ISSN : 0917-415X DOI:10.3759/tropics.25.23

TROPICS Vol. 25 (1) 23-31 Issued June 1, 2016

ORIGINAL ARTICLE

Effects of radial growth rate on anatomical characteristics and wood properties of 10-year-old *Dysoxylum mollissimum* trees planted in Bengkulu, Indonesia

Futoshi Ishiguri[1*], Haruna Aiso[1,2], Mirai Hirano[1], Ridwan Yahya[3], Imam Wahyudi[4], Jyunichi Ohshima[1], Kazuya Iizuka[1] and Shinso Yokota[1]

[1] Faculty of Agriculture, Utsunomiya University, Utsunomiya, Tochigi 321-8505, Japan
[2] United Graduate School of Agricultural Science, Tokyo University of Agriculture and Technology, Fuchu, Tokyo 183-8509, Japan
[3] Faculty of Agriculture, University of Bengkulu, Bengkulu 38371, Indonesia
[4] Faculty of Forestry, Bogor Agricultural University, Bogor 16680, Indonesia
* Corresponding author: ishiguri@cc.utsunomiya-u.ac.jp

ABSTRACT The growth characteristics, anatomical characteristics, and wood properties of *Dysoxylum mollissimum*, a fast-growing tree species, were investigated. To clarify the effect of radial growth rate on these characteristics and properties, 10-year-old trees planted in Bengkulu, Indonesia were examined and classified into three categories (fast-, medium-, and slow-growing). Xylem maturation type was also evaluated in this species. The mean values of stem diameter, tree height, stem volume, and stress-wave velocity in the 50 measured trees were 18.0 cm, 10.6 m, 0.119 m^3, and 3.48 km s^{-1}, respectively. Mean values of anatomical characteristics and wood properties in nine selected trees were as follows: vessel diameter, 129 μm; vessel frequency, 3.5 vessels mm^{-2}; cell wall thickness of wood fiber, 1.2 μm; percentages of vessels, wood fiber, ray parenchyma, axial parenchyma, and cell wall, 8.8, 72.9, 12.4, 5.9, and 33.5%, respectively; vessel element length, 0.36 mm; wood fiber length, 1.04 mm; basic density, 0.45 g cm^{-3}; and compressive strength parallel to the grain in green condition, 29.9 MPa. These obtained values were similar to or smaller than previous results obtained in research on other *Dysoxylum* spp. For almost all of the anatomical characteristics and wood properties, no significant differences among the categories were found. This suggests that the trees with faster radial growth characteristics do not always produce lower quality wood in this species. Judging from the radial variation of anatomical characteristics, the xylem maturation of this species depends on the diameter growth, and it might occur at around 6 to 8 cm from the pith.

Key words: cell morphology, stress-wave velocity, basic density, radial growth rate, xylem maturation

INTRODUCTION

In Indonesia, several species, such as *Acacia mangium* and *Falcataria moluccana*, have been used to establish large-scale industrial plantations owned by companies as well as small-scale plantations such as community forests. The wood properties of these species have been investigated by many researchers (Wahyudi et al. 1999, Honjo et al. 2005, Ishiguri et al. 2007, 2009, 2012a, Kojima et al. 2009a, b, Makino et al. 2012, Nugroho et al. 2012, Darmawan et al. 2013). On the other hand, Istikowati et al. (2014) examined growth and wood properties in less-utilized-fast-growing tree species found in a secondary forest naturally regenerated in South Kalimantan, Indonesia. Istikowati et al. (2014) found that wood properties might be improved by tree breeding programs for wood quality in these species. Therefore, further research is needed to identify other fast-growing tree species that can be used to establish plantations.

It is important to understand the xylem maturation process in plantation species to effectively use wood resources. In the case of softwood species grown in the temperate zone, tracheid length and microfibril angle which are closely related to the physical and mechanical properties of wood, become stable after the 15th to the 20th annual ring from the pith, suggesting that xylem maturation in temperate softwood species depends on cambial age (Watanabe et al. 1963). Several researchers have investigated the xylem maturation process in tropical hardwood species (Honjo et al. 2005, Kojima et al. 2009a, Ishiguri et al. 2012b, Nugroho et al. 2012, Makino et al. 2012, Hidayati et al. 2014). Researches have shown that the maturation process in some fast-growing species, such as *Acacia mangium*, *A. auriculiformis*, and *Falcataria moluccana*, depends on the diameter growth (Honjo et al. 2005, Kojima et al. 2009a, Makino et al. 2012, Nugroho et al. 2012). For example, basic density

