Wood Properties of Three Fruit Tree Species Planted in Central Kalimantan, Indonesia

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Abstract

The objective of this study was to evaluate the properties for wood utilization of fruit trees planted in Central Kalimantan, Indonesia. A total of 9 jambu bol (*Syzygium malaccense*), rambutan (*Nephelium lappaceum*), and durian (*Durio zibethinus*) trees were randomly selected from the plot (20 by 30 m) and measured for stem diameter, tree height, stress-wave velocity (SWV), and Pilodyn penetration of the trees. Mean values of stem diameter were 11.8, 15.9, and 29.3 cm for *S. malaccense*, *N. lappaceum*, and *D. zibethinus*, respectively. Mean values of stress-wave velocity were 3.16, 3.95, and 3.63 km/s for *S. malaccense*, *N. lappaceum*, and *D. zibethinus*, respectively. Core samples (5 mm in diameter) were collected from these trees to investigate the wood properties [basic density (BD) and compressive strength parallel to grain (CS)], anatomical characteristics [vessel diameter (VD), cell wall thickness (CWT) in wood fiber, and cell length (CL) of wood fiber and vessel element], and amounts of chemical components. In VD, CWT in wood fiber, and CL in wood fiber and vessel element, almost the same radial variation patterns were found in the three species. Relatively higher values in SWV, BD, and CS were found in *N. lappaceum*, suggesting that its wood can be used for construction lumber. On the other hand, *S. malaccense* and *D. zibethinus* had relatively thicker CWT in wood fiber, longer CL in wood fiber, and lower Klason lignin content. It is considered that the wood of these two species may be suitable for pulpwood.

Keywords: lesser-known species, stress-wave velocity, Pilodyn penetration, anatomical characteristics, chemical components.

Introduction

Shifting cultivation is an agroforestry system that is regarded as the traditional farming system in the rain forest regions of Indonesia (Kong 1996; Whitmore 1996). On Kalimantan Island, the people of Dayak have been performing shifting cultivation (Kong 1996). Recently, however, part of Dayak people have been encouraged to abandon the traditional shifting cultivation practices to go to work on estates (Kong 1996). Instead of abandoning the traditional shifting cultivation, they started to cultivate rice in paddy fields. In addition, they also started to plant trees or shrubs, such as fruit trees, rubber wood (*Hevea brasiliensis*), and rattan to obtain non-timber forest products. However, once the productivity of desired non-timber forest products decreases, the trees or shrubs will be cut down and replaced with new ones. After cutting the trees or shrubs, their wood is just used as fuel wood as these trees and shrubs have been regarded as "unutilized" or "lesser-known species."

In general, wood properties, such as wood density and Young's modulus of wood, are considered important characteristics for evaluating the strength properties of wood (Panshin and de Zeeuw 1980; Nugroho *et al*. 2012). In addition, quality and strength in pulp and paper can be evaluated by wood density, cell morphologies, and amounts of chemical components (Kayama 1968; Perez and Fauchon 2003; Yahya *et al*. 2010; Nugroho *et al*. 2012). Thus, wood properties should be clarified to promote the utilization of "unutilized" or "lesser-known species".

In the present study, basic wood properties, anatomical characteristics, and amounts of chemical components were investigated for three unutilized fruit tree species—*Syzygium malaccense* (L.) Merr. & L.M. Perry, *Nephelium lappaceum* L., and *Durio zibethinus* Murray—grown in regenerated forests after shifting cultivation. Based on the obtained results, appropriate utilization of wood from these species was also discussed.

Materials and Methods

The experimental site is located in Desa Tanjung Paku, Central Kalimantan, Indonesia (0°45'S, 112°05'E). Twenty-five years ago, some fruit trees were planted in renunciation field after shifting cultivation. A plot (20m × 30 m) was set in the field. In the plot, a total of 43 trees from 7 species including one non-fruit tree species, were found: Durian (*Durio zibethinus,* n = 9), Jambu bol (*Syzygium malaccense,* n = 5), Lengkeng hutan (unknown*,* n = 6), Medang buah (unknown*,* n = 9), Ombak (*Becaurea motleyana,* n = 3), Rambutan (*Nephelium lappaceum,* n = 5), and Karet (*Hevea brasiliensis,* n = 12). The stem diameter of 1.3 m above the ground and stress-wave velocity (SWV) were measured for all trees in the plot.

