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ANATOMICAL VARIATION IN PLANTED KELEMPAYAN (NEOLAMARCKIA CADAMBA, RUBIACEAE)

by

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SUMMARY

Six plantation grown Kelempayan trees [*Neolamarckia cadamba* (Roxb.) Bosser, syn. *Anthocephalus chinensis* (Lamk.) A. Rich. ex Walp., Rubiaceae] were sampled along their radii and at five different height levels to evaluate variations of wood anatomical properties. Analysis of variance indicates that between tree differences in all anatomical properties measured were significant. Vessel proportion increases while ray proportion decreases with height, while both fibre diameter and fibre lumen diameter decrease with height. No significant trend was found for fibre length vertically. Cell wall substance and vessel and ray proportion increase from pith to bark, while fibre proportion decreases. Fibre length and fibre wall thickness increase from pith to bark, while fibre diameter and fibre lumen diameter first increase and then decrease. Within-tree variations are more consistent radially than vertically.

Key words: Kelempayan, *Neolamarckia cadamba*, *Anthocephalus chinensis*, tropical hardwoods, tissue proportions, fibre dimensions, radial variation, vertical variation.

INTRODUCTION

The demand for tropical timbers is always on the increase. This is an advantage to the Malaysian economy due to its vast area of tropical rain forest. However, the prime natural forest species are becoming scarce. Thus the wood industry is expected to rely on lesser known and plantation grown species for a considerable portion of the supply of raw materials.

Kelempayan [*Neolamarckia cadamba* (Roxb.) Bosser, syn. *Anthocephalus chinensis* (Lamk.) A. Rich. ex Walp., Rubiaceae] is a fast-growing tree species with a tall and straight bole. It self-prunes and grows very well in exploited and denuded areas. Kelempayan is distributed in the Indo-Malesian region extending from India to Papua New Guinea (Willis 1973; Ridsdale 1978; Wong 1989). Gamble (1922) and Burkill (1966) reported that it is found in areas of up to 650 m altitude, although Wong (1989) stated the upper limit as 1000 m. Kelempayan dominates the initial regrowth stage of tropi-

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cal secondary forest, where it makes the greatest ingrowth on logging trails and other openings after logging (Meijer 1970), particularly on moist sites (Fox 1971). It is also found by streams, rivers and in open sites on deep moist alluvial soil as a pioneer species that is frequently gregarious (Fox 1971; Wong 1989).

According to Wong (1989), the first attempt to establish a Kelempayan plantation was in 1933 in Indonesia. In the Philippines, the tree is described as 'gem of a tree', 'wonder tree' and 'miracle tree' due to its rapid growth and multiple uses (Lopez 1966). It is widely used in reforestation projects both in the government and private sector (Cacanindin 1983). In Malaysia, Kelempayan was grown in plantations as early as 1953 and 1961 at Sibuga Forest Reserve near Sandakan, Sabah (Fox 1968). To date this plantation still remains but as a research plot. Kelempayan is grown as an exotic in Fiji (Palmer et al. 1983), Jari, Brazil (Hornick et al. 1984), Western Samoa (Donaldson 1984), and Puerto Rico (Lugo & Figueroa 1985).

This tree has the potential to be utilized for sawn timber, veneer, chips, pulp and composites (Monsalud & Lopez 1967; Peh 1970; Phillips et al. 1979; Logan et al. 1986). Though it is common in Malaysia, it has yet to make its way into the processing mills. Nevertheless, as the supplies of the prime natural forest species become scarce and in view of its multiple uses, the future of this tree as a source of raw material is great. Information on its characteristics is vital prior to processing and selection for breeding programmes. Variation in anatomical structure may cause variation in wood quality. Fibre characteristics, for instance, are highly correlated with density, an important factor in wood quality (Panshin & De Zeeuw 1980).

