using a tape meter after felling the tree.

Logs were obtained at 2-m intervals from 1 m above the ground to the top of the tree. Three to five logs were obtained in each tree. A total of 20, 22, and 19 logs from terap, medang, and balik angin, respectively, were collected for determination of dynamic modulus of elasticity (DMOE). Log DMOE was determined by the tapping method (Ishiguri et al. 2005). A portable Fast Fourier Transform (FFT) analyzer (AD-3527; A&D) with an acceleration sensor (PV-85; RION) was used to measure the natural frequency of longitudinal vibration due to sound emitted by hitting the cross section of a specimen with a hammer. DMOE (GPa) was calculated as

$$\mathrm{DMOE} = (2Lf)^2 \rho \cdot 10^{-3} \quad (1)$$

where ρ (kg m^{-3}) is the density of the log at testing, L (m) is the length of the specimen, and f (kHz) is the first resonance frequency of the longitudinal vibration.

Basic density (BD) was measured on 10-cm-thick disks cut from 1 m above the ground and 5-cm-thick disks cut from 3, 5, 7, 9, and 11 m above the ground. Thin radial strips (2 cm in width, 1 cm in thickness, and length dependent on disk diameter) were prepared from each disk. Due to indistinct growth rings in medang and terap, the radial variation of BD was determined at 1-cm intervals from pith to bark. In addition, small blocks were obtained from two opposite sides with respect to the pith of the disks. BD was calculated as the ratio of oven-dry weight to green volume as determined by the water displacement method (Barnett and Jeronimidis 2003).

A total of 115 specimens (2 by 2 by 2 cm) from the three species were prepared from an air-dried, radial-sawn board cut from logs at 1 m above the ground. Radial and tangential dimensions of the specimens under air- and oven-dried conditions were measured by a digital screw meter (MDC-25M; Mitutoyo). Shrinkage in the radial and tangential directions per 1 percent change in moisture content (MC) was calculated as

$$\delta = \frac{l_a - l_o}{nl} \cdot 100\% \quad (2)$$

where δ is shrinkage per 1 percent change in MC, l_a is length under air-dried condition, l_o is length under oven-dried condition, n is MC at measuring l_a, and l is length at 15 percent MC calculated as

Table 1.—Stem diameter, tree height, and tree density per hectare of three species grown in the experimental site, South Kalimantan, Indonesia.[a]

Species	D (cm)	H (m)	Tree density (trees/ha)
Terap (n = 10)			
Max.	28.7	20.0	1,000
Mean	21.7	14.9	
Min.	18.2	10.0	
SD	3.3	3.7	
Medang (n =11)			
Max.	35.0	25.0	1,100
Mean	21.3	14.5	
Min.	11.8	8.0	
SD	7.0	6.5	
Balik angin (n =11)			
Max.	25.5	15.0	1,100
Mean	15.7	10.6	
Min.	10.2	7.0	
SD	6.1	3.2	
Significance among species	*	ns	—

[a] Tree density was calculated by the number of trees in a block divided by the area of a block (100 m^2). D = stem diameter; H = tree height; n = number of trees; Max. = maximum; Min. = minimum; SD = standard deviation; * = significant at the 5 percent level among three species; ns = no significance among three species.

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Table 2.—Statistical values of growth characteristics and wood properties in three species.[a]

Property	Terap ($n = 5$)				Medang ($n = 5$)				Balik angin ($n = 5$)			
	Max.	Mean	Min.	SD	Max.	Mean	Min.	SD	Max.	Mean	Min.	SD
D (cm)	22.5	19.4	16.8	2.3	20.3	19.0	17.6	1.1	21.3	18.8	16.5	1.7
H (m)	30.0	20.8	13.1	8.0	21.6	20.8	18.5	1.3	20.0	18.8	17.0	1.3
SWV (km s^{-1})	3.82	3.36	3.07	0.32	4.44	4.21	3.99	0.19	3.92	3.73	3.72	0.17
DMOE (GPa)	8.38	7.08**	5.81	1.10	16.76	14.54^{ns}	13.17	1.75	9.99	9.54^{ns}	9.03	0.40
BD (g cm^{-3})	0.38	0.34*	0.29	0.03	0.58	0.55**	0.48	0.05	0.40	0.39^{ns}	0.37	0.01
RS per 1% change in MC (%)	0.19	0.15**	0.10	0.04	0.26	0.22*	0.18	0.03	0.17	0.17^{ns}	0.16	0.01
TS per 1% change in MC (%)	0.28	0.24^{ns}	0.22	0.02	0.34	0.31^{ns}	0.27	0.02	0.23	0.22^{ns}	0.21	0.01
CS (MPa)	45.0	37.9**	24.6	8.2	73.1	68.0**	57.2	6.3	45.5	42.2*	36.7	3.4