Among 6 fruit tree species, a total of 9 trees of 3 species (jambu bol, rambutan, and durian) were randomly selected from the plot for measuring tree height and wood properties [SWV of tree, cell morphology, moisture content, basic density (BD), compressive strength parallel to grain (CS), and chemical components]. SWV of trees was determined according to our previous report (Ishiguri *et al*. 2007). Stress-wave propagation time was measured by using a commercial handheld stress-wave propagation timer (Fakopp, Fakopp). Sensors were set at positions from 50 to 150 cm above the ground. SWV was calculated by dividing the distance between sensors (100 cm) by the stress-wave propagation time between two sensors.

Core samples (5 mm in diameter) were collected from 9 selected trees for determining the cell morphology, wood properties, and chemical contents. These characteristics, except for CS and chemical components, were measured at 1 cm intervals from the pith. To measure the cell morphologies, transverse sections (20 μm in thickness) were obtained from each 1 cm segment using a sliding microtome (Yamato Kohki, ROM-380). These sections were stained with safranine (1% in 50% ethanol) and dehydrated by graded ethanol. Dehydrated sections were treated with xylene and mounted with Bioleit (Oken). For measuring vessel and wood fiber morphologies, images of transverse sections were taken with a digital camera equipped with a microscope (Olympus, BX51). Vessel diameter (VD), wood fiber cell wall thickness (CWT), and cell length (CL) were measured for 30 vessels or wood fibers in each radial position. BD was calculated by dividing the oven-drying weight by the green volume as measured by water displacement. CS was measured by using a strength-testing machine for core samples (Fractometer II, IML) according to the method described in our previous reports (Ishiguri *et al*. 2007). Core samples were cut in 5 mm lengths from pith to bark for measuring CS. To analyze the radial variation of cell morphologies and wood properties, mean values were calculated at 2-cm intervals from the pith. To determine the chemical components, wood meal (42 to 80-mesh) from each tree was prepared from the specimens after determining their CS. Wood meal was extracted with ethanol-toluene mixtures for 6 hours by Soxhlet extractor. Chemical components, Klason lignin, holocellulose, and α-cellulose, were determined by using extracted wood meal according to ordinary methods (Dence 1992; The Japan Wood Research Society 2000).

Results and Discussion

Table 1 shows mean values of growth characteristics and wood properties in three selected trees. Although tree ages differed among the three species, the highest stem diameter and tree height were found in *D. zibethinus.*

The mean values of SWV were 3.16, 3.95, and 3.63 km/s for *S. malaccense*, *N. lappaceum*, and *D. zibethinus*, respectively (Table 1). In tropical fast-growing hardwood species planted in Indonesia, mean values of SWV were 3.75 km/s for 7-year-old *Acacia mangium* trees (Makino *et al*. 2012) and 3.08 km/s for 13-year-old *Falcataria moluccana* (formerly known as *Paraserianthes falcataria*) trees (Ishiguri *et al*. 2007). SWV mean values of 15 clones from 12-year-old *Tectona grandis* trees grown in Cepu, Central Java and Ciamis, West Java, Indonesia were 3.57 and 3.52 km/s, respectively (Hidayati *et al*. 2013). In the present study, mean SWV in all species showed higher values than those in *F. moluccana*. *D. zibethinus* also showed similar mean value to SWV in *T. grandis* (Hidayati *et al*. 2013). On the other hand, in *N. lappaceum*, the mean value of SWV was higher than those of *A. mangium* and *T. grandis*. It was reported that SWV of trees is positively correlated with Young's modulus of wood (Wang *et al*. 2001, 2004; Ishiguri *et al*. 2007; Wu *et al*. 2011). Therefore, it is considered that *N. lappaceum* and *D. zibethinus* may have higher Young's modulus of wood values as compared to commercial fast-growing plantation species in Indonesia. These results suggest that wood from these two species can be used for construction lumber.

Table 1. Mean values of growth characteristics and wood properties in three selected fruit trees.

