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EFFECTS OF RADIAL GROWTH RATE ON ANATOMICAL CHARACTERISTICS AND WOOD PROPERTIES IN *PERONEMA CANESCENS* TREES PLANTED IN SOUTH KALIMANTAN, INDONESIA

Ishiguri F[1, *], Wahyudi I[2], Takashima Y[3], Ohshima J[1] & Yokota S[1]

[1] *School of Agriculture, Utsunomiya University, Utsunomiya 321-8505, Japan*
[2] *Faculty of Forestry, Bogor Agricultural University, Bogor 16680, Indonesia*
[3] *Forest Tree Breeding Centre, Forestry and Forest Products Research Institute, Hitachi 319-1301, Japan*

**ishiguri@cc.utsunomiya-u.ac.jp*

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Radial variations of anatomical characteristics and wood properties were investigated for a relatively slow-growing tropical tree species, *Peronema canescens*. Based on the results, effects of radial growth rate on anatomical characteristics and wood properties were evaluated. The mean values of stress-wave velocity of stem, vessel diameter, cell wall thickness of wood fibre, wood fibre length, vessel element length, basic density and compressive strength parallel to grain at green condition were 3.94 km s^{-1}, 201 μm, 2.05 μm, 1.05 mm, 0.21 mm, 0.48 g cm^{-3} and 36.9 MPa, respectively. No significant correlations were found between growth characteristics (stem diameter at 1.3 m above ground and tree height) and anatomical characteristics or wood properties. These results suggested that anatomical characteristics and wood properties of this species were independent from growth characteristics, even in relatively slow-growing tree species in the tropics.

Keywords: Vessel and fibre morphologies, basic density, compressive strength, radial growth rate, *Peronema canescens*

INTRODUCTION

Relationships between radial growth rate and anatomical characteristics or wood properties have been investigated for hardwood species by many researchers (Zobel & van Buijtenen 1989, Zhang 1995, Lei et al. 1997). Zobel and van Buijtenen (1989) reviewed the relationships between radial growth rate and wood density in hardwoods; there is no apparent relationships in diffuse-porous wood, while increase of growth ring width resulted in increase of wood density in ring-porous wood. Many researchers also focused on the relationships in fast-growing tree species grown in tropical countries (Ohbayashi & Shiokura 1990, DeBell et al. 2001, Wahyudi et al. 2001, 2016, Kojima et al. 2009a,b, Makino et al. 2012, Pillai et al. 2013, Ishiguri et al. 2016, Hidayati et al. 2017, Pertiwi et al. 2017a,b, 2018). Kojima et al. (2009b) showed that high growth rates did not intrinsically affect the wood properties of fast-growing tropical or subtropical species that has reached harvesting age. On the other hand, in the tropics, non-fast-growing tree species are also important for sustainable forest management. Thus, the relationships should be investigated in non-fast-growing tree species grown in tropical countries.

Peronema canescens is natively distributed in Peninsula Malaysia, Sumatra, Riau Archipelago, West Java and Kalimantan (Soerianegara & Lemmens 1994). The wood of this species is ring-porous with distinct growth ring, whereas sometimes the ring-porosity becomes obscure under certain growth conditions (Ogata et al. 2008). In addition, the wood is of good quality, being somewhat similar to that of teak (*Tectona grandis*) (Ogata et al. 2008). Therefore, this species, classified as fancy wood, has been exported at a high selling price, and is one of the preferred species planted in industrial timber estates of Indonesia (Kartawinata 1994). To promote plantation establishment of this species, basic information about wood properties is important. However, available data on anatomical characteristics and wood properties of this species is limited to mean values, ranging from minimum and maximum values, from previous studies

(Soerianegara & Lemmens 1994, Ogata et al. 2008). Thus, more detailed data, such as radial variation or among-tree variation is needed for accessing anatomical characteristics and wood properties of this species.

