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NOTE

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Wood properties of *Pericopsis mooniana* grown in a plantation in Indonesia

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Abstract The relationships between growth characteristics and wood properties were investigated for a threatened species, *Pericopsis mooniana*, to promote the establishment of plantations of this species in the tropics. Growth characteristics (diameter and height) and stress-wave velocity (SWV) of trees were measured for 22-year-old *P. mooniana* trees planted in Indonesia. The trees were categorized into three groups, fast-growing, middle-growing, and slow-growing trees, to investigate the effect of growth rate on the wood properties. In addition, radial variation of anatomical characteristics and wood properties were determined. No significant correlation was found between growth characteristics and SWV. The values for the vessel diameter, cell wall thickness of wood fibers, wood fiber length, basic density, modulus of elasticity, and modulus of rupture from wood at the bark side were higher than those at the pith side. On the other hand, vessel frequency gradually decreased from pith to bark. These results suggested that low-quality wood, such as juvenile wood, existed near the pith area.

Key words *Pericopsis mooniana* · Stress-wave velocity · Growth rate · Plantation

Introduction

Pericopsis mooniana has a large area of distribution and is found in many Southeast Asian countries.[1] Wood of *Pericopsis mooniana* is used for cabinet making, furniture, and others as well as for construction purposes.[1] The wood is sometimes used as a substitute for *Tectona grandis*, which yields valuable timber in the tropics. Thus, it is considered to be a valuable multipurpose wood. However, the supply of the wood is very limited, because wood of this species is mainly harvested from natural forest. In addition, this species is considered a threatened species (vulnerable) by the International Union for Conservation of Nature and Natural Resources.[2] Therefore, plantation of *P. mooniana* should be established to increase the supply of wood and prevent this species from becoming extinct. On the other hand, for the plantation of this species to become established, we should know the variation of wood properties among trees. However, only a few reports are available on the wood properties of this species.[3,4]

Wood quality is generally affected by the growth characteristics of trees, such as the radial growth rate. Especially in plantation species in the tropics, many plantation managers pay attention to the relationship between the growth rate and wood quality, and they have wondered why fast-growing trees do not always make xylem yielding good wood quality. Recently, Kojima et al.[5] reported that in *Acacia* spp. and *Paraserianthes* spp., xylem maturation depends on the diameter growth: formation of mature wood in these species starts after trees have reached a certain diameter. These results indicate that accelerating lateral growth from an early growing stage could produce mature wood earlier.[5] However, they also reported that xylem maturation is controlled by cambium age in *Eucalyptus* spp.: accelerating lateral growth at the early stage of growth results in an increase in the immature wood volume. The maturation process of xylem, therefore, may depend on the species. Thus, the relationships between growth rate and wood properties should be clarified in many plantation species in the tropics. However, there are no reports on the relationships between growth and wood properties in *P. mooniana*.

The objective of this study was to establish plantation of *P. mooniana* to utilize its wood and protect this species from extinction. The diameter and height of trees and their

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stress-wave velocity (SWV) were measured for 22-year-old trees of *P. mooniana* planted in South Kalimantan, Indonesia. From the obtained results, the relationships between growth rate and wood properties are discussed. Sampling of the wood disk is very difficult in this area, and we obtained only one small part of a branch from 10 m above ground level of a tree that had been blown over. The anatomical characteristics and wood properties were also determined using this branch.

Materials and methods

Twenty-two-year-old plantation trees of *P. mooniana* were used in the present study. The plantation was established in 1987 in Semaras, Pulau Laut, South Kalimantan, Indonesia (3°47′ S, 116°06′ E). The seed source is unknown. Trees were initially planted at a spacing of 3 × 3 m; thinning treatment of the plantation was conducted once after planting the trees.

A plot (25 × 25 m) was set in the central part of the plantation for measuring the stem diameter at 1.3 m above the ground and the stress-wave velocity (SWV) of trees. After measuring the diameter, the trees were categorized into three groups by using the mean and standard deviation of the diameter: fast-growing trees (larger than the average diameter plus one standard deviation), middle-growing trees (within two standard deviations of the average diameter), and slow-growing trees (smaller than the average diameter minus one standard deviation). Tree height was measured for the 15 selected trees (5 trees in each category). The selected trees in the fast-growing and slow-growing categories were the largest five trees and the smallest 5 trees in terms of diameter, respectively. In addition, five trees with almost the mean diameter in the plot were selected as middle-growing trees.