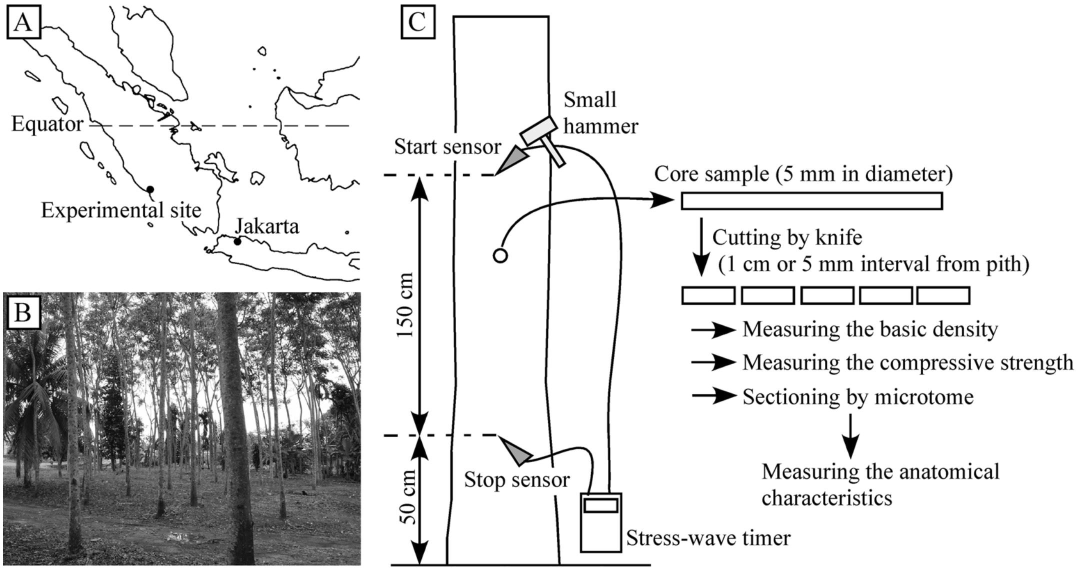

Fig. 1. Location of experimental site (A and B) and illustration of experimental procedures (C).

became stable after about 6 cm from the pith in *A. mangium* trees with different diameter sizes and ages (Makino et al. 2012). However, xylem maturation of some tropical hardwood species, such as *Shorea acuminatissima* and *Tectona grandis*, depends on cambial age (Ishiguri et al. 2012b, Hidayati et al. 2014). Therefore, xylem maturation might differ among tropical hardwood species.

In general, trees are cut in order to investigate their anatomical characteristics and wood properties. In addition, a large number of trees is needed to identify variations in these characteristics and properties among trees. However, in Southeast Asian countries, it is sometimes difficult (or prohibited) to cut a large number of trees to investigate these characteristics and properties. Therefore, non- or semi-destructive methods should be applied to clarify the anatomical characteristics and wood properties of tropical trees. Measurement of stress-wave velocity is one non-destructive method for evaluating the Young's modulus of wood (Nanami et al. 1993, Ikeda and Arima 2000, Dickson et al. 2003, Wang et al. 2004). In addition, as a semi-destructive method, some researchers have used core samples obtained with a core borer to investigate anatomical characteristics and wood properties, including wood strength (Lin et al. 2007, Ishiguri et al. 2012b, Makino et al. 2012).

The genus *Dysoxylum* is found from India to Southern China and throughout Southeast Asia and the Western Pacific, and it comprises ca. 80 species (Sosef et al. 1998, Ogata et al. 2008). The wood of *Dysoxylum* spp. is used for many purposes, including structural lumber, furniture, plywood, and pulp production (Sosef et al. 1998). Recently, *D. mollissimum* Blume has been selected from North Bengkulu, Sumatra, Indonesia as a fast-growing species that could be used in plantations in Bengkulu (Depari et al. 2013). In addition, some small-scale plantations have been established for this species in Central Bengkulu.

In this study, to obtain basic knowledge of *D. mollissimum* wood, we investigated the growth characteristics, anatomical characteristics, and wood properties of 10-year-old *D. mollissimum* trees planted in Bengkulu, Indonesia. In addition, the effects of radial growth rate on anatomical characteristics and wood properties were examined, and xylem maturation of this species was evaluated.

MATERIALS AND METHODS

Experimental site and field survey

The experimental site was a private forest located in Bengkulu, Indonesia (03°44′S, 102°15′E) (Fig. 1A). About 100 10-year-old *Dysoxylum mollissimum* trees were growing in a flat area with about 3 by 3 m initial spacings. Botanical identification of the planted species was conducted by Indonesian Institute of Sciences. Unfortunately, the seed sources and silvicultral managements were unknown.

The stem diameter, tree height, and stress-wave velocity of trees were determined for 50 trees in the forest. Stem diameter was measured at 1.3 m above the ground by tape measure. Tree height was measured by a height meter (Vertex IV, Haglöf). Stem volume was calculated by the equation proposed by Monteuuis et al. (2011) for *Tectona grandis* (the bole volume below and above 1.3 m from ground was calculated as cylinder and cone, respectively). Stress-wave velocity was determined by the method described in a previous paper (Ishiguri et al. 2007). The start and stop sensors were set on the stems at 150 and 50 cm above the ground, respectively (Fig. 1C). The stress-wave propagation time (μs) was measured by a commercial stress-wave timer (FAKOPP, Fakopp enterprise). Stress-wave velocity (km s^{-1}) was calculated by dividing the span of the sensors (1 m) by the obtained stress-wave propagation time.

To clarify the effects of radial growth rate on the anatomical characteristics and wood properties, 50 trees were measured and classified into three categories based on the mean values and standard deviations (SD) of stem diameter (d) according to the method of Ishiguri et al. (2012b): fast-growing trees (d ≧ mean + one SD), medium-growing trees (mean - one SD < d < mean + one SD), and slow-growing trees (d ≦ mean - one SD).