In the present study, radial variation of anatomical characteristics and wood properties were investigated for 23-year-old *P. canescens* planted in Indonesia. Based on the obtained results, the effects of radial growth rate on wood properties were discussed.

MATERIALS AND METHODS

Field experiments

Fifty trees of 23-year-old *P. canescens* in a stand were used for this experiment. The stand was located in Semaras, Pulau Laut, South Kalimantan, Indonesia (3˚47' S, 116˚6' E), and was initially established by seedlings produced from unknown seed source at 3 × 3 m spacing. A plot (25 × 25 m) was set in the centre of the stand. Diameter at 1.3 m above the ground was measured by a tape meter for all trees in the plot. To evaluate the effects of radial growth rate on cell morphologies and wood properties, the trees in the plot were categorised into three groups according to mean (μ) and standard deviation (SD) of stem diameter (D) in the plot: fast-growing (D > μ + one SD), medium-growing (μ - one SD < D < μ + one SD), and slow-growing (D < μ - one SD cm) trees (Ishiguri et al. 2012b). Cell morphologies and wood properties were determined for five trees in each category. In addition, tree height was measured for these 15 selected trees by a height meter.

Stress-wave velocity of trees was measured for all trees in the plot according to the method described in previous reports (Ishiguri et al. 2012b, Makino et al. 2012). Sensors of a commercial handheld stress-wave timer were set at 50 to 150 cm above ground for measuring the stress-wave propagation time. Stress-wave velocity was calculated by dividing distance between sensors (100 cm) by stress-wave propagation time.

Anatomical characteristics and wood properties

Core samples (5 mm in diameter) were collected from five tree in each category to examine the anatomical characteristics and wood properties. Four core samples were collected at 1.3 m above the ground by an increment borer from each tree and used for the following experiments. *Peronema canescens* is a ring-porous wood. However, ring-porosity sometimes becomes obscure under certain growing conditions (Ogata et al. 2008). In the present study, some growth rings also showed obscure ring-porosity. Due to this reason, wood properties and cell morphologies were determined in relation to distance from pith.

The core samples were cut into small segments at 1 cm intervals from pith to bark. The obtained small segments included at least one or more growth rings. Transverse sections (20 μm in thickness) were obtained from each segment by using a sliding microtome (ROM-380 or REM-710, Yamatokohki). Transverse sections were stained with 1% safranin, and dehydrated by graded ethanol. Then, dehydrated sections were dipped into xylene, and mounted on slide glass. Anatomical characteristics, such as vessel diameter in pore zone, and diameter and cell wall thickness of wood fibre, were determined by using digital images obtained by a microscope (BX51, Olympus) equipped with a digital camera (DSE330, Olympus). Radial and tangential diameters of vessels and wood fibre were measured, and the mean values were calculated as vessel diameter and wood fibre diameter. At each radial position, diameters of vessels in pore zone were measured for 30 vessels, and diameter and cell wall thickness of wood fibre was measured for 50 fibres.

Core samples were also cut into small segments at 1 cm intervals from pith to bark. Small strip specimens for measuring the vessel element length were separately collected from pore of each segment. For measurement of wood fibre length, strips were obtained from outer pore zone of each segment. The obtained small strips for measuring the length of vessel elements and fibres were macerated with Schulze's solution at room temperature for 12 hours, and then at 70 °C for 1 hour. A microprojector (V-12, Nikon) and a digital calliper (CD-30C, Mitutoyo) was used for measuring the total 30 vessels and 50 fibres in each radial position.

Core samples obtained from five selected trees in each category were used for measuring the basic density and compressive strength parallel to grain, according to the method described in a previous study (Ishiguri et al. 2012b). One-cm long segments from pith to bark were obtained from the core samples to measure basic density. Basic density was determined by dividing oven-drying weight by green volume measured by water displacement. A strength testing equipment for core samples (Fractometer II, IML) was employed to measure the compressive strength parallel to grain at green condition. Core samples were cut at 5 mm interval from pith to barks and compressive strength was successively measured from pith to bark.