The SWV was determined by a previously described method.[6,7] Although the SWV was measured at the tree surface, statistical regression analyses indicates that there is a good relationship between the stress wave properties of standing trees and the strength and stiffness of small clear specimens obtained from trees.[8] A commercial hand-held stress-wave timer (FAKOPP, Fakopp Enterprise) was used in this experiment. Start and stop sensors were set on the trees at 0.5 m and 1.5 m above ground level, respectively. The propagation time of stress waves was measured six times, and then the average value was calculated. The stress-wave velocity was calculated by dividing the distance between the sensors by the average propagation time of a stress wave.

A sample (8 cm in diameter and 25 cm in length) was obtained from a branch at 10 m above ground level from a tree which had been blown over. According to the diameter at 1.3 m above ground level, this tree belonged to the middle-growing category. Some anatomical characteristics and basic wood properties were determined at 1-cm intervals from the pith to the bark using this branch. Small strip specimens were macerated with Schulze's solution for measuring the length of the vessel elements and wood fibers. A total of 50 vessel elements and 100 wood fibers were measured using a microprojector (Nikon, V-12) and a digital caliper (Mitsutoyo, CD-30CP) at each radial position. To determine the anatomical characteristics, cross sections (20 μm in thickness) were obtained by a sliding microtome. After staining with 1% saflanin, dehydration with a graded alcohol series, and dipping in xylen, cross sections were mounted on slides. Digital images were obtained by a microscope equipped with a digital camera for determining the vessel morphology (diameter and frequency) and fiber morphology (diameter and cell wall thickness). Morphological data were determined for 30 vessels and 50 fibers at each radial position. Three fan-shaped specimens were obtained from a disk for measuring the basic density. Basic density was calculated from the oven-dried weight dividing by the green volume determined by the water displacement method. A total of 12 specimens [9 (R) × 8 (T) × 140 (L) mm] were prepared for static bending tests. Static bending tests were conducted using a universal testing machine (MCS-5000, Tokyo Testing Machine). A load was applied to the center of the radial surface to give a displacement of 1 mm/min; the span was 120 mm. The modulus of elasticity (MOE) and modulus of rupture (MOR) were calculated from the obtained stress–deflection diagrams.

Results and discussion

Table 1 shows stem diameters and SWV measured for all trees in the plot. In the present study, the trees in the plot were classified into three categories according to the mean value and standard deviation of the stem diameter. The numbers of fast-growing, medium-growing, and slow-growing trees were 6, 24, and 7, respectively. The mean diameter in the plot was 24.2 cm. SWV had almost the same value for all three categories (ca 4.10 km/s). An analysis of variance (ANOVA) test (5% level) showed no significant differences among the three categories. There are some reports on the relationship between the stem diameter and SWV of trees.[6,7,9–11] In previous research, we found that there is a weak negative correlation between diameter and SWV in *Larix kaempferi* (a softwood species)[7] and in *Paraserianthes*

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

Category	n	Stem diameter (cm)		Stress-wave velocity (km/s)		
		Mean	SD	Mean	SD	ANOVA
Fast growing	6	34.6	4.4	4.13	0.13	ns
Medium growing	24	25.1	3.7	4.11	0.11	
Slow growing	7	16.0	2.1	4.04	0.13	
Total	37	24.2	6.6	4.10	0.12	–

n, number of sample trees; SD, standard deviation; ANOVA, analysis of variance; ns, not significant at 5% level *falcataria* (a fast-growing hardwood species in the tropics).[6] On the other hand, several researchers found no correlation between them.[9–11] Ikeda et al.[10] reported that no significant correlation was found between diameter at breast height and SWV in *Chamaecyparis obtusa* growing in four different stands with different ages. This was also true for 9- and 25-year-old *Eucalyptus dunnii* trees.[11] Thus, the relationship between stem diameter and SWV in trees is still unclear. In the present study, however, no significant correlation coefficient (r = 0.123) was recognized between diameter and SWV in any trees in the plot (Fig. 1). Similar results were observed between height and SWV in 15 selected trees (Fig. 2).