Anatomical characteristics and wood properties

To determine the anatomical characteristics and wood properties, core samples (5 mm in diameter) were collected from three trees in each category (Fig. 1C). Three core samples in each tree were obtained at around 1.3 m above ground by a core borer (Haglöf). To prevent core samples from drying, the samples were wrapped in plastic sheets before use. Three core samples were used to determine the anatomical characteristics, basic density, and compressive strength parallel to the grain.

Due to indistinct growth rings, all properties, except for compressive strength parallel to the grain were determined at a 1 cm interval from the pith. Core samples were cut into 1 cm segments from pith to bark. The transverse sections with 15 μm in thickness were obtained by a sliding microtome (ROM-380, Yamato Koki). The sections were stained with safranin, dehydrated through a graded ethanol series, and mounted with biolite. Digital images of transverse sections were obtained by a digital camera (E-P3, Olympus) equipped to a microscope (BX51, Olympus). The vessel diameter and cell wall thickness of wood fibers were measured using a software (ImageJ, National Institutes of Health). To determine the vessel frequency, the vessels in five digital images were counted, and the number of vessels was then divided by the total area of the five digital images. In each radial position, 20 vessels and 30 wood fibers were measured, and the mean value was calculated. The proportions of cell types were determined by the point counting method (Taylor 1973, Denne and Hale 1999). A total of 24 digital images in each radial position were taken by the same method described above. Grid lines with 50 μm intervals were drawn on each image to obtain the 600 counting points. The cell types were classified into the following categories: vessel wall/lumen, wood fiber wall/lumen, ray parenchyma wall/lumen, and axial parenchyma wall/lumen. The cell proportions were determined as the percentage per counted total number (600 points).

To determine the cell length, small sticks were obtained from the core samples at 1 cm intervals. The sticks were macerated with Schulze's solution, and 20 vessel elements and 30 wood fibers projected on a microprojector (V-12, Nikon) were measured using a digital caliper (CD-15 CP, Mitsutoyo).

Basic density was determined as the ratio of oven-dried weight (g) to green volume (cm^3) measured by the water-displacement method.

Compressive strength parallel to the grain in green condition was measured by the method described in the previous paper (Ishiguri et al. 2012b). The core sample was cut into 5 mm intervals from the pith. Compressive strength parallel to the grain was measured by a strength testing equipment for core samples (Fractometer II, IML).

Data analysis

Mean values at 2 cm intervals for all examined characteristics and properties were calculated to clarify the radial variation. A one-way analysis of variance (ANOVA) test was conducted by a free statistical analysis program (StatPlus:mac LE Version 2009, AnalystSoft Inc.) to detect the differences among the three radial growth categories. To clarify the xylem maturation process, radial variation in relation to relative distance from pith to bark was calculated by the method described in our previous paper (Fig. 2, Chowdhury et al. 2009).

RESULTS AND DISCUSSION

Growth characteristics and stress-wave velocity

Table 1 shows the growth characteristics and stress-wave velocity of trees. The mean values of stem diameter, tree height, stem volume, and stress-wave velocity were 18.0 cm, 10.6 m, 0.119 m^3, and 3.48 km s^{-1}, respectively. The mean values of stress-wave velocity were 3.18, 3.23,

Table 1. Stem diameter, tree height, and stress-wave velocity of 10-year-old *Dysoxylum mollissimum* trees

Property	All trees (n = 50)		Fast-growing (n = 7)		Medium-growing (n = 34)		Slow-growing (n = 9)		Significance among category
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
Stem diameter (cm)	18.0	3.4	24.4	1.7	17.9	1.6	13.7	1.1	**
Tree height (m)	10.6	1.9	11.4	0.8	10.9	2.0	9.0	1.4	*
Stem volume (m^3)	0.119	0.056	0.220	0.034	0.115	0.033	0.057	0.013	**
SWV ($km\ s^{-1}$)	3.48	0.21	3.53	0.2	3.48	0.23	3.42	0.13	ns

Note: n, number of trees; SD, standard deviation; SWV, stress-wave velocity; *, significance at 5% level; **, significance at 1% level; ns, no significance.

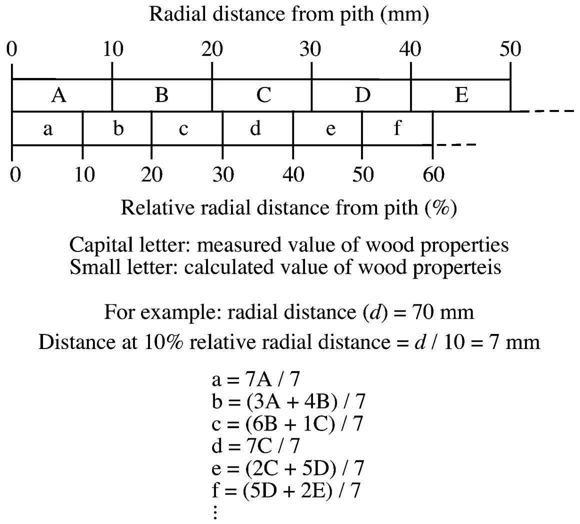

Fig. 2. Calculation method of anatomical characteristics and wood properties in relation to relative distance from the pith (Chowdhury et al. 2009).