Statistical analysis

All statistical analysis was conducted by a software (R version 3.2.1, R Core Team 2015). The differences of measured characteristics or properties among growth categories were detected by one-way analysis of variance test. In addition, the relationships between two measured characteristics or properties were evaluated by Pearson's correlation coefficient.

RESULTS AND DISCUSSION

Anatomical characteristics and wood properties

Mean values of stem diameter at 1.3 m above ground and stress-wave velocity of stem in the plot were 16.8 cm and 3.94 km s^{-1}, respectively (Table 1). Based on the results of stem diameter, number of trees was 11, 29 and 10 for fast-, medium- and slow-growth categories, respectively. A significant difference was observed in stem diameter, whereas not in stress-wave velocity. In *Tectona grandis* planted in Indonesia, mean values of stress-wave velocity were 3.23 to 3.78 km s^{-1} for 15 clones of 12-year-old trees, and 3.07 to 3.39 km s^{-1} for 24-year-old trees originating from 21 seed provenances (Hidayati et al. 2013a,b). The results obtained in the present study showed relatively higher values compared to those of teak trees.

Figure 1 shows radial variations of anatomical characteristics and wood properties. All anatomical characteristics and wood properties, except for cell wall thickness of wood fibre, increased from pith to bark. The tendency was the same for all radial growth categories.

Table 2 shows mean values of cell morphologies and wood properties in 15 selected trees. Mean values of vessel diameter, wood fibre diameter, cell wall thickness of wood fibre, wood fibre length and vessel element length were 201 µm, 13 µm, 2.05 µm, 1.05 mm and 0.21 mm, respectively. In addition, mean values of basic density and compressive strength parallel to grain at green condition were 0.48 g cm^{-3} and 36.9 MPa, respectively. Among the three categories, no significant differences were found in all cell morphologies and wood properties. In *P. canescens*, Ogata et al. (2008) reported that tangential diameter of solitary vessels in pore zone, cell wall thickness of wood fibre and wood fibre length of this species were up to 250 to 290 µm, 3 µm, and 0.9 to 1.5 mm (1.2 mm in mean), respectively. On the other hand, Soerianegara & Lemmens (1994) also reported that these values were 180 to 260 µm, 3.5 to 4.0 µm, and 0.9 to 1.6 mm, respectively. In the present study, cell wall thickness of wood fibre showed relatively smaller value compared to those obtained by previous studies. It has been reported that the air-drying density of this species ranged from 0.35 to 0.73 (0.52 in mean) g cm^{-3} (Soerianegara & Lemmens 1994). Although the values of basic density (ratio of oven-drying weight to green volume) showed relatively lower values compared to air-drying density, the obtained results in the present study was similar to those reported by Soerianegara & Lemmens (1994). On the other hand, Soerianegara &

Table 1 Stem diameter and stress-wave velocity of trees in the plot

Category	*n*	D (cm)		SWV (km s^{-1})	
		Mean	SD	Mean	SD
Total	50	16.8	2.3	3.94	0.15
Fast-growth	11	19.8	0.9	3.91	0.14
Medium-growth	29	16.6	1.3	3.95	0.14
Slow-growth	10	13.8	0.7	3.95	0.14
Significance among category		**		ns	

n = number of trees, D = stem diameter at 1.3 m above ground, SWV = stress-wave velocity of stem, SD = standard deviation, ns = not significant, ** = significant at 1% level