Properties	*S. malaccense* (n=3)		*N. lappaceum* (n=3)		*D. zibethinus* (n=3)	
	Mean	SD	Mean	SD	Mean	SD
Stem diameter (cm)	11.8	1	15.9	9.7	29.3	0.6
Tree height (m)	8.3	0.8	14.8	4.1	25	0.9
SWV (km/s)	3.16	0.27	3.95	0.37	3.63	0.11
P (mm)	21	1.2	15.7	2.4	24.6	0.8
BD (g/cm^3)	0.54	0.01	0.57	0.04	0.53	0.03
CS (MPa)	29.6	3	38.2	0.1	32.7	1.4

Note: SD, standard deviation; n, number of sample trees; SWV, stress-wave velocity; P, Pilodyn penetration; BD, basic density; CS, compressive strength parallel to grain. CS was measured at green condition

As shown in Table 1, mean values of P were 21.0, 15.7, and 24.6 mm for *S. malaccense*, *N. lappaceum*, and *D. zibethinus*, respectively. Several researchers have reported finding significant negative correlation between the P value and BD (Greaves *et al*. 1997; Raymond and MacDonald 1998; Wu *et al*. 2010, 2011; Wessels *et al*. 2011). Greaves *et al*. (1997) demonstrated a high significant negative correlation between the P value and BD in 7-year-old *Eucalyptus nitens* trees. Wu *et al*. (2011) also reported that, in *Eucalyptus* clones, significant correlation was found between the P value and BD. In addition, they also found that the correlation coefficient between the P value and outer wood density (r = -0.755) was higher than that between P value and heartwood density (r = -0.543) and suggested that the P value could be used as an indirect measurement of the wood density of the outer part of the stem (Wu *et al*. 2011). In the present study, as shown in Figure 1, a significant correlation coefficient at 5% level was obtained between the P value and mean BD (r = -0.65). Furthermore, the higher correlation coefficient was recognized between the P value and mean BD of the outermost part of wood (r = -0.84), suggesting that the BD of outer wood in the three species tested here can also be predicted by the P value.

The mean values of BD in *S. malaccense*, *N. lappaceum*, and *D. zibethinus* were 0.54, 0.57, and 0.53 g/cm^3, respectively (Table 1). Gan and Lim (2004) have reported that wood density at 12% moisture content of *D. zibethinus* ranged from 0.42 to 0.82 g/cm^3. In *Syzygium gaertner* and *N. lappaceum*, minimal and maximal wood densities at 15% moisture content were 0.45 and 1.11 g/cm^3, and 0.62 and 1.11 g/cm^3, respectively (Lemmens *et al*. 1995). Our results were similar to those of the study. However, the mean values of CS at green condition in *S. malaccense*, *N. lappaceum*, and *D. zibethinus* were 29.6, 38.2, and 32.7 MPa, respectively (Table 1). These obtained values in the present study were relatively higher than those of the previous studies (Lemmens *et al*. 1995; Gan and Lim 2004). Radial variations of BD and CS are shown in Figures 2 and 3. In *N. lappaceum*, BD and CS gradually increased toward the bark side (Figures 2 and 3). However, BD and CS in *S. malaccense* and *D. zibethinus* showed almost constant values from pith to bark.