Table 2 shows the mean diameter, height, and SWV of 15 selected trees. The height gradually decreased with decreasing radial growth, indicating that the height of fast-growing trees is large compared to the others. Significant differences in tree height were recognized among the three categories. In contrast to the weak relationships between growth characteristics and SWV, a relatively highly significant correlation (r = 0.776) was found between stem diameter and tree height (Fig. 2), indicating that growth characteristics are closely related.

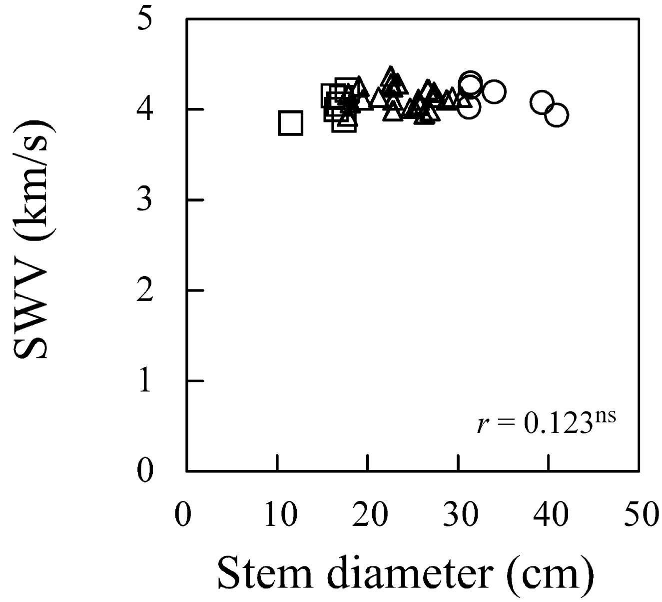

Fig. 1. Relationship between stem diameter and stress-wave velocity (*SWV*) in all trees in the plot. *Circles, triangles*, and *squares* indicate fast-growing, medium-growing, and slow-growing trees, respectively. *ns*, no significance

Fig. 2. Relationships between growth characteristics and SWV in 15 selected trees. *Circles, triangles*, and *squares* indicate fast-growing, medium-growing, and slow-growing trees, respectively. **Significant at the 1% level; *ns*, not significant