[a] n = number of trees; Max. = maximum; Min. = minimum; SD = standard deviation; D = stem diameter; H = tree height; SWV = stress-wave velocity; DMOE = dynamic modulus of elasticity; BD = basic density; RS = radial shrinkage; MC = moisture content; TS = tangential shrinkage; CS = compressive strength parallel to grain; * = significant at the 5 percent level among five trees; ** = significant at the 1 percent level among five trees; ns = no significance among five trees.

$$l = l_o + \frac{15(l_a - l_o)}{n} \quad (3)$$

Air-dried small specimens (4 by 2 by 2 cm) for compression tests were obtained at 2-cm intervals from the 15 disks (100 mm in thickness) collected 1 m from ground level. In all, 39, 41, and 41 specimens were prepared for terap, medang, and balik angin, respectively. Air-dried density of the specimens was also measured before conducting the test. Compressive tests were conducted using a universal testing machine (Tensilon RTF-2350; A&D) with a load speed of 0.3 mm min^{-1}. Compressive strength parallel to grain (CS) was calculated by dividing the maximum load by the cross-sectional area of the specimen.

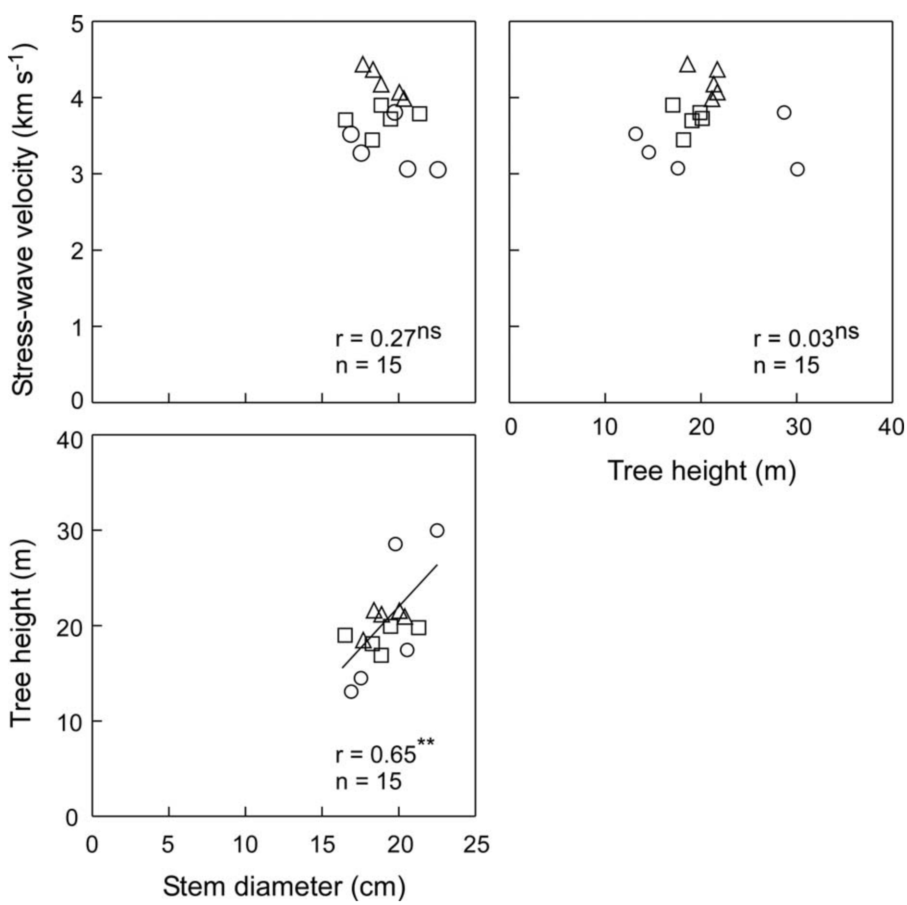

Figure 1.—Relationships between growth characteristics and stress-wave velocity in three species. Circles, squares, and triangles indicate terap, medang, and balik angin, respectively. n = *number of trees;* r = *correlation coefficient; ns = not significant; ** = significant at the 1 percent level.*

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Results and Discussion

Table 1 shows *D, H,* and density of trees per hectare in the experimental site. Significance at the 5 percent level in *D* and no significance in *H* were found among the three species. The density of trees per hectare for the three species was 1,000, 1,100, and 1,100 for terap, medang, and balik angin, respectively. The density of trees per hectare was similar in the three species used for the present study.