and 3.36 km s^{-1} in 13-year-old *Eucalyptus nitens* trees of Connor's plain race, northern race, and southern race, respectively (Blackburn et al. 2010), 3.59 and 3.75 km s^{-1} in 5- and 7-year-old *A. mangium* trees (Makino et al. 2012), 3.06 km s^{-1} in 13-year-old *F. moluccana* trees (Ishiguri et al. 2007), and 3.45 km s^{-1} in 4-year-old *E. camaldulensis* trees (Ishiguri et al. 2013). Because the stress-wave velocity of trees is positively correlated with the Young's modulus of wood (Ikeda and Arima 2000), the dynamic Young's modulus (E) can be calculated by using two parameters: velocity (V) and density at testing (ρ): $E = V^2 \rho$ (Nanami et al. 1993). Therefore, the Young's modulus of wood in this species may be in the range of that of other fast-growing species, even though the wood density differed among fast-growing species.

Anatomical characteristics and wood properties

Table 2 shows the mean values of anatomical characteristics and wood properties. Vessel diameter, vessel frequency, and cell wall thickness of wood fibers were 129 µm, 3.5 vessels mm^{-2}, and 1.2 µm, respectively. Ogata et al. (2008) reported that the tangential vessel diameter, vessel frequency, and cell wall thickness of wood fibers in *Dysoxylum* spp. ranged from 110 to 310 µm, 3.5 to 29.0 vessels mm^{-2}, and 1.5 to 3.0 µm, respectively. In *D. spectabile*, the mean tangential vessel diameter and vessel frequency were 64 µm (ranging from 36 to 106 µm) and 10 vessels mm^{-2} (ranging from 4 to 18 vessels mm^{-2}) (Patel 1974). Our results are relatively low compared to the values reported by Ogata et al. (2008), but they are similar to the results obtained in research on *D. spectabile* (Patel 1974). Vessel diameter gradually increased up to 6 cm from the pith and then rapidly increased toward the bark (Fig. 3). Vessel frequency decreased up to 4 cm from the pith, and then it showed almost constant values. On the other hand, the cell wall thickness of the wood fibers showed an almost constant value.

Cell percentages are shown in Table 2. Percentages of vessel, wood fiber, ray parenchyma, and axial parenchyma were 8.8, 72.9, 12.4, and 5.9%, respectively. In addition, the cell wall percentage was 33.5%. Figure 3 shows radial variation of cell percentages. Vessel percentages were almost constant up to 8 cm from the pith, and they then increased toward the bark. Wood fiber percentages gradually decreased from pith to bark. Axial parenchyma percentages increased up to 6 cm from the pith and then showed almost constant values. On the other hand, no consistent radial pattern was recognized in the ray parenchyma percentages.

The mean values for vessel element length and wood fiber length were 0.36 and 1.04 mm, respectively (Table 2). Vessel element length was almost constant from pith to bark, whereas wood fiber length steadily increased from pith to bark (Fig. 3). Patel (1974) reported that vessel ele-

Table 2. Anatomical characteristics and wood properties of nine selected trees

Property	All trees (n = 9)		Fast-growing (n = 3)		Medium-growing (n = 3)		Slow-growing (n = 3)		Significance among category
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
Stem diameter (cm)	18.7	5.1	24.8	1.5	18	0.4	13.2	1.0	*
Tree height (m)	9.8	1.7	11.6	1.0	8.8	1.7	8.9	0.4	**
Stress-wave velocity (km s^{-1})	3.33	0.16	3.36	0.07	3.3	0.27	3.33	0.12	ns
Vessel diameter (µm)	129	10	135	4	126	11	126	14	ns
Vessel frequency (vessel mm^{-2})	3.5	0.4	3.6	0.5	3.4	0.6	3.5	0.3	ns
Cell wall thickness of WF (µm)	1.2	0.2	1.0	0.1	1.2	0.0	1.4	0.1	**
Vessel (%)	8.8	1.5	8.7	2.5	8.7	0.9	9	1.1	ns
Wood fiber (%)	72.9	2.3	73.0	3.3	72.9	2.0	72.8	2.4	ns
Ray parenchyma (%)	12.4	1.1	12.1	0.9	12.9	1.0	12.3	1.5	ns
Axial parenchyma (%)	5.9	1.0	6.2	1.8	5.6	0.4	5.9	0.3	ns
Cell wall (%)	33.5	2.7	33.8	1.2	35.6	2.9	31.0	1.5	ns
Vessel element length (mm)	0.36	0.04	0.34	0.01	0.34	0.03	0.40	0.00	**
Wood fiber length (mm)	1.04	0.05	1.02	0.07	1.05	0.04	1.05	0.04	ns
Basic density (g cm^{-3})	0.45	0.02	0.43	0.00	0.46	0.02	0.45	0.01	ns
Compressive strength (MPa)	29.9	1.9	29.7	0.6	31.0	2.6	29.0	2.1	ns

Note: n, number of trees; SD, standard deviation; WF, wood fiber; *, significance at 5% level; **, significance at 1% level; ns, no significance.