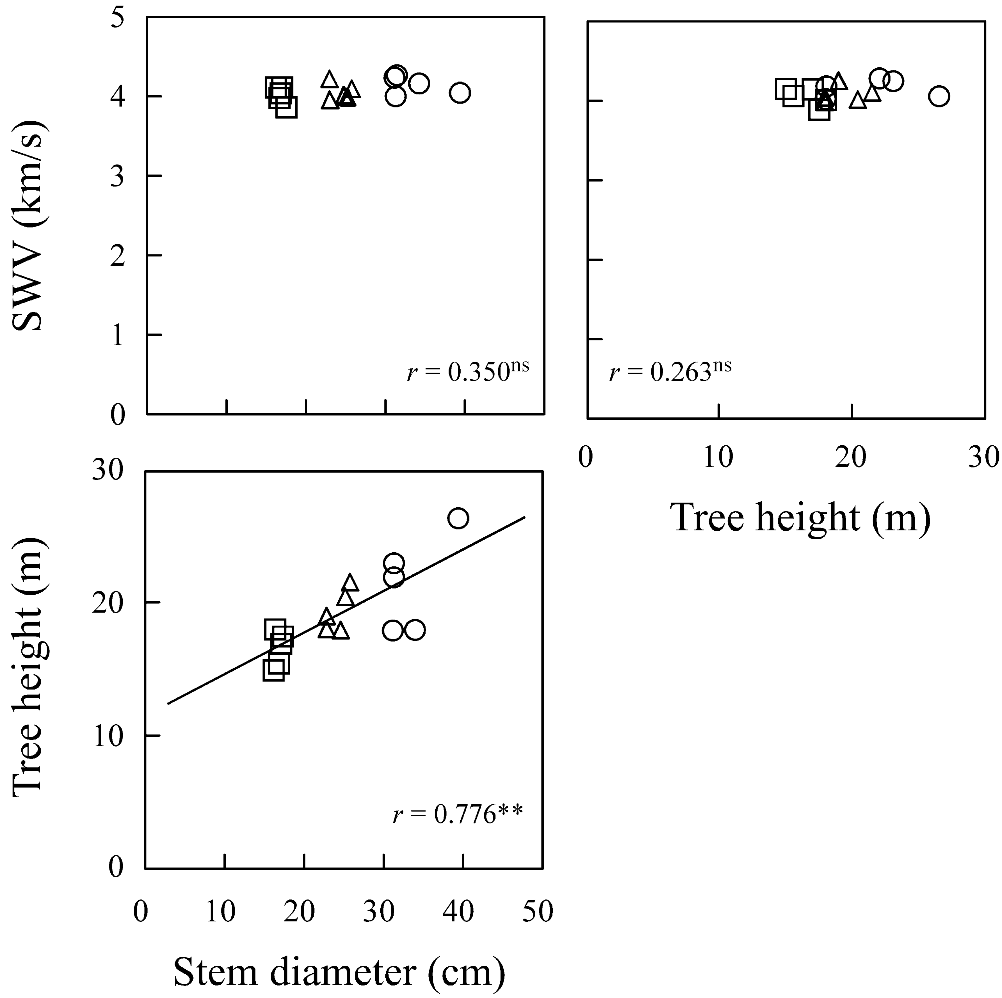

Table 2. Stem diameter, tree height, and stress-wave velocity of 15 selected trees

Category	*n*	Stem diameter (cm)		Tree height (m)			Stress-wave velocity (km/s)		
		Mean	SD	Mean	SD	ANOVA	Mean	SD	ANOVA
Fast growing	5	33.3	3.5	21.5	3.6	5%	4.16	0.11	ns
Medium growing	5	24.4	1.3	19.4	1.6		4.06	0.11	
Slow growing	5	16.7	0.5	16.6	1.3		4.04	0.11	

n, number of sample trees; SD, standard deviation; ANOVA, analysis of variance among the three categories; ns, not significant at 5% level

Table 3. Anatomical characteristics and wood properties in a branch collected at 10 m above ground level

		Mean	SD
Vessel	Cell length (mm)	0.32	0.01
	Mean diameter (μm)	123	16
	Frequency (no./mm^2)	11.1	3.6
Fiber	Cell length (mm)	1.33	0.11
	Mean diameter (μm)	14.3	0.5
	Mean cell wall thickness (μm)	2.8	0.6
Wood	Basic density (g/cm^3)	0.59	0.03
	Air-dried density (g/cm^3)	0.73	0.02
	MOE (GPa)	15.46	1.29
	MOR (MPa)	139.8	12.7

Mean values were calculated from the mean value obtained at each radial position
Air-dried density was measured using the static bending test specimen
Moisture content of the static bending test specimen was 10.1% ± 0.3%
SD, standard deviation; MOE, modulus of elasticity in static bending; MOR, modulus of rupture in static bending