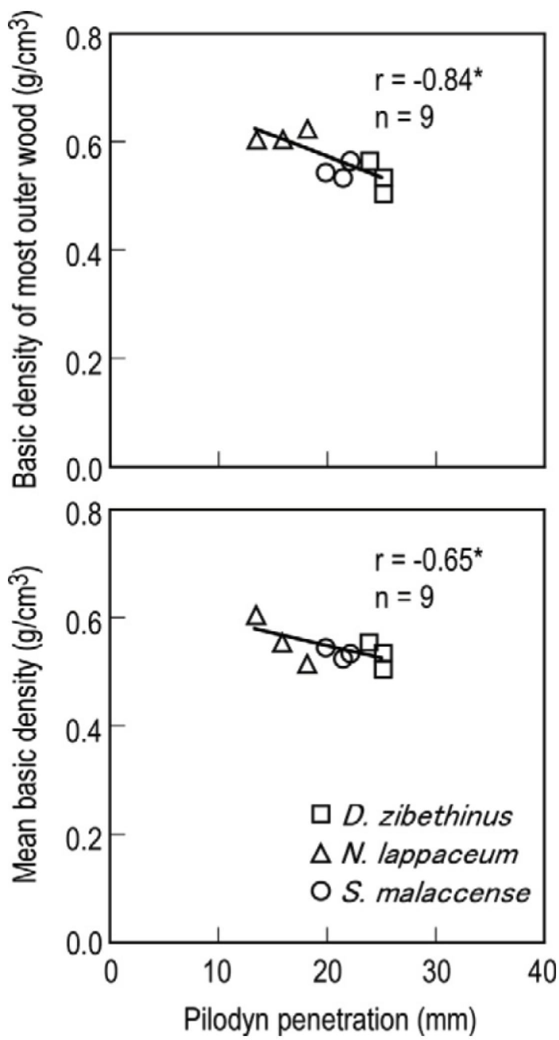

Figure 1. Relationships between Pilodyn penetration value and basic density. r, correlation coefficient; n, number of sample trees. Mean basic density was defined as mean values of basic density from pith to bark in each sample tree. Basic density of most outer wood was defined as mean values of basic density measured 2 cm from the bark side in each sample tree.

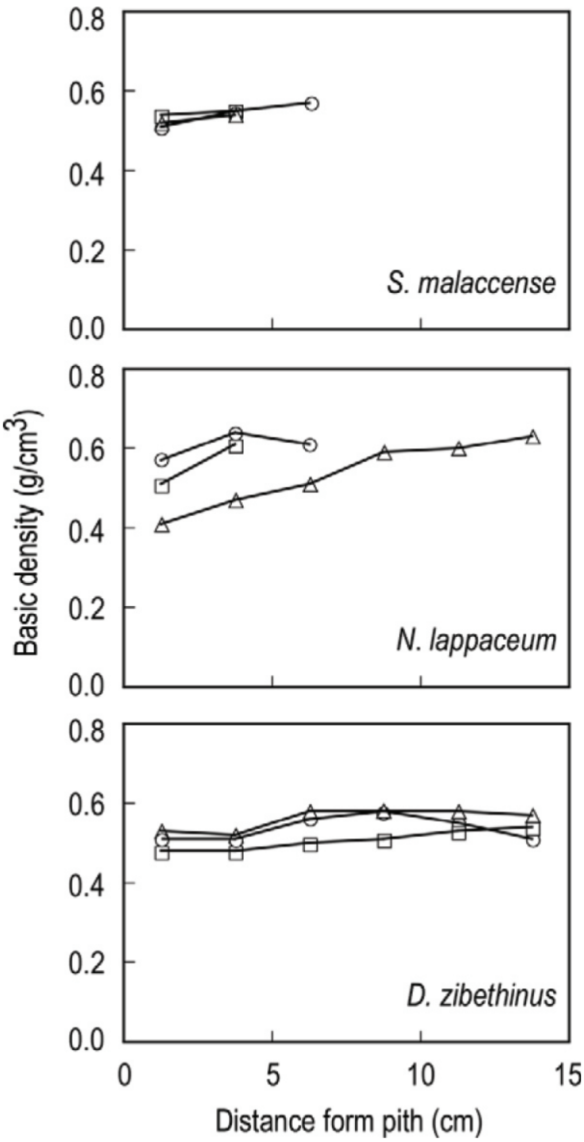

Figure 2. Radial variations of basic density in three selected fruit trees.