Table 2 shows growth characteristics and wood properties of the terap, medang, and balik angin trees used in the present study. The mean *D* and *H* were 19.4 cm and 20.8 m, 19.0 cm and 20.8 m, and 18.8 cm and 18.8 m in terap, medang, and balik angin, respectively. The mean SWV for terap, medang, and balik angin was 3.36, 4.21, and 3.73 km s^{-1}, respectively. A positive correlation between stem SWV and Young's modulus of wood has been reported (Ishiguri et al. 2007, Yamasaki et al. 2010, Yin et al. 2010, Wessels et al. 2011). Medang has the highest Young's modulus of wood among the three species tested. A significant positive correlation ($r = 0.65$) between *D* and *H* was found, whereas no significant correlation between growth characteristics and SWV was observed (Fig. 1). These results indicate that in the three species tested, growth characteristics are closely related to each other, but the SWV is independent from growth characteristics. This is also true for other tropical hardwood species (Ishiguri et al. 2007, 2011; Makino et al. 2012). Based on these results, the superior trees, with both good growth characteristics and high Young's modulus of wood, could be selected as the seed sources in tree breeding programs for these species.

The mean values and standard deviations of log DMOE for terap, medang, and balik angin are shown in Table 2, with the highest values for medang. The DMOE of logs is positively correlated with the mechanical properties of wood (Yin et al. 2010, Wessels et al. 2011). The highest compressive strength among the three species could be obtained in medang. In these results, the DMOE of logs was consistent with the stem SWV. Figure 2 shows a significant correlation ($r = 0.85$) between SWV and DMOE, suggesting that the Young's modulus of terap, medang, and balik angin wood can be predicted by the stem SWV.

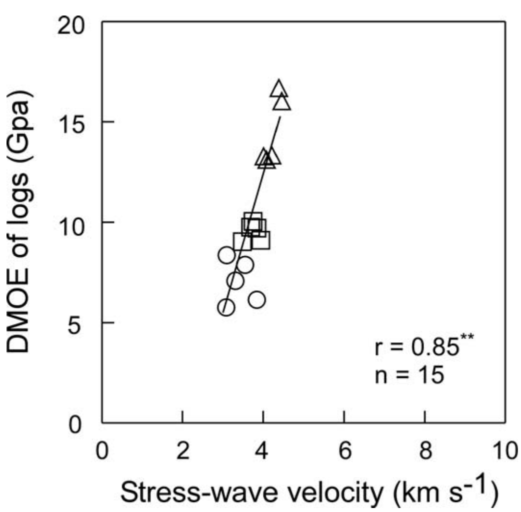

Figure 2.—Relationship between stress-wave velocity of stem and mean dynamic modulus of elasticity (DMOE) of logs. Circles, squares, and triangles indicate terap, medang, and balik angin, respectively. n = *number of trees;* r = *correlation coefficient; ** = significant at the 1 percent level.*