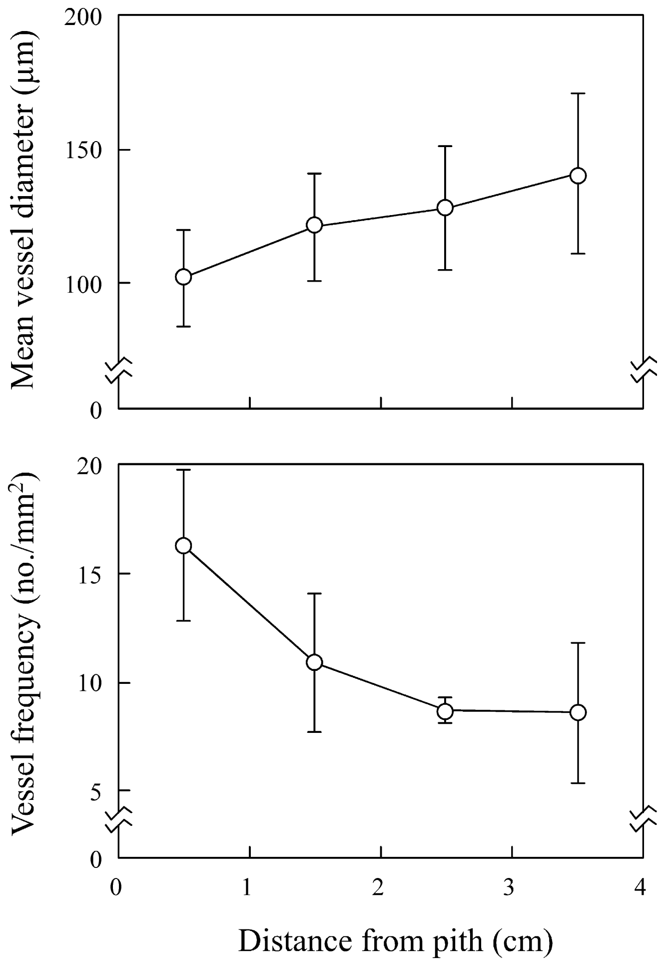

Fig. 3. Radial variation of vessel morphology. Vessel diameter values are the mean value of 30 vessels at each radial position. The vessel frequency was determined from four images in each radial position. *Bars* indicate standard deviation

Although only one small branch from 10 m above ground level was used, the radial variation of anatomical characteristics and wood properties was determined. Table 3 shows the mean values of cell morphologies and wood properties. Ogata et al.[4] reported that the values for vessel diameter, vessel frequency, fiber length, fiber cell diameter, fiber cell wall thickness, and air-dried density were 160–170 μm, 8–10 vessels/mm^2, 1.0–1.7 mm, 15–20 μm, 3.5 μm, and 0.75–0.84 g/cm^3, respectively, in *P. mooniana*. In addition, Koning-Vrolijk et al.[3] reported that MOE and MOR of specimens (50 × 50 mm in section, 700 mm in span) with a 12.3% moisture content were 16.07 GPa and 151.3 MPa, respectively, in *P. mooniana*. Our results are similar to the results obtained by Koning-Vrolijk et al.[3] and Ogata et al.[4]

Figures 3–7 show the radial variations of anatomical characteristics and wood properties. The values of vessel diameter, cell wall thickness of wood fibers, wood fiber length, basic density, MOE, and MOR on the bark side were higher than those on the pith side. On the other hand, vessel frequency gradually decreased from pith to bark. In addition, the cell diameter of wood fibers and vessel element length showed almost constant values from pith to bark. Zobel and van Buijtenen[12] pointed out that, although juvenile wood occurs in both softwood and hardwood, it is usually much less evident or important in hardwood. The definition of juvenile wood in hardwood species is still not clear. However, several researchers have reported the existence of juvenile wood in fast-growing tropical species, such as *Acacia mangium*[5,13] and *Paraserianthes falcataria*[5] by analyzing the radial variation of wood fiber length. Furthermore, Chowdhury et al.[14] examined the radial variation of basic density and cell length in *Casuarina equisetifolia* and reported that wood near the pith area might be considered low-quality wood, such as juvenile wood. In the present study, wood near the pith area contained smaller-diameter