Some information is available on the general anatomy of Kelempayan wood (Metcalfe & Chalk 1950; Monsalud & Lopez 1967; Menon 1971; Donaldson 1984; Kumar & Chaubey 1987; Martawijaya et al. 1989; Ismail 1993). However, there is very limited information on the variation patterns of the anatomical properties. Previous studies found that fibre length increases rapidly from 0.5 mm near the pith to 1.5–2.0 mm near the bark (Ohbayashi & Shiokura 1990). Average fibre length has been reported to be 1.44 mm (Monsalud & Lopez 1967), 1.70 mm (Logan et al. 1986), 0.80–2.0 mm (Subramanyam 1987), and 1.98 mm (Martawijaya et al. 1989). Information on the patterns of variation of other anatomical characteristics is not available. Thus this study was carried out to examine within- and between-tree variations of anatomical properties in Kelempayan.

MATERIALS AND METHODS

Six Kelempayan trees from a trial plot in Mantin, Negeri Sembilan, were felled. The trees were planted in 1966 and spaced quite regularly at about 5 to 8 metres (m) within planting line and 10 to 12 m between planting lines. The gradient of the ground of the stand is more or less flat. There is no report of any silvicultural treatment done to this trial plot. The trees were chosen based on straightness of bole and absence of excessive defects, and fall within the main range of the stand diameter at breast height (DBH) which is 30 to 40 cm, except for tree no. 2 which was 25 cm. They were felled at 15 cm above ground or immediately above the buttress. The north and south directions were

Table 1. Characteristics of the sampled trees of Kelempayan.

Tree no.	DBH (cm)	Total height (m)	Bole height (m)	Crown length (m)
1	30.0	21.5	19.0	2.5
2	25.0	23.0	20.0	3.0
3	31.8	22.2	18.2	4.0
4	33.5	26.2	23.8	2.4
5	33.0	24.0	19.0	5.0
6	38.5	27.5	24.0	3.5

marked on the tree surface prior to felling. The characteristics of these trees are summarized in Table 1.

Each tree was sampled by the removal of a cross-sectional disc approximately 5 cm in thickness at five height levels, namely stump, 10%, 30%, 50%, and 70% of the total height. The stump discs were taken immediately above the buttress (30–50 cm above ground). Whenever knots coincided with the designated heights, the discs were taken either immediately above or below the defects. The discs were labeled and wrapped in plastic bags. From these discs, radial strips (1.5 cm wide, 1 cm thick) were cut from pith to northern bark. From these strips, 1 cm long cubes were cut at three different positions: near the pith (inner wood: i), halfway the radius (middle wood: m) and near the bark (outer wood: o).

Prior to sectioning, the cubes were softened by boiling in water for at least 32 hours. A sledge microtome was used to cut c. 20 μm thick transverse sections that were stained with 1% saffranin-O and mounted in Canada balsam. All wood anatomical measurements were made by using the Quantimet 520 (Q520) Image Analysis System. The parameters measured from the transverse sections were cell wall, lumen, vessel, ray, and fibre area percentages, which subsequently are referred to as wood tissue proportions . The cell wall proportion was measured as the total cell wall material of all types of cells while the lumen proportion was the total void volume. The magnification used for each field was × 100 and seven fields were measured from each slide.

Macerations were prepared by placing two or three wood slivers in a solution of 1 part glacial acetic acid and 2 parts hydrogen peroxide (Berlyn & Miksche 1976). Thirty fibres from each slide were measured for length, diameter, lumen diameter, and wall thickness.

Vessel diameters were measured by digitizing the widest point of the tangential lumina in the transverse sections. Using the magnification of × 40, five fields were measured for every slides. The number of vessels per square millimetre was determined by counting individual vessels present in a field of 1 × 1 mm. From each slide, ten fields were measured at the magnification of × 4.

The two-way analysis of variance with interaction was used to analyse the data. Least significant different (LSD) tests were used to further analyse between- and within-tree variation. All analyses were computed using the Statistical Analysis System (SAS). Only significant results will be presented and discussed.