The mean BD of whole trees in terap, medang, and balik angin is shown in Table 2, with medang having the highest values. Densities of terap and medang at 15 percent MC and of balik angin at 12 percent MC were 0.37 to 0.55, 0.59 to 0.74, and 0.69 to 0.83 g cm^{-3}, respectively (Lemmens et al. 1995, Sosef et al. 1998). These results were similar to previous findings with the same species (Lemmens et al. 1995, Sosef et al. 1998). Figure 3 shows the radial variations of BD at 1 m above the ground in each species. BD gradually increased from pith to bark in terap and balik angin, whereas a constant trend from pith to bark in medang was observed. Figure 4 depicts the longitudinal variation of BD for each species. BD of terap and balik angin decreased from 1 to 3 m above the ground and then gradually increased to the top of the tree. On the other hand, BD of medang showed a constant trend from the bottom to the top of the tree. Moreover, for medang, uniform patterns of BD were found in both radial and axial directions. In general, it is well known that wood density positively correlates with

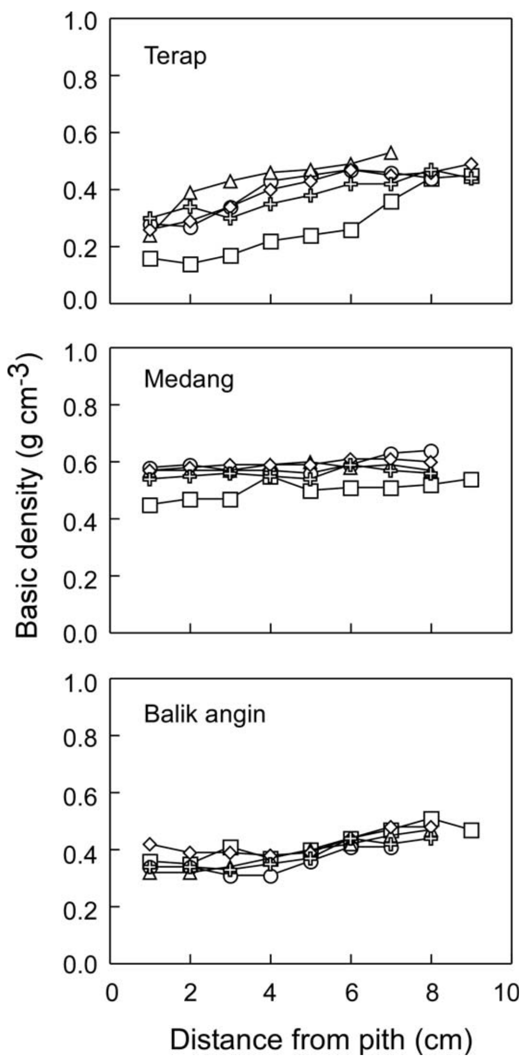

Figure 3.—Radial variations of basic density at 1.0 m above the ground. Squares, circles, triangles, diamonds, and crosses indicate individual samples.

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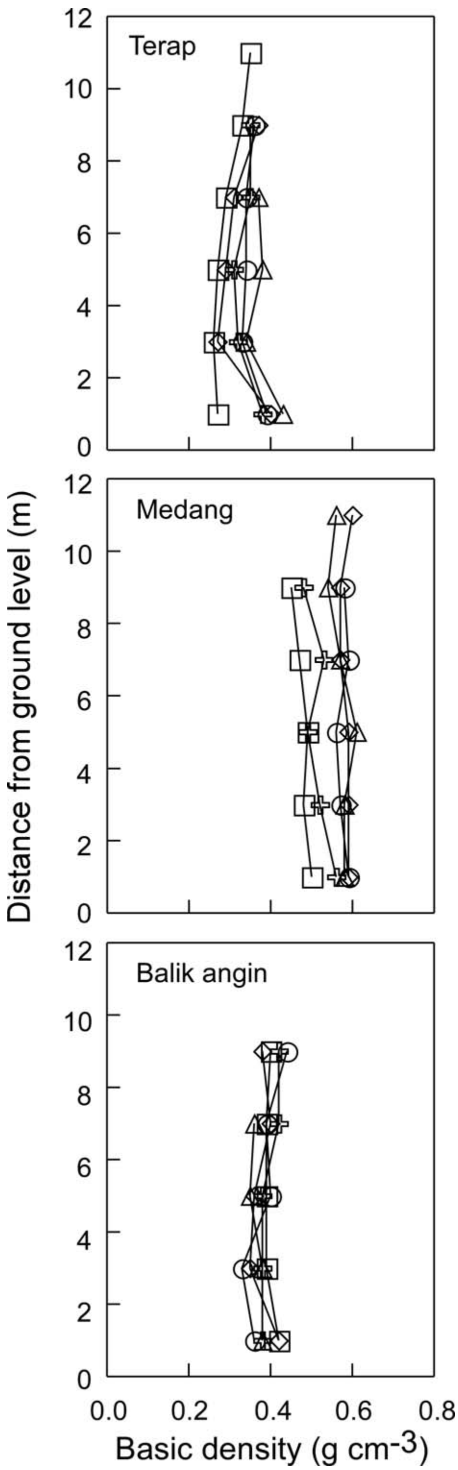