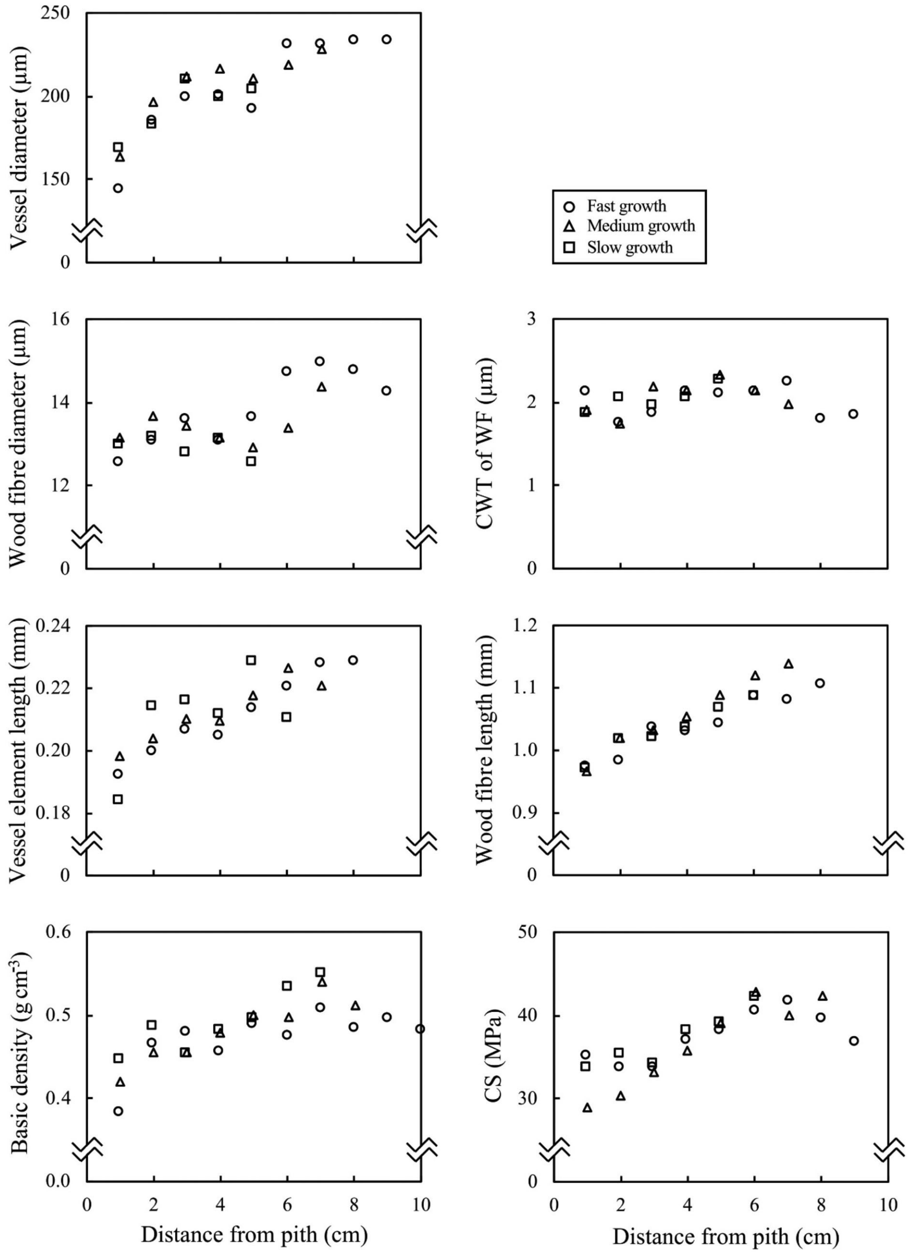

Figure 1 Radial variations of anatomical characteristics and wood properties; CWT of WF = cell wall thickness of wood fibre, CS = compressive strength parallel to grain at green condition; the values of symbols in each graph were mean values of each growth category at a certain radial position

Lemmens (1994) reported that compressive strength parallel to grain at green condition was 25 MPa. In the present study, relatively higher mean value (36.9 MPa) was obtained in compressive strength parallel to grain at green condition.