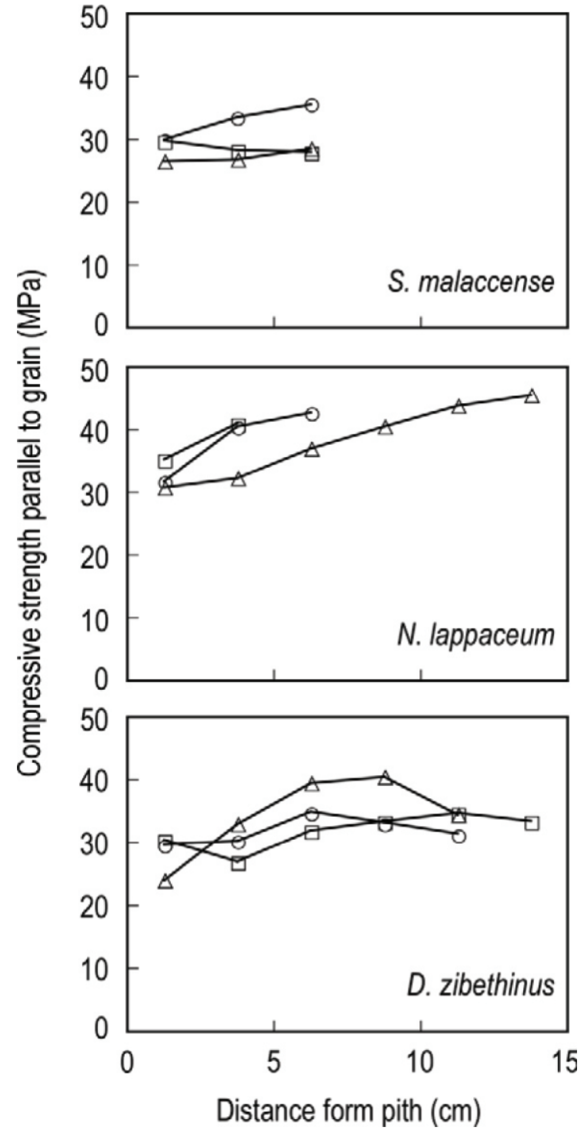

Figure 3. Radial variations of compressive strength parallel to grain in three selected fruit trees. CS was measured at green condition.

Mean VD values were 96, 155, and 192 μm for *S. malaccense*, *N. lappaceum*, and *D. zibethinus*, respectively (Table 2). Mean VD values in *S. malaccense* and *D. zibethinus* were similar to those previously reported in other *Syzygium* sp. and *Durio* sp. (Ogata *et al*. 2008). Mean VD value of *N. lappaceum* was in the range of VD values in *Ganophyllum falcatum*, which belongs to the same family (Sapindaceae) as does *N. lappaceum* (Ogata *et al*. 2008). VD gradually increased from pith to bark in all three species (Figure 4). This tendency was similar to those observed in other tropical hardwood species, such as *A. mangium*, *F. moluccana*, and *E. camaldulensis* (Veenin *et al*. 2005; Ishiguri *et al*. 2009; Nugroho *et al*. 2012). CWT in wood fiber also gradually increased from pith to bark (Figure 5). The highest mean value of CWT in wood fiber was observed in *S. malaccense* and *D. zibethinus* (Table 2). Regarding CL of wood fiber and vessel element, similar radial variation patterns were observed in three species, showing almost constant values from pith to bark (Figures 6 and 7).

Table 2. Mean values of anatomical characteristics in three selected fruit trees.

Properties	*S. malaccense* (n=3)		*N. lappaceum* (n=3)		*D. zibethinus* (n=3)	
	Mean	SD	Mean	SD	Mean	SD
VD (µm)	96	15	155	45	192	35
CWT in Wf (µm)	4	1	2	1	4	1
CL in Wf (mm)	1.57	0.12	1.09	0.07	1.43	0.18
CL in V (mm)	0.65	0.08	0.5	0.04	0.5	0.11

Note: SD, standard deviation; n, number of sample trees; VD, vessel diameter; CL, cell length; CWT, cell wall thickness; Wf, wood fiber; V, vessel.

