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MECHANICAL PROPERTIES OF 10-YEAR-OLD SENTANG *(AZADIRACHTA EXCELSA)* GROWN FROM VEGETATIVE PROPAGATION

AS Nordahlia[1], UMK Anwar[1], H Hamdan[1], A Zaidon[2] & MK Mohamad Omar[1]

[1]*Forest Research Institute Malaysia, 52109 Kepong, Selangor Darul Ehsan, Malaysia*
[2]*Faculty of Forestry, Universiti Putra Malaysia, 43400 Serdang, Selangor Darul Ehsan, Malaysia*

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NORDAHLIA AS, ANWAR UMK, HAMDAN H, ZAIDON A & MOHAMAD OMAR MK. 2014. Mechanical properties of 10-year-old sentang (*Azadirachta excelsa*) grown from vegetative propagation. This paper reports the mechanical properties of sentang (*Azadirachta excelsa*) wood cut from trees that were planted by vegetative propagation, their variations along tree height and also between sapwood and heartwood. The correlation between selected anatomical properties as well as density and mechanical properties were also presented. There was no significant difference in modulus of rupture between wood from seedling and rooted-cutting trees. However, wood from rooted-cutting trees showed higher modulus of elasticity compared with wood from seedling trees. On the other hand, compression and shear parallel to the grain were significantly higher in wood planted from seedling compared with wood from rooted-cutting trees. There was an increase in mechanical properties at the bottom portion towards the top irrespective of the planting technique. Mechanical properties were higher in heartwood than in sapwood. Mechanical properties were correlated with anatomical properties rather than density. Rooted cutting could be a promising method for planting sentang, apart from seedling.

Keywords: Static bending, compression, shear, rooted cuttings, seedlings, fast growth

INTRODUCTION

The area planted with fast-growing tree species has been expanding due to the scarcity of commercial timber from natural forests. The Compensatory Forest Plantation Programme established in 1982 promoted the planting of fast-growing species such as akasia (*Acacia* spp.), yemane (*Gmelina arborea*) and sentang (*Azadirachta excelsa*) in Malaysia (Thai 2000). At the Forest Research Institute Malaysia (FRIM), plantation of fast-growing species such as sentang began in 1997. Sentang was planted using seedlings and rooted cuttings at FRIM. Rooted cuttings have been used to propagate sentang and other plantation species as an alternative to seedlings because some species do not fruit regularly or they produce recalcitrant seeds (Aminah et al. 2002).

In vegetative propagation such as rooted cutting and tissue culture, consideration is given not only to survival and growth of trees but also to wood quality which should be comparable or even better than those of trees grown from wildings or seedlings. This is very important as characteristics of wood will differ when using different propagation techniques (Veenin et al. 2005, Quilho et al. 2006).

Mechanical properties are usually the most important wood quality indicator for structural applications (Bodig & Jayne 1982). Significant difference was observed in mechanical properties of *Eucalyptus tereticornis* wood when using different propagation techniques in a study of 10-year-old seedling and coppice (Sharma et al. 2005). The aims of this paper were to study the mechanical properties (static bending, compression and shear parallel to the grain) of sentang wood cut from trees planted by vegetative propagation, namely, rooted cutting and seedlings and their variations along the tree height. This paper also discusses variations between sapwood and heartwood of both wood from seedling and rooted-cutting trees. The correlation between selected anatomical properties as well as density and mechanical properties was also discussed. It is hoped that these basic properties will be useful to the wood-based industry.

MATERIALS AND METHODS

Preparation of materials

Samples were collected from plots 44 and 48 at Bukit Hari, FRIM. The trees were planted in 1997 and the age at the time of felling was 10 years. The soil is Renggam series. The trees were planted at a spacing of 3 m × 3 m. Only six trees were felled since this was a preliminary study and the main purpose was to compile data on the basic properties of young timber species. Three trees which were planted from seedlings were felled from plot 48 and another three trees planted from rooted cuttings were felled from plot 44. The range of diameter breast height (dbh), total bole height and clear bole height of the trees were 16 to 20 cm, 14 to 18 m and 6.5 to 7.6 m respectively. Trees were felled 15 cm above the ground. Each tree was cut into three portions, namely, bottom, middle and top. Two discs approximately 3 cm in thickness and billets of 2 m length were cut from each portion. Discs were assigned for two different studies, namely, anatomical and density, while billets of 2 m long were used for mechanical strength testing.