Relationships among anatomical characteristics and wood properties

Table 3 shows correlation coefficients among cell morphologies and wood properties. Significant correlation was found between basic density and compressive strength (r = 0.579). It is known that significant positive correlation was found between wood density and compressive strength (Kollmann & Côté 1984). This tendency is also true for tropical-fast-growing tree species (Chowdhury et al. 2009, Ishiguri et al. 2012a, Pertiwi et al. 2018). The obtained results in the present study were similar to these reports, suggesting that mechanical properties of this species can be predicted by basic density. On the other hand, fibre wall thickness was also significantly correlated with fibre diameter

Table 2 Mean values and standard deviation of growth characteristics, cell morphologies and wood properties in each category

Property	Total (*n* = 15)		Fast growth (*n* = 5)		Medium growth (*n* = 5)		Slow growth (*n* = 5)		Significance among category
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
D (cm)	16.8	2.5	19.6	0.4	16.9	0.6	13.9	0.6	**
TH (m)	15.8	1.3	17.0	0.8	15.6	1.4	14.8	0.7	*
VD (μm)	201	12	202	8	207	5	194	16	ns
FD (μm)	13	2	14	2	13	2	13	2	ns
FWT (μm)	2.05	0.36	2.01	0.41	2.08	0.39	2.05	0.34	ns
VEL (mm)	0.21	0.01	0.21	0.01	0.21	0.01	0.21	0.01	ns
WFL (mm)	1.05	0.03	1.05	0.04	1.06	0.04	1.03	0.01	ns
SWV (km s^{-1})	3.94	0.12	3.92	0.08	3.91	0.07	4.00	0.19	ns
BD (g cm^{-3})	0.48	0.02	0.47	0.03	0.48	0.02	0.49	0.02	ns
CS (MPa)	36.9	1.6	37.4	1.5	36.4	1.4	37.0	2.1	ns

n = number of trees, SD = standard deviation, D = stem diameter at 1.3 m above ground, TH = tree height, VD = vessel diameter, FD = wood fibre diameter, FWT = fibre wall thickness, VEL = vessel element length, WFL = fibre length, SWV = stress-wave velocity of stem, BD = basic density, CS = compressive strength, ns = not significant, * = significant at 5% level, ** = significant at 1% level

Table 3 Correlation coefficients among cell morphologies and wood properties

	VD	FD	FWT	VEL	WFL	SWV	BD	CS
VD		ns	ns	ns	ns	ns	ns	ns
FD	-0.092		**	ns	ns	ns	ns	ns
FWT	0.026	-0.866		ns	ns	ns	*	ns
VEL	0.224	0.379	-0.287		ns	ns	ns	ns
WFL	0.291	-0.204	0.069	-0.232		ns	ns	ns
SWV	-0.418	-0.047	0.085	0.064	-0.010		ns	ns
BD	-0.243	-0.330	0.592	-0.239	-0.333	-0.024		*
CS	0.143	-0.123	0.342	0.185	-0.156	-0.369	0.579	

VD = vessel diameter, FD = wood fibre diameter, FWT = fibre wall thickness, VEL = vessel element length, WFL = fibre length, SWV = stress-wave velocity of stem, BD = basic density, CS = compressive strength, ns = not significant, * = significant at 5% level, ** = significant at 1% level; number of trees = 15; lower diagonal and upper diagonals are correlation coefficients and significant levels, respectively

(r = -0.866) or basic density (r = 0.592). Pertiwi et al. (2018) reported that a significant correlation (r = 0.47) was found between fibre wall thickness and basic density in *Neolamarckia cadamba* trees planted in Indonesia. Similar results were also obtained in *Eucalyptus tereticornis* and *Falcataria moluccana* (syn. *Paraserianthes falcataria*) (Sharma et al. 2005, Ishiguri et al. 2009). It is considered that basic density of this species is closely related with fibre wall thickness rather than vessel diameter which sometimes affects wood density in hardwood species (Ishiguri et al. 2009).