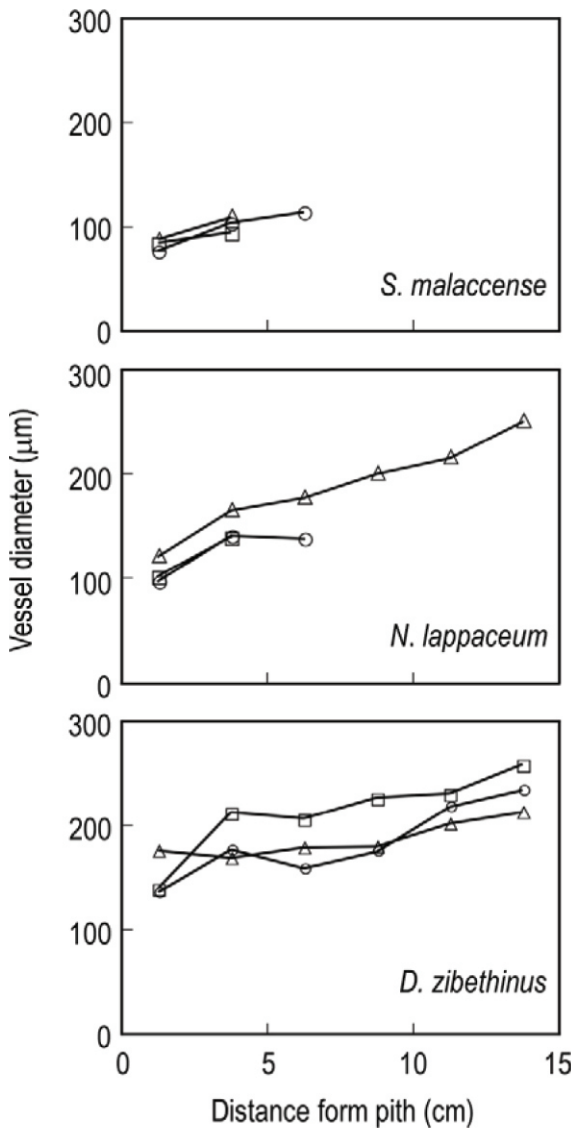

Figure 4. Radial variations of vessel diameter in three selected fruit trees.

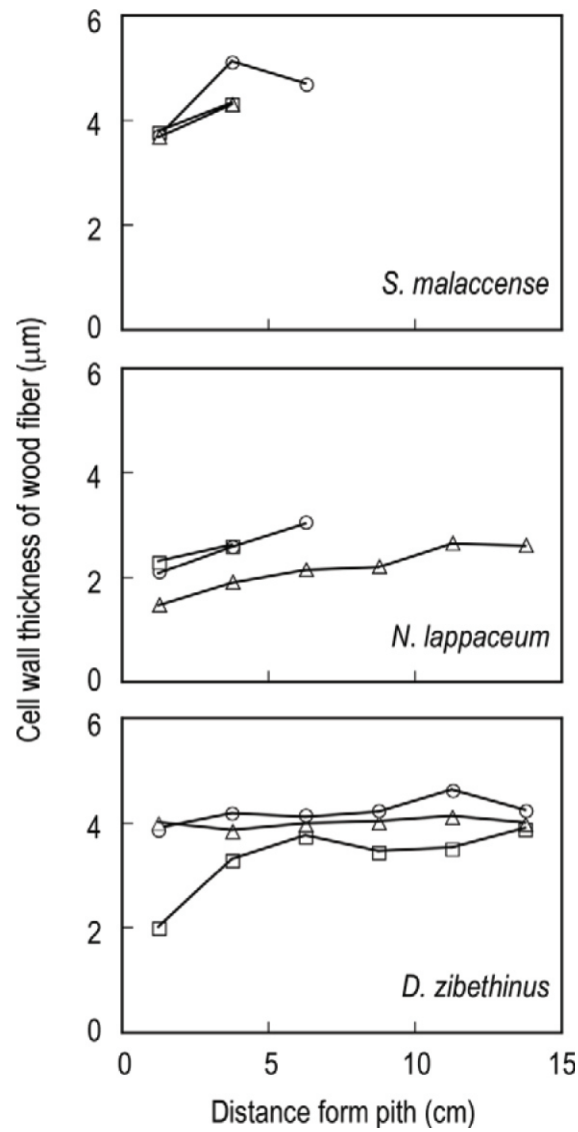

Figure 5. Radial variations of cell wall thickness of wood fiber in three selected fruit trees.