Figure 4.—Longitudinal variations of basic density. Squares, circles, triangles, diamonds, and crosses indicate Trees 1, 2, 3, 4, and 5, respectively.

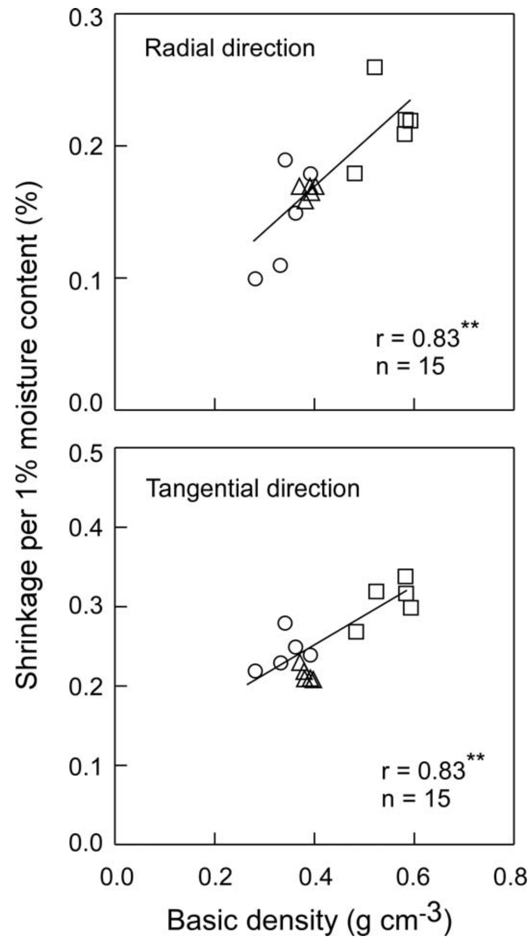

Figure 5.—Relationships between basic density and shrinkage per 1 percent change in moisture content. n = *number of trees;* r = *correlation coefficient; ** = significant at the 1 percent level.*

the mechanical properties of wood (Kollman and Côté 1984, Carrillo et al. 2011, Wessels et al. 2011).

Table 2 shows the mean values of radial and tangential shrinkages. The lowest values of radial and tangential shrinkages were observed in terap and balik angin, respectively. Kord et al. (2010) analyzed the correlation between wood density and shrinkage on fast-growing *Populus euramericana* and found a significant positive correlation between wood density and radial, tangential, and volumetric shrinkages. In the present study, as shown in Figure 5, significant positive correlations were found between BD and shrinkage in both radial and tangential directions, suggesting that BD is a good indicator for predicting the magnitude of shrinkage in the three tested species.

Of the three species, the highest value of CS was obtained in medang (Table 2). The MC of the CS specimens at testing was 8.8, 9.4, and 8.0 percent for terap, medang, and balik angin, respectively. This result is consistent with the SWV of the stem and DMOE of logs (Table 2). Figure 6 shows significant positive correlations between air-dry density and CS observed in all species. A high relationship between mechanical properties and air-dry density has been reported (Kollmann and Côté 1984, Chowdhury et al. 2009). The tendency is also true for terap, medang, and balik angin.