Table 2. Analysis of variance of anatomical properties of 20-year-old Kelempayan.

Property	Source of variation			
	Tree	Height level	Radial position	Height × radial interaction
Cell wall (%)	0.0001	0.1439	0.0001	0.2227
Lumen (%)	0.0001	0.1439	0.0001	0.2157
Vessel (%)	0.0003	0.0007	0.0045	0.8312
Ray (%)	0.0001	0.0001	0.0125	0.0068
Fibre (%)	0.0001	0.4762	0.0001	0.1629
Fibre length	0.0001	0.0351	0.0001	0.0268
Fibre diameter	0.0001	0.0003	0.0015	0.1144
Fibre lumen diameter	0.0001	0.0001	0.1058	0.1058
Fibre wall thickness	0.0001	0.0679	0.6947	0.6947
Vessel diameter	0.0117	0.0676	0.0001	0.0646
Number of vessels mm^{-2}	0.0003	0.0151	0.0001	0.0036

Values less than 0.05 indicate significance at 95% confidence level; smaller than 0.01 at 99% level.

Table 3. Between-tree anatomical variation of 20-year old Kelempayan .

Property	Tree number					
	Tree 1	Tree 2	Tree 3	Tree 4	Tree 5	Tree 6
Cell wall (%)	40.2 a	42.3 ab	43.8 b	48.2 c	49.4 c	47.5 c
Lumen (%)	59.8 a	57.8 ab	56.3 b	51.8 c	50.6 c	52.5 c
Vessel (%)	15.4 a	16.4 a	20.3 b	17.1 a	16.4 a	15.8 a
Ray (%)	8.9 a	7.5 b	13.0 c	11.8 c	14.8 d	12.9 c
Fibre (%)	76.2 a	76.2 a	66.8 b	71.2 cd	68.8 bc	71.8 d
Fibre length (μm)	1425.5 a	275.8 b	1254.9 b	1421.1 a	1250.1 b	1402.8 a
Fibre diameter (μm)	39.3 a	40.2 a	32.2 b	31.6 c	31.2 c	30.1 c
Fibre lumen diameter (μm)	31.1 a	31.5 a	25.0 b	20.4 c	20.3 c	19.2 c
Fibre wall thickness (μm)	4.1 a	4.4 a	5.6 b	5.6 b	5.5 b	5.4 b
Vessel diameter (μm)	183.2 ab	180.6 abc	186.7 a	173.7 bcd	167.9 d	170.1 cd
Number of vessels mm^{-2}	6.4 a	6.6 a	7.8 b	7.7 b	8.1 b	7.9 b

Means followed by a different letter within a row are statistically different at $P \geq 0.05$ using Least Significant Difference test.

RESULTS AND DISCUSSION

Between-tree variation

The analysis of variance (ANOVA) summary in Table 2 shows that the between-tree variations of tissue proportions varies significantly. Table 3 summarizes their mean differences between individual trees.

The highest cell wall proportion was 49.4% in tree 5 and the lowest 40.2% in tree 1 and the difference in cell wall percentage between trees 1 and 3 was significant. Similar observations were found between tree 3 and the rest of the trees. Between-tree variations of lumen percentage were also highly significant. Examination of individual tree means of lumen proportion indicated that the trend was the reverse of that for cell wall proportion. This pattern was expected because, when the size of the cell lumen is small, the cells will have thicker walls. The LSD test showed that individual mean difference of each tree for lumen proportion was similar (but not identical) to that for cell wall proportion.

Vessel, ray and fibre proportions vary significantly between trees ($P < 0.05$). Vessel proportion showed no significant difference between trees 1, 2, 4, 5, and 6 ($P < 0.05$). However, the highest mean value of 20.3% in tree 3 was significantly different from the other trees. The highest mean ray proportion of 14.8% was found in tree 5 and the lowest, at 7.5%, in tree 2. The differences in mean ray proportions for all trees were significant ($P < 0.05$) except among trees 3, 4, and 6. Fibre proportion varied from 76.2% in tree 1 to 66.8% in tree 3. The values for tree 1 and tree 2 were significantly different from the rest of the trees.