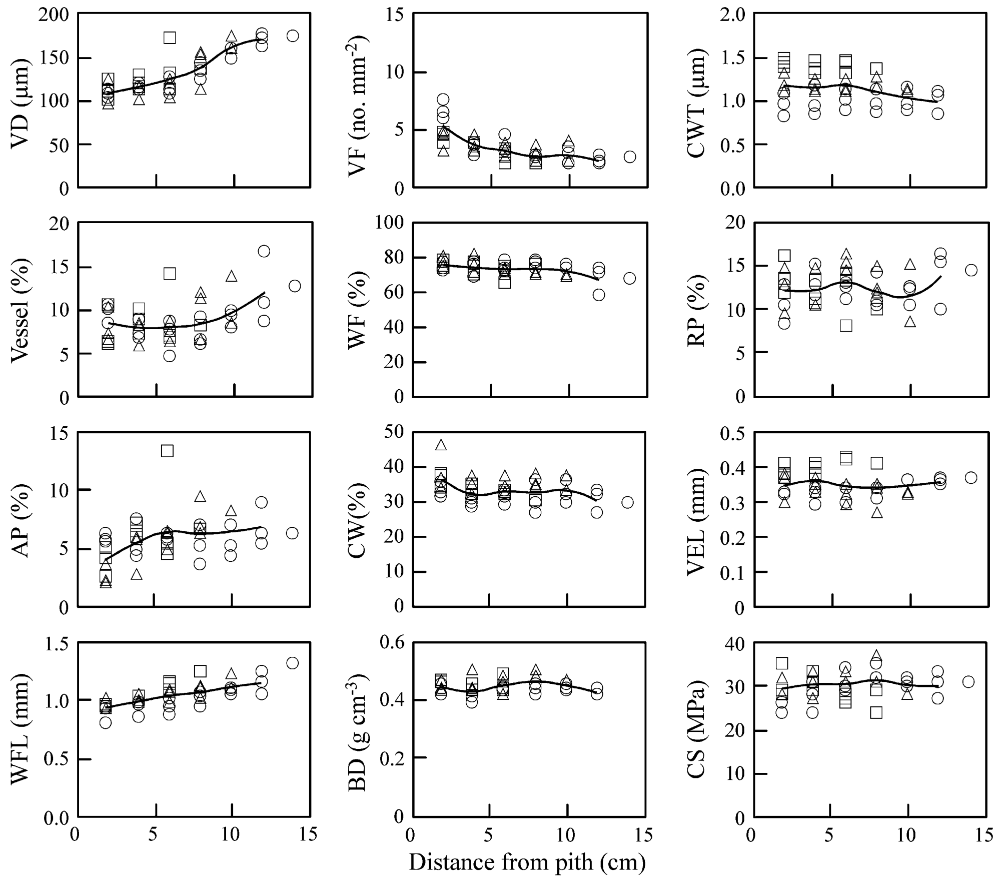

Fig. 3. Radial variations of anatomical characteristics and wood properties in nine selected trees. Circles, triangles, and squares indicate fast-, medium-, and slow-growing trees, respectively. Solid lines indicate the mean values of nine selected trees. VD: vessel diameter, VF: vessel frequency, CWT: cell wall thickness of wood fiber, WF: wood fiber, RP: ray parenchyma, AP: axial parenchyma, CW: cell wall, VEL: vessel element length, WFL: wood fiber length, BD: basic density, CS: compressive strength.

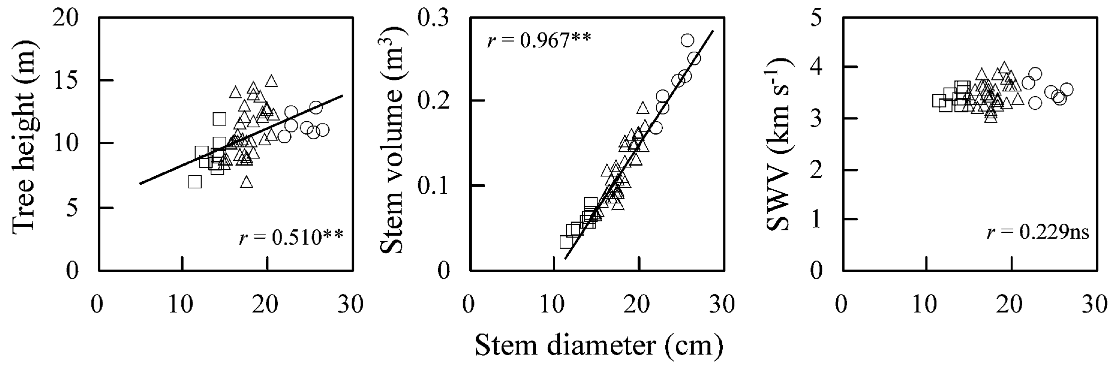

Fig. 4. Relationships between stem diameter and tree height, stem volume, or stress-wave velocity of stem. Circles, triangles, and squares indicate fast-, medium-, and slow-growing trees, respectively. **: Significance at 1% level, ns: no significance, *r*: correlation coefficient.

ment length and wood fiber length in *D. spectabile* ranged from 0.26 to 0.84 mm and from 0.57 to 1.55 mm, respectively. The mean values were 0.58 and 1.07 mm for vessel element length and wood fiber length, respectively (Patel 1974). Ogata et al. (2008) also reported that the minimum, maximum, and mean values of wood fiber length in *D. arnoldianum* were 1.1, 2.0, and 1.6 mm, respectively. The mean values of vessel element length and wood fiber length in the present study were shorter than those found in *D. spectabile* (Patel 1974) and the wood fiber length in *D. arnoldianum* (Ogata et al. 2008).