Analysis of variance (ANOVA) was applied to determine differences in wood properties among the five test trees in each species (Table 2). Significant differences in terap DMOE were found. Significant differences in BD and radial shrinkage were also observed in the five trees of terap and of medang. Furthermore, significant differences in CS were found among the five trees within each species. Although numbers of sample trees were limited, significant differences in some wood properties were found among the five

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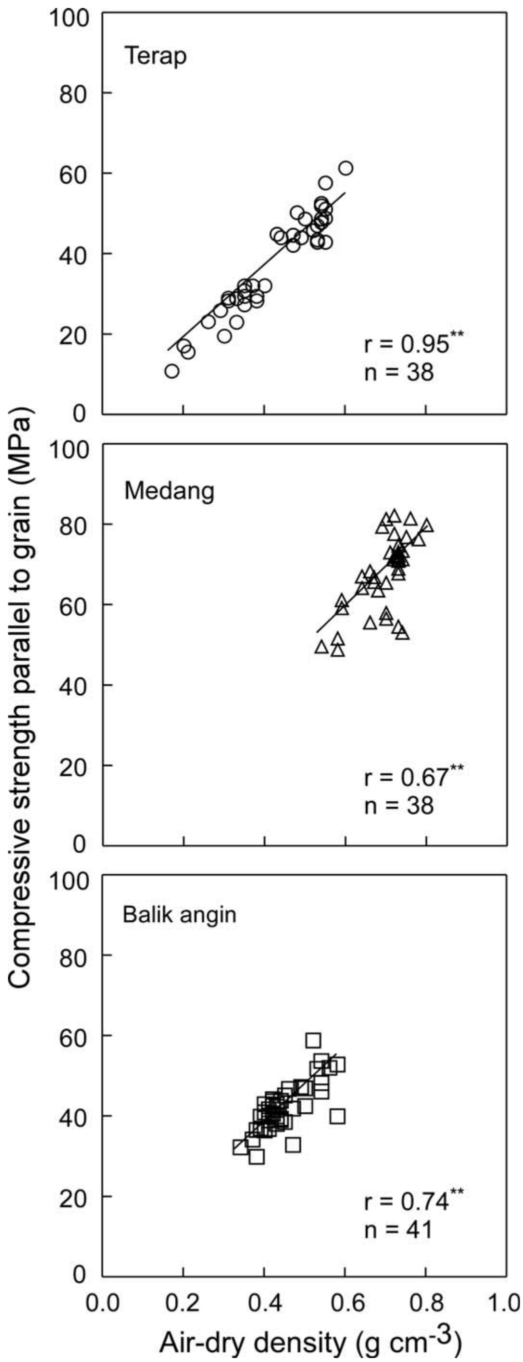

Figure 6.—Relationships between air-dry density and compressive strength parallel to grain. n = *number of samples;* r = *correlation coefficient; ** = significant at the 1 percent level.*

trees, suggesting that wood-quality improvement in these three species might be possible through tree breeding. In addition, results shown in Figures 2, 5, and 6 suggest that SWV and density are useful indicators to select the superior trees in breeding programs for the three species.

Conclusions

In the present study, growth characteristics and wood properties from three native fast-growing species in Indonesia, terap, medang, and balik angin, were investigated. No significant correlation was found between growth characteristics (*D* and *H*) and SWV for the three species. On the other hand, significant positive correlation between the SWV of stems and DMOE of logs was found, suggesting that stem SWV is a useful indicator for evaluating the Young's modulus of wood. The mean BD of whole trees in terap, medang, and balik angin was 0.34, 0.55, and 0.39 g cm^{-3}, respectively. BD in terap and balik angin gradually increased from pith to bark, decreased from 1 to 3 m above the ground, and then showed an almost constant value to the top of the tree. On the other hand, the BD in medang was almost the same as that in the stems. In this study, the relationships between growth characteristics and wood properties were clarified in the three tested species. In addition, significant positive correlations were found between shrinkage per 1 percent change in MC and BD and between air-dry density and CS in the three species. Therefore, the mechanical properties of terap, medang, and balik angin can be predicted by the SWV of stems and the air-dry density. Based on the results of ANOVA, wood properties (e.g., DMOE, BD, shrinkage per 1 percent change in MC, and CS) might be improved by tree breeding programs for wood quality in these three species.

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