Effects of radial growth rate on anatomical characteristics and wood properties

No significant or weak significant correlations were found between stem diameter and stress-wave velocity of stem in tropical fast-growing tree species, such as *F. moluccana*, *Acacia mangium*, *N. cadamba*, *Ochroma pyramidale*, *Azadirachta excelsa* and *Dysoxylum mollissimum* (Ishiguri et al. 2007, Makino et al. 2012, Ishiguri et al. 2016, Wahyudi et al. 2016, Pertiwi et al. 2017a,b). Similar results were obtained in non-fast-growing tree species in the tropics (Ishiguri et al. 2012b, Hidayati et al. 2013a,b). As shown in Figure 2, no significant correlation was found between stem diameter and stress-wave velocity of stem. In addition, significant difference in stress-wave velocity was not found among three growth categories, by analysis of variance test (Table 1). These results suggest that trees with faster radial growth rate in this species do not always produce wood with lower Young's modulus. In addition, it has been reported that growth characteristics were not always related with anatomical characteristics and wood properties in tropical fast-growing tree species (DeBell et al. 2001, Wahyudi et al. 2001, Kojima et al. 2009a,b, Pillai et al. 2013, Ishiguri et al. 2016, Pertiwi et al. 2017a,b, 2018). There were no significant differences in anatomical characteristics and wood properties investigated in the present study among three growth categories (Table 2). No significant correlations were found between growth characteristics (stem diameter and tree height) and anatomical characteristics or wood properties (Table 4). It is considered, therefore, that anatomical characteristics and wood properties of slow-growing tree species may be independent from radial growth rate.

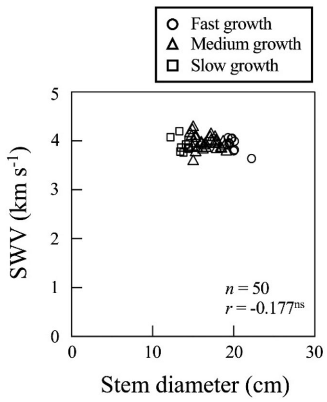

Figure 2 Relationship between stem diameter and stress-wave velocity of stem; SWV = stress-wave velocity of stem, r = correlation coefficient, n = number of trees, ns = not significant

Table 4 Correlation coefficients between growth characteristics and cell morphologies or wood properties

Property	Stem diameter at 1.3 m above ground	Tree height
VD	0.242 ns	0.165 ns
FD	0.284 ns	0.378 ns
FWT	-0.121 ns	-0.308 ns
VEL	0.183 ns	0.162 ns
WFL	0.263 ns	-0.020 ns
SWV	-0.216 ns	-0.240 ns
BD	-0.300 ns	-0.507 ns
CS	0.062 ns	0.057 ns

VD = vessel diameter, FD = wood fibre diameter, FWT = fibre wall thickness, VEL = vessel element length, WFL = fibre length, SWV = stress-wave velocity of stem, BD = basic density, CS = compressive strength, ns = not significant; number of samples = 15

CONCLUSIONS

Radial variations of anatomical characteristics and wood properties were investigated for 23-year-old *P. canescens* planted in Indonesia. Effects of radial growth rate were also discussed on the characteristics and the properties. Mean values of stem diameter at 1.3 m above ground and stress-wave velocity of stem in the plot were 16.8 cm and 3.94 km s^{-1}, respectively. All anatomical characteristics and wood properties, except for cell wall thickness of wood fibre, increased from pith to bark. Mean values of vessel diameter, wood fibre diameter, cell wall thickness of wood fibre, wood fibre length and vessel element length were 201 µm, 13 µm, 2.05 µm, 1.05 mm and 0.21 mm, respectively. In addition, mean values of basic density and compressive strength parallel to grain at green condition were 0.48 g cm^{-3} and 36.9 MPa, respectively. No significant differences among three growth categories were found in anatomical characteristics and wood properties, suggesting that anatomical characteristics and wood properties are independent from radial growth rate even in the relatively slow-growing tropical tree species.

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