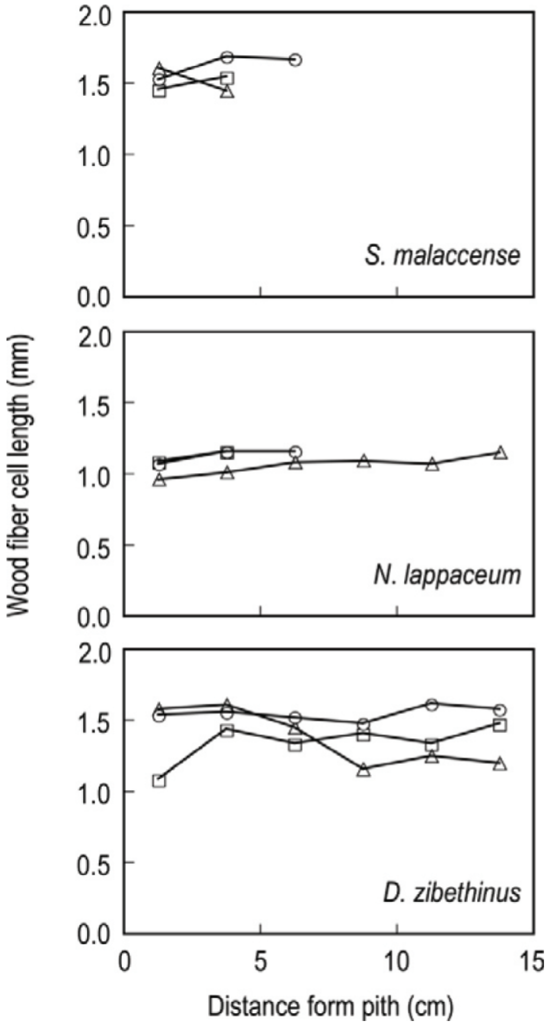

Figure 6. Radial variations of wood fiber cell length in three selected fruit trees.

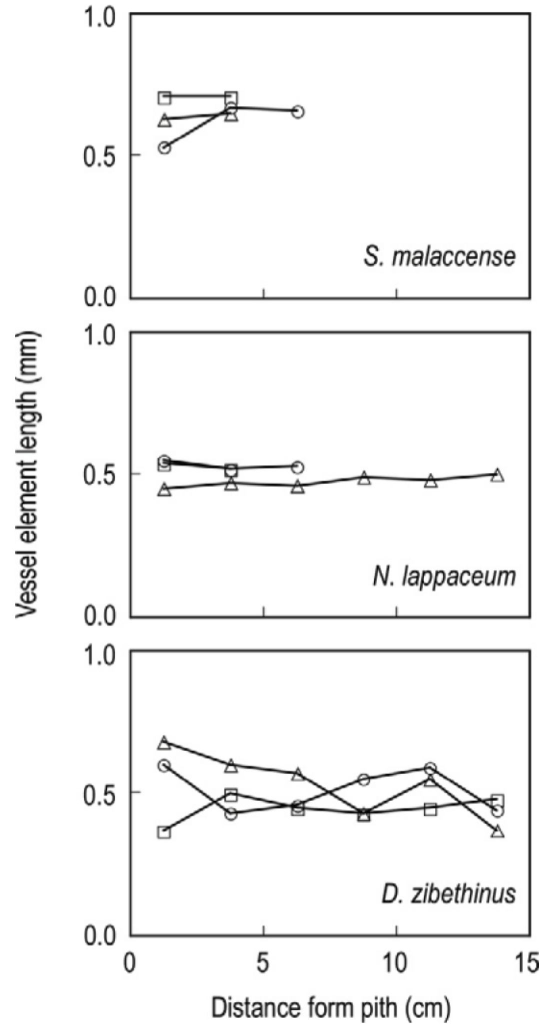

Figure 7. Radial variations of vessel element length in three selected fruit trees.'