The ANOVA (Table 2) for fibre characteristics, vessel diameter and number of vessels mm^2 shows that these parameters varied significantly between all trees. The mean fibre length ranged from 1.25 to 1.43 mm and the differences are significant ($P < 0.05$). The mean fibre lengths of trees 1, 4, and 6, and among trees 2, 3, and 5 were not significantly different ($P < 0.05$). Fibre diameters of the trees investigated varied from 30.1 to 40.2 μm and the lumen diameters ranged from 19.2 to 31.5 μm. The thickest fibre wall averaged 5.6 μm in tree 4 and the thinnest was 4.1 μm in tree 1. Fibre diameter and fibre lumen diameter in tree 3 were significantly different ($P < 0.05$) to the rest of the trees. Vessel diameter varied significantly between all trees, ranging from 167.9 to 186.7 μm. However, between individual trees a significant difference ($P < 0.05$) was only found between tree 3 and the rest of the trees except trees 1 and 2. Vessels per mm^2 ranged from 6.4 to 8.1 and the vessel frequency in tree 1 and tree 2 was significantly different ($P < 0.05$) to trees 3, 4, 5, and 6.

There were significant between-tree variations in all anatomical properties. However, further comparison between individual trees showed that some of the mean values were not significantly different ($P < 0.05$). The significance in variations observed may be due to inherited genetic differences of the individual trees. However, in addition to the genetically controlled effects, between-tree differences may also be due to the growth micro-environment of the trees. Kelempayan is very sensitive to soil moisture (Corner 1988; Wong 1989). Micro-environment will affect the growth of the trees (Wilson & White 1986) and thus their wood properties. Environmental factors

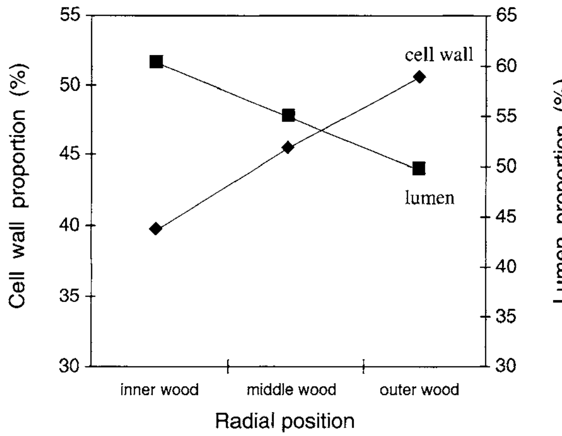

Fig. 1. Radial variation in cell wall and lumen proportion in Kelempayan.

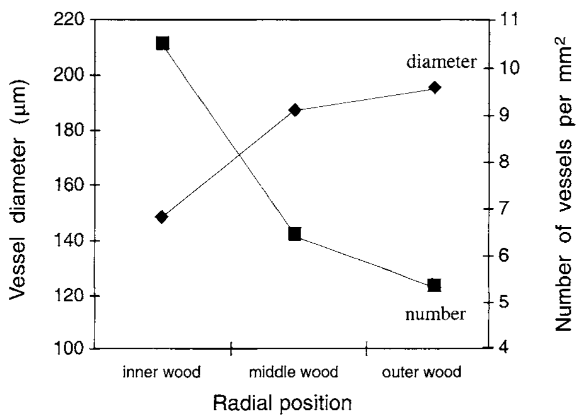

Fig. 2. Radial variation in vessel diameter and the frequency of vessels in Kelempayan.