The mean values of basic density and the compressive strength parallel to the grain in green condition were 0.45 g cm^{-3} and 29.9 MPa, respectively (Table 2). As shown in Fig. 3, nearly constant values were found from pith to bark for both basic density and compressive strength. In the previous reports, the basic density of *D. arnoldianum* grown in natural forests in Papua New Guinea ranged from 362 to 414 kg m^{-3} (0.362 to 0.414 g cm^{-3}) (Working Group on Utilization of Tropical Woods 1978). In addition, the wood density values of *D. excelsum* at 15% moisture content and *D. mollissimum* at 12% moisture content were 460 kg m^{-3} (0.46 g cm^{-3}) and 640 kg m^{-3} (0.64 g cm^{-3}), respectively (Sosef et al. 1998). Ogata et al. (2008) reported that the air-dry density in *Dysoxylum* spp. ranged from 0.48 to 1.04 g cm^{-3}, and it generally showed 0.70 to 0.85 g cm^{-3}. On the other hand, compressive strength parallel to the grain in green condition was 35 MPa and 31 MPa for *D. densiflorum* and *D. mollissimum*, respectively (Sosef et al. 1998). Compared to the previous results, the results obtained in our study showed relatively lower values in basic density, but the compressive strength values were almost the same.

These results indicate that the anatomical characteristics and wood properties of *D. mollissimum* show values similar to or smaller than those obtained in research on other *Dysoxylum* spp.

Effects of radial growth rate on anatomical characteristics and wood properties

The mean value and standard deviation of stem diameter in the 50 examined trees were 18.0 and 3.4 cm, respectively (Table 1). In the present study, the trees were classified into three categories based on the mean value and the standard deviation of stem diameters (Ishiguri et al. 2012b). The ranges of stem diameter in fast-, medium-, and slow-growing categories were $d \geqq 21.4$ cm, 14.6 cm $< d <$ 21.4 cm, and $d \leqq 14.6$ cm, respectively. The number of trees in each category was 7, 34, and 9, respectively. Significant differences among the three categories were found in tree height and stem volume, but not in stress-wave velocity (Table 1). In addition, positive significant correlations were obtained between stem diameter and tree height or stem volume (Fig. 4). However, no significant correlation was observed between stem diameter and stress-wave velocity (Fig. 4). The results obtained in the present study were similar to those obtained in research on other tropical hardwood species (Ishiguri et al. 2012b, Makino et al. 2012, Istikowati et al. 2014). Furthermore, as shown in Table 2, no significant differences in basic density were found among growth categories. Young's modulus of stem can be calculated from stress-wave velocity and basic density (Nanami et al. 1993). Therefore, we conclude that wood properties, including basic density and Young's modulus of *D. mollissimum* trees, are independent from growth characteristics.

Kojima et al. (2009b) examined growth stress, wood density, microfibril angle, and wood fiber length in several fast-growing tree species. They found that, with a few exceptions, these characteristics are constant, regardless of the

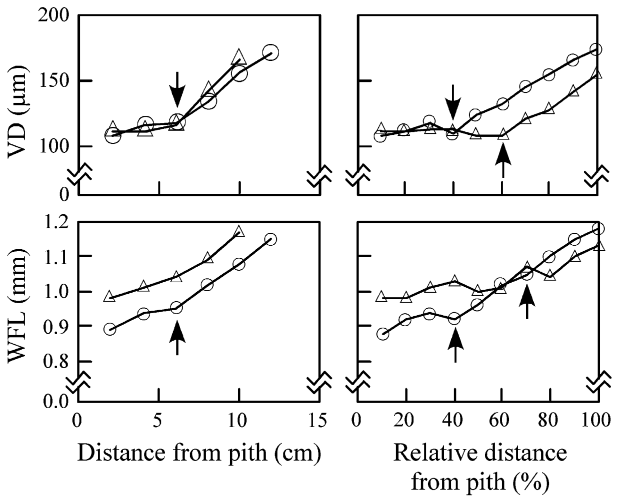

Fig. 5. Radial variations of vessel diameter and wood fiber length in relation to distance from pith (left side graphs) and relative distance from pith to bark (right side graphs). Circles and triangles indicate fast- and medium-growing trees, respectively. Arrows indicate the alternation points of these characteristics.

lateral growth rate of each species. In the present study, no significant differences were found among three categories in almost all characteristics and properties, except for vessel element length and cell wall thickness of wood fiber (Table 2). These results are similar to those obtained in Kojima's research on several fast-growing tree species (Kojima et al. 2009b). Based on the results, we conclude that, in *D. mollissimum*, faster radial growth characteristics do not always result in the production of wood of lower quality.