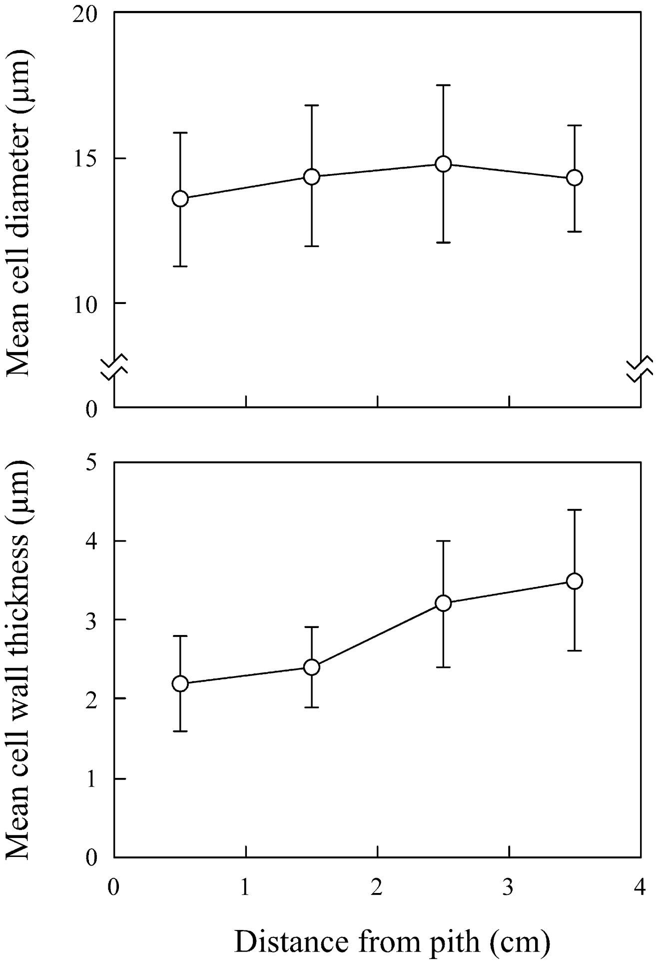

Fig. 4. Radial variation of fiber morphology. Shown are the mean values of 50 fibers at each radial position

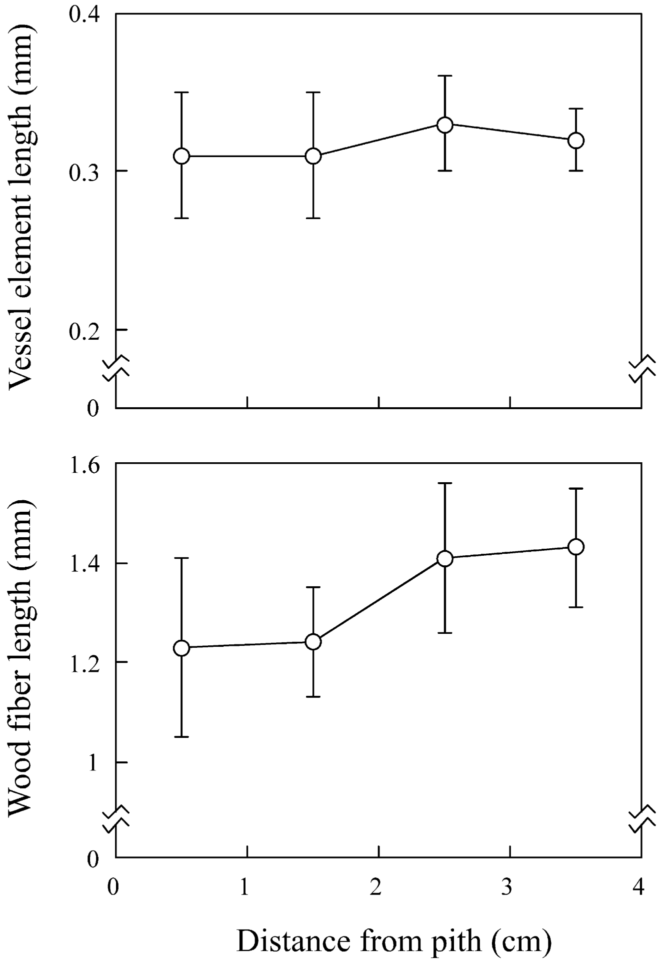

Fig. 5. Radial variation of cell length. Shown are the mean values of 50 vessels and 100 fibers at each radial position

vessels at a higher frequency, shorter wood fibers with thinner cell walls, lower basic density, and lower bending properties, suggesting that low-quality wood such as juvenile wood existed in the pith area of *P. mooniana*. Further research is needed to clarify the definitions of low-quality wood and high-quality wood, i.e., juvenile wood and mature wood.