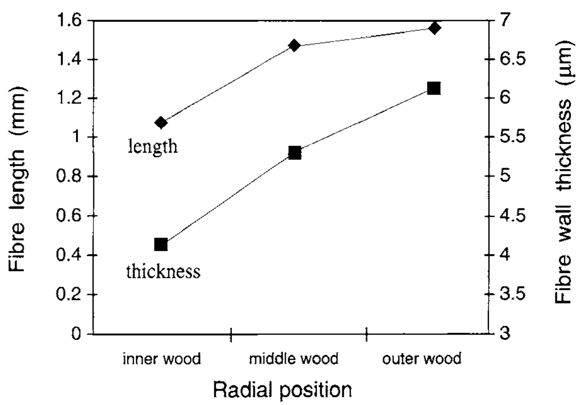

Fig. 3. Radial variation in fibre length and fibre wall thickness in Kelempayan.

affect both within- and between-tree variations (Panshin & De Zeeuw 1980; Zobel & Buijtenen 1989). Since the samples were taken from one location and their provenance was unknown, this study cannot explain the factor or interaction of factors that exerts control over the anatomical properties among individual trees.

Within-tree variation

The results for within-tree variations were discussed in terms of vertical and radial variations. Graphs (Fig. 1–3) show radial pattern or trend for significantly different variables.

Vertical variation — Significant differences in vessel and ray proportions were found among sampling heights (Table 4). Vessel proportions were lowest at the stump, increased slowly to mid trunk, and then rapidly increased. A reverse trend was observed for ray proportion. Ray proportion generally decreased with height, except for a small increase between 30 and 50% height level. No significant trends were observed for the proportion of cell wall, lumen and fibre.

No general trend was observed for fibre length with height. The fibre lengths between stump, 10, 30 and 50% of the total height were not significantly different ($P < 0.05$). However, fibre lengths decreased significantly towards 70% of the height levels. Fibre diameter and fibre lumen diameter decreased with height, but fibre diameter and fibre lumen diameter are not significantly different ($P < 0.05$) between stump, 10, and 30% height levels, nor between 30 and 50% height levels. Fibre diameter at 70% height level is significantly different from those at all other height levels.

Radial variation — Radial variation reflects the effects of increasing cambial age on wood characteristics. The effect of increasing cambial age on cell wall proportion is significant. Cell wall proportion increased from pith to bark while lumen proportion decreased from pith to bark (Fig. 1).

The increase of cell wall proportion can be explained by the fact that more cell wall was being synthesized with increasing age. The available photosynthates at the early stage of Kelempayan growth used to build new cells and little is left for cell wall thickening. At the later stages of growth, more photosynthates were available for cell wall synthesis.

Table 4. Vertical analysis of anatomical properties of 20-year-old Kelempayan.

Height level (%)	Tissue proportion		Fibre characteristics			Number of vessel mm^{-2}
	vessel (%)	ray (%)	length (µm)	diameter (µm)	lumen diameter (µm)	
Stump	15.2 a	13.0 a	1387.1 a	36.3 a	26.5 a	6.8 a
10	16.3 a	11.9 ab	1340.3 a	36.1 a	26.5 a	7.5 a
30	16.2 a	11.0 bc	1343.4 a	35.1 ab	24.9 ab	7.3 a
50	17.2 a	11.3 bc	1345.6 a	34.1 b	23.5 b	7.2 a
70	19.7 b	10.1 c	1275.7 b	31.8 c	20.9 c	8.2 b

Means followed by a different letter within a column are statistically different at $P \geq 0.05$ using Least Significant Difference test.

Table 5. Radial analysis of tissue proportions and fibre characteristics of 20-year-old Kelempayan trees.

Radial position	Tissue proportion			Fibre characteristics	
	vessel (%)	ray (%)	fibre (%)	diameter (μm)	lumen diameter (μm)
Inner wood	15.9 a	10.7 a	73.5 a	33.3 a	25.1 a
Middle wood	16.4 a	11.5 ab	72.3 a	36.2 b	25.6 a
Outer wood	18.4 b	12.2 b	69.5 b	34.7 ab	22.8 b

Means followed by a different letter within a column are statistically different at $P \geq 0.05$ using Least Significant Difference test.