Xylem maturation in *D. mollissimum*

It has been reported that xylem maturation depends on the diameter growth in tropical fast-growing tree species, such as *A. mangium*, *F. moluccana*, and others (Honjo et al. 2005, Kojima et al. 2009a, Makino et al. 2012, Nugroho et al. 2012). On the other hand, xylem maturation depends on cambial age in some tropical species that are not considered to be fast-growing species, such as *Shorea acuminatissima* and *Tectona grandis* (Ishiguri et al. 2012b, Hidayati et al. 2014). In the former species, a faster radial growth characteristic results in an increase in the yield of "mature wood," which has high wood quality. In contrast, if xylem maturation depends on cambial age, "immature wood" volume is increased with increased radial growth rate at the initial stage of tree growth. Fig. 5 shows radial variation in mean values for vessel diameter and wood fiber length in fast- and medium-growing categories. Radial variation patterns in relation to distance from pith were almost the same in fast- and medium-growing categories. On the other hand, radial variation patterns in relation to relative distance differed among radial growth categories. The results suggest that xylem maturation in *D. mollissimum* depends on diameter growth. In addition, radial patterns in some anatomical characteristics, such as vessel diameter, vessel frequency, vessel percentage, and wood fiber length, changed at 6 to 8 cm from the pith, suggesting that xylem maturation in *D. mollissimum* occurs around 6 to 8 cm from the pith.

CONCLUSION

In this study, we examined the growth characteristics, anatomical characteristics, and wood properties of 10-year-old *Dysoxylum mollissimum* trees planted in Bengkulu, Indonesia. The mean values of stem diameter, tree height, stem volume, and stress-wave velocity in the 50 measured trees were 18.0 cm, 10.6 m, 0.119 m^3, and 3.48 km s^{-1}, respectively. The values for vessel diameter, vessel frequency, vessel element length, cell wall thickness of the wood fiber, and wood fiber length were 129 μm, 3.5 vessels mm^{-2}, 0.36 mm, 1.2 μm, and 1.04 mm, respectively. Percentages of vessel, wood fiber, ray parenchyma, axial parenchyma, and cell wall were 8.8, 72.9, 12.4, 5.9, and 33.5%, respectively. The mean values of basic density and compressive strength parallel to the grain in green condition were 0.45 g cm^{-3} and 29.9 MPa, respectively. These anatomical characteristics and wood properties showed values similar to or smaller than the results obtained in the other *Dysoxylum* spp. There were no significant differences among radial growth categories in almost all anatomical characteristics and wood properties, except for cell wall thickness of the wood fiber and vessel element length, examined in the present study. In addition, xylem maturation in this species depended on radial growth rather than cambial age. Based on the results, we conclude that *D. mollissimum* trees with faster radial growth characteristics do not always produce wood of lower quality.

ACKNOWLEDGEMENTS A part of this research was financially supported by the VBL Department of the Collaboration Center for Research and Development at Utsunomiya University, Japan. The authors express sincere thanks to Efratenta Katherina Depari at the Faculty of Agriculture in Bengkulu University, Indonesia for botanical identification of the sample trees.

REFERENCE

Blackburn D, Hamilton M, Harwood C, Innes T, Potts B, Williams D. 2010. Stiffness and checking of *Eucalyptus nitens* sawn boards: genetic variation and potential for genetic improvement. *Tree Genetics and Genomes* 6: 757–765.

Chowdhury MQ, Ishiguri F, Iizuka K, Takashima Y, Matsumoto K, Hiraiwa T, Ishido M, Sanpe H, Yokota S, Yoshizawa N. 2009. Radial variations of wood properties in *Casuarina equisetifolia* growing in Bangladesh. *Journal of Wood Science* 55: 139–143.

Darmawan W, Nandika D, Rahayu I, Fournier M, Marchal R. 2013. Determination of juvenile and mature transition ring for fast growing sengon and jabon wood. *Journal of the Indian Academy of Wood Science* 10: 39–47.

Denne MP, Hale MD. 1999. Cell wall and lumen percentages in relation to wood density of *Nothofagus nervosa*. *IAWA Journal* 20: 23–26.

Depari EK, Istomo, Rusdiana O. 2013. The effect of growth site factors and silvicultural treatments on productivity of kayu bawang (*Dysoxylum mollissimum* Blume) in private forest in Bengkulu. The Third International Symposium for Sustainable Humanosphere.

Dickson RL, Raymond CA, Joe W, Wilkinson CA. 2003. Segregation of *Eucalyptus dunnii* logs using acoustics. *Forest Ecology and Management* 179: 243–251.

Hidayati F, Ishiguri F, Iizuka K, Makino K, Marsoem SN, Yokota S. 2014. Among-clone variations of anatomical characteristics and wood properties in *Tectona grandis* planted in Indonesia. *Wood and Fiber Science* 46: 385–393.

Honjo K, Furukawa I, Sahri MH. 2005. Radial variation of fiber length increment in *Acacia mangium*. *IAWA Journal* 26: 339–352.

Ikeda K, Arima T. 2000. Quality evaluation of standing trees by a stress-wave propagation method and its application II. Evaluation of sugi stands and application to production of sugi (*Cryptomeria japonica* D. Don) structural square sawn timber. *Mokuzai Gakkaishi* 46: 189–196.

Ishiguri F, Eizawa J, Saito Y, Iizuka K, Yokota S, Priadi D, Sumiasri N, Yoshizawa N. 2007. Variation in the wood properties of *Paraserianthes falcataria* planted in Indonesia. *IAWA Journal* 28: 339–348.