It has previously been reported that wood properties are closely related to anatomical characteristics, such as CWT (Bhat and Priya 2004; Ishiguri *et al*. 2010; Nugroho *et al*. 2012). Bhat and Priya (2004) reported that significant correlation coefficients were obtained among cell wall area, modulus of elasticity, and modulus of rupture in 21- and 65-year-old *T. grandis* in India. In addition, significant correlation was found between fiber wall area and wood density (r = 0.82) of *A. mangium* planted in Indonesia (Nugroho *et al*. 2012). It is known that there is a significant positive correlation between BD and CS (Panshin and de Zeeuw 1980). This is also true for tropical hardwood species (Panshin and de Zeeuw 1980; Ishiguri *et al*. 2012). In the present study, significant correlation coefficients were obtained between BD and CS in *N. lappaceum* (r = 0.82) and *D. zibethinus* (r = 0.63) (Table 3). However, significant correlation was not found in *S. malaccense*. Based on the results, the value of BD can be used as an indicator for selecting trees with high CS value in these two species. Significant correlation was found between CWT in wood fiber and BD in all selected tree species, while only *N. lappaceum* trees showed significant correlations between CWT in wood fiber and BD or CS (Table 3). Regarding the relationships between mechanical properties and anatomical characteristics, previous studies (Yang and Evans 2003; Ishiguri *et al*. 2010, 2012) demonstrated significant correlations between CS and the microfibril angle (MFA) in tracheids or the wood fiber S_2 layer. For example, CS was significantly correlated with the MFA of S_2 layer in wood fiber in tropical hardwood species, such as 13-year-old *F. moluccana* planted in Indonesia (Ishiguri *et al*. 2012). Based on the results, therefore, it is suggested that CS in *S. malaccense* and *D. zibethinus* depends on CWT in wood fiber as well as the microfibril angle of the S_2 layer in wood fiber.

Table 3. Correlation coefficients among properties in three selected fruit trees.

Property 1	Property 2	*S. malaccense* (n=7)	*N. lappaceum* (n=11)	*D. zibethinus* (n=16)
BD	CS	0.58 ns	0.82 **	0.63 **
CWT in Wf	BD	0.75 *	0.87 **	0.60 **
CWT in Wf	CS	0.66 ns	0.85 **	0.19 ns

Note: n, number of sample trees; BD, basic density; CS, compressive strength parallel to grain; CWT, cell wall thickness; Wf, wood fiber; ns, no significant difference at 5% level; *, significant difference at 5% level; **, significant difference at 1% level.

Table 4. Contents of chemical components in three selected fruit trees.

Component	*S. malaccense*	*N. lappaceum*	*D. zibethinus*
Klason lignin (%)	25.5	28	25.9
α-Cellulose (%)	44.1	43	42.8
Hemicellulose (%)	30.5	29	31.4

Note: Amount of hemicellulose content was calculated by subtracting the amount of hololleculose from the amount of α-cellulose. Measurement of chemical components carried out one time.

As shown in Table 4, the highest Klason lignin, α-cellulose, and hemicellulose content were found in *N. lappaceum*, *S. malaccense*, and *D. zibethinus*, respectively. Lemmens *et al*. (1995) reported that lignin and cellulose contents in *S. gaertner* were 27.5% and 46.0%, respectively. On the other hand, lignin content in *D. zibethinus* was 24.5 to 27.5% (Lemmens *et al*. 1995). In other tropical fast-growing hardwood species, lignin content ranged from 24 to 27% for *Acacia* species such as *A. mangium* and *A. auriculiformis* (Lauria 1995).

Regarding the mechanical properties, relatively higher values in SWV and CS were found in *N. lappaceum*. Therefore, the wood of *N. lappaceum* can be used for construction lumber. On the other hand, the required characteristics for pulpwood are higher BD, smaller VD, longer wood fiber length, shorter vessel element length, and lower lignin content (Kayama 1968; Perez and Fauchon 2003; Yahya *et al*. 2010). Thus, *S. malaccense* and *D. zibethinus* may be suitable for pulp production.

Conclusions

The objective of the present study was to clarify basic wood properties, anatomical characteristics, and chemical components for three unutilized fruit tree species grown in regenerated fallow forests after shifting cultivation in Indonesia. In radial variation patterns of *S. malaccense* and *D. zibethinus*, BD and CS showed almost constant values from pith to bark. VD and CWT in wood fiber gradually increased from pith to bark. In *N. lappaceum*, BD, CS, VD, and CWT in wood fiber gradually increased from pith to bark. On the other hand, CL in wood fiber and vessel element demonstrated almost constant values toward the bark side in the three species. The wood of *N. lappaceum* had relatively higher mean values of SWV, BD, and CS as compared with two other species. *S. malaccense* and *D. zibethinus* have relatively thicker CWT in wood fiber, longer CL in wood fiber, and lower Klason lignin content than those of *N. lappaceum*. Therefore, it is considered that wood of *N. lappaceum* can be used for construction lumber, and *S. malaccense* and *D. zibethinus* may be suitable for pulpwood.

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