Examination of transverse sections reveals that the cross-sectional proportion or area of vessels increased from pith to bark (Fig. 2). The increase of vessel proportion towards bark was observed in *Shorea leprosula* and *S. parvifolia* by Bosman et al. (1994), who associated this increase in vessel proportion with an increase in vessel size as the number of vessels remain constant from pith to bark. However, in Kelempayan the number of vessels decreases from pith to bark (Fig. 2), thus the increase in vessel proportion is mainly due to an increase in vessel size.

The proportion of fibres decreased from pith to bark (Table 5). A similar result was observed by Bosman et al. (1994) for *Shorea leprosula* and *S. parvifolia*. Ray proportion was found to have relatively small variation across the radial direction. The decreasing trend from pith to bark of fibre proportion was in accordance with the increase of vessel proportion. Taylor and Wooten (1973) stated that the increase of one cell type must necessarily be accompanied by the decrease of at least one other cell type.

Fibre length and fibre wall thickness increased significantly from pith to bark (Fig. 3). There was a marked increase in fibre length from inner wood to middle wood, with a tendency to level off towards the outer wood. Ohbayashi and Shiokura (1990) reported a similar trend in fibre length for Kelempayan taken from the Philippines. Recent work by Butterfield et al. (1993) on *Hyeronima alchorneoides* and *Vochysia guatemalensis* also recorded an increase in fibre length radially.

The significant increase of fibre wall thickness from pith to bark (Fig. 3) was expected because cell wall proportion also increases pith to bark and the bulk of wood tissue is made up of fibres. Thus as shown by both trends, it could be expected that towards a later stage of growth, fibre length and fibre wall thickness in Kelempayan reach their maxima. The increase in fibre length and fibre wall thickness is associated with the normal transition from juvenile to mature wood (Bendtsen 1978).

The radial trends for fibre diameter and fibre lumen diameter were similar but not identical (Table 5). Fibre diameter increased significantly ($P < 0.05$) from the pith and reached a maximum size in the middle wood and then remained fairly constant towards the bark. Contrarily, the increment of fibre lumen diameter from pith to middle wood is small, fibres attain their maximum size in the middle wood and then decrease significantly ($P < 0.05$) towards the bark. This suggests that fibre diameter increases as the girth increases, reaches a maximum at the middle wood and then more or less level off after that. In terms of fibre lumen diameter, the outer wood has the narrowest lumina compared with middle wood and inner wood. This, combined with the thick fibre walls, explains the high percentage of cell wall substance in the outer wood. The decrease in fibre lumen size from pith to bark is characteristic of the transition of juvenile to mature wood.

Height × radial interaction term was not significant ($P < 0.05$) for all tissue proportions and fibre characteristics with the exception of ray percentage and fibre length (Table 2). The nonsignificant interaction indicates that height and radial distance act independently in influencing the proportion of wood tissues. Significant interaction in ray proportion and fibre length shows that they vary significantly with the combined effects of height level and radial distance. This suggests that height and radial distance jointly influence the proportion of ray and fibre length in Kelempayan wood.

CONCLUSIONS

Tree to tree differences within the same environment were found to be significant in Kelempayan. It is apparent from even this small sample that there is considerable between-tree variation in anatomical characteristics. The present study indicates that within-tree variation patterns are more consistent in radial than in vertical directions, suggesting that cambial age contributes more to these patterns than height. All properties measured are consistently significantly different from pith to bark, which can be attributed to cambial age and the transition from juvenile to mature wood. Thus the effects of cambial age on anatomical structure play an important role in the total variation of Kelempayan wood. Radial variation and vertical variation are independent of each other in influencing most anatomical properties, except for ray proportion and fibre length. These results were based on samples taken from one site. More samples from different sites should be studied to obtain a general between- and within-tree variation in the anatomy of Kelempayan.

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