Conclusions

It is considered that the basic density and microfibril angle might be genetically controlled.[15,16] On the other hand, many physical and mechanical properties, such as the shrinkage and Young's modulus, are strongly affected by basic wood properties, such as basic density and microfibril angle.[17] These facts suggest that wood properties such as Young's modulus could be genetically controlled. In the present study, the relationships between growth characteristics and wood properties were clarified for *P. mooniana*. There were no significant correlations between the growth characteristics and SWV of trees. As described before, the

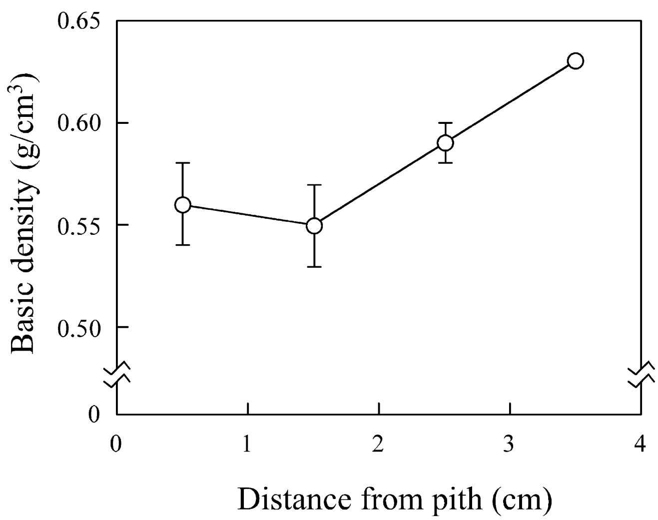

Fig. 6. Radial variation of basic density. Shown are the mean values for three samples

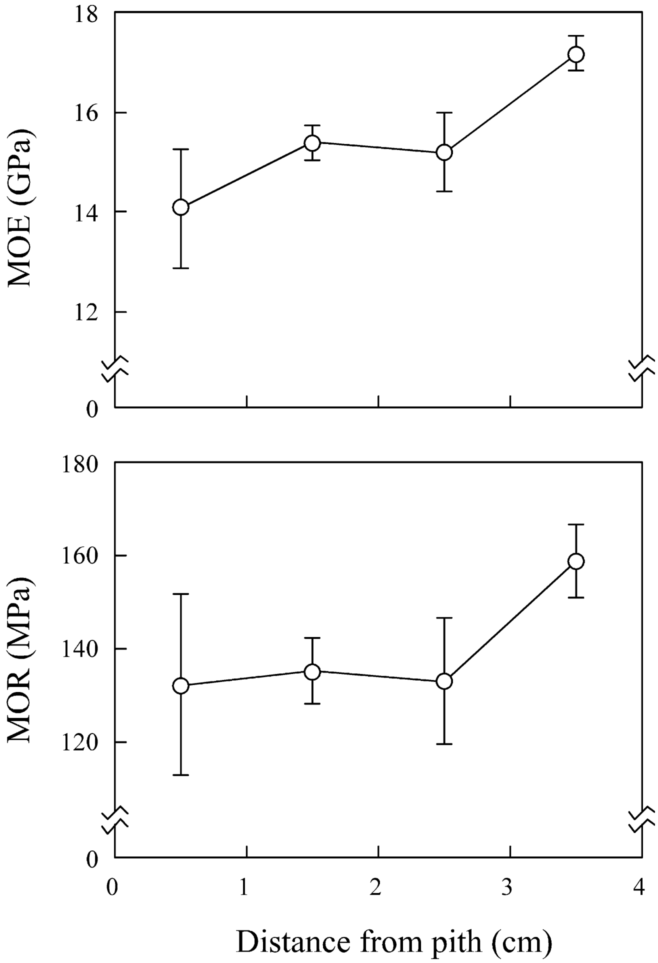

Fig. 7. Radial variation of static bending properties. Shown are the mean values for each radial position. *MOE*, modulus of elasticity; *MOR*, modulus of rupture

SWV of trees was positively correlated with the Young's modulus.[8] Thus, wood properties, such as Young's modulus in *P. mooniana* could be improved by tree breeding programs for wood quality. Tree breeding programs for wood quality, therefore, should be set up to promote the establishment of plantation of *P. mooniana*.

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