Ishiguri F, Hiraiwa T, Iizuka K, Yokota S, Priadi D, Sumiasri N, Yoshizawa N. 2009. Radial variation of anatomical characteristics in *Paraserianthes falcataria* planted in Indonesia. *IAWA Journal* 30: 343–352.

Ishiguri F, Hiraiwa, Iizuka K, Yokota S, Priadi D, Sumiasri N, Yoshizawa N. 2012a. Radial variation in microfibril angle and compression properties of *Paraserianthes falcataria* planted in Indonesia. *IAWA Journal* 33: 15–23.

Ishiguri F, Takeuchi M, Makino K, Wahyudi I, Takashima Y, Iizuka K, Yokota S, Yoshizawa N. 2012b. Cell morphology and wood properties of *Shorea acuminatissima* planted in Indonesia. *IAWA Journal* 33: 25–38.

Ishiguri F, Diloksumpun S, Tanabe J, Iizuka K, Yokota S. 2013. Stress-wave velocity of trees and dynamic Young's modulus of logs of 4-year-old *Eucalyptus camaldulensis* trees selected for pulpwood production in Thailand. *Journal of Wood Science* 59: 506–511.

Istikowati WT, Ishiguri F, Aiso H, Hidayati F, Tanabe J, Iizuka K, Sutiya B, Wahyudi I, Yokota S. 2014. Physical and mechanical properties of woods from three native fast-growing species in a secondary forest in south Kalimantan, Indonesia. *Forest Products Journal* 64: 48–54.

Kojima M, Yamamoto H, Yoshida M, Ojio Y, Okumura K. 2009a. Maturation property of fast-growing hardwood plantation species: A view of fiber length. *Forest Ecology and Management* 257: 15–22.

Kojima M, Yamamoto H, Okumura K, Ojio Y, Yoshida M, Okuyama T, Ona T, Matsune K, Nakamura K, Ide Y, Marsoem SN, Sahri MH, Hadi YS. 2009b. Effect of the lateral growth rate on wood properties in fast-growing hardwood species. *Journal of Wood Science* 55: 417–424.

Lin CJ, Wang SY, Chiu CM. 2007. Crushing strength sampling with minimal damage to taiwania (*Taiwania cryptomerioides*) using a fractometer. *Wood and Fiber Science* 39: 39–47.

Makino K, Ishiguri F, Wahyudi I, Takashima Y, Iizuka K, Yokota S, Yoshizawa N. 2012. Wood properties of young *Acacia mangium* trees planted in Indonesia. *Forest Products Journal* 62: 102–106.

Monteuuis O, Goh DKS, Garcia C, Alloysius D, Gidman J, Bacilieri R, Chaix G. 2011. Genetic variation of growth and tree quality traits among 42 diverse genetic origins of *Tectona grandis* planted under humid tropical conditions in Sabah, East Malaysia. *Tree Genetics and Genomes* 7:1263–1275.

Nanami N, Nakamura N, Arima T, Okuma M. 1993. Measuring the properties of standing trees with stress waves III. Evaluating the properties of standing trees for some forest stands. *Mokuzai Gakkaishi* 39: 903–909.

Nugroho WD, Marsoem SN, Yasue K, Fujiwara T, Nakajima T, Hayakawa M, Nakaba S, Yamagishi Y, Jin HO, Kubo T, Funada R. 2012. Radial variations in the anatomical characteristics and density of the *Acacia mangium* of five different provenances in Indonesia. *Journal of Wood Science* 58: 185–194.

Ogata K, Fujii T, Abe H, Baas P. 2008. Identification of the Timbers of Southeast Asia and the Western Pacific. Kaiseisha Press, Otsu.

Patel RN. 1974. Wood anatomy of the dicotyledons indigenous to New Zealand 6. Meliaceae. *New Zealand Journal of Botany* 12: 159–166.

Sosef MSM, Hong LT, Prawirohatmodjo S. 1998. Plant Resources of South-East Asia 5 (3) Timber Trees: Lesser-Known Timbers. Procea, Bogor.

Taylor FW. 1973. Variations in the anatomical properties of South African grown *Eucalyptus grandis*. *Appita Journal* 27: 171–178.

Wahyudi I, Okuyama T, Hadi YS, Yamamoto H, Yoshida M, Watanabe H. 1999. Growth stresses and strains in *Acacia mangium*. *Forest Products Journal* 49(2): 77–81.

Wang X, Ross RJ, Green DW, Brashaw B, Englund K, Wolcott M. 2004. Stress wave sorting of red maple logs for structural

quality. *Wood Science and Technology* 37: 531–537.
Watanabe H, Tsutsumi J, Kojima K. 1963. Studies on juvenile wood I, experiments on stems of sugi trees (*Cryptomeria japonica* D. Don). *Mokuzai Gakkaishi* 9: 225–230.
Working Group on Utilization of Tropical Woods. 1978. Properties of some Papua New Guinea woods relating with manufacturing processes VI, wood qualities, physical properties and decay durability of some West New Britain woods. *Bulletin of Forestry and Forest Products Research Institute* 299: 23–84.

Received: April 21, 2015
Accepted: August 12, 2015