Sapwood percentage

The sapwood and heartwood were distinguishable on the basis of colour (Lim et al. 2011, Miranda et al. 2011). The sapwood was yellowish white, grey-pink or greyish white while the heartwood, pale reddish brown (Mabberly & Pannell 1989, Lathsamy 1998). The sapwood percentage from each stem was determined by measuring the radius of the disc and heartwood portion as shown in Figure 1. The sapwood percentage was calculated according to the equation:

$$\text{Sapwood percentage} = \frac{(R^2 - r^2)}{R^2} \times 100 \qquad (1)$$

where R = average disc radius (mm) and r = average heartwood radius (mm).

Anatomical properties

A wood block of 10 mm × 10 mm × 15 mm was each taken from the sapwood and heartwood portions of the wood disc and was also obtained from the bottom, middle and top. The blocks were boiled in distilled water until they sank. This took approximately 48 hours. A sledge microtome was used to cut thin sections from the cross, radial and tangential surfaces of each block. The thickness of wood sections was in the range of 15 to 20 µm. The cross-, radial and tangential sections were kept in separate Petri dishes for the staining process. Staining was carried out using 1% safranin-O. Wood sections were immersed overnight in 1% safranin-O dissolved in 70% alcohol. Thin wood sections were mounted on glass slides. Quantitative measurements, namely, vessel diameter and percentage of fibre proportion were taken from the cross-sections using a light microscope. The magnification was 100 ×.

A wood block (10 mm × 10 mm × 15 mm) each was cut from the sapwood and heartwood portions of each height. They were split into matchstick size pieces before being macerated using a mixture of 30% hydrogen peroxide:glacial acetic

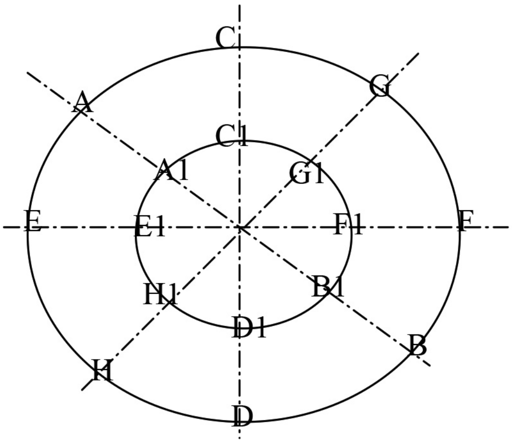


Figure 1 Axial lines drawn across the disc surface for measurement of disc and heartwood radii; A1B1, C1D1, E1F1, G1H1 = heartwood radius; AB, CD, EF, GH = disc radius

acid at a ratio of 1:1 at 45 °C. Macerated fibres were thoroughly mixed and spread on a glass slide. Fibre length and fibre wall thickness were measured using light microscope. Magnifications of 40 × were used for fibre length and 400 × for fibre wall thickness. For all anatomical property measurements, 50 readings were taken randomly.

Density

Samples of dimensions 20 mm in radial × 20 mm in longitudinal × 40 mm in tangential directions were cut for density determination. Test samples were cut in accordance with BS 373 (BSI 1957). Oven dry weight of the samples was measured after drying them in the oven at 103 ± 2 °C for 48 hours. The green volume was obtained by measuring the samples using digital vernier callipers in radial (R), tangential (T) and longitudinal (L) directions to the nearest 0.01 mm. Density was determined on the basis of oven dry weight and green volume as below.

$$\text{Density (kg m}^{-3}\text{)} = \frac{W_o}{V_g} \qquad (2)$$

where W_o = oven dry weight (kg) and V_g = green volume (m^3). A total of 180 samples were used for density determination.

Mechanical properties

Billets of 2 m long from trees grown from seedlings and rooted cuttings were cut and sawn into boards with nominal thickness of about 38 mm. The green moisture content was 94.5%. Boards were left to air dry for 3 months until it reached 12% moisture content. Moisture content was determined by the standard oven dry method. Samples for each test were cut and tested in accordance with BS 373. Three types of tests were conducted, namely, static bending, compression and shear parallel to the grain. The standard dimensions for static bending test were 300 mm × 20 mm × 20 mm. During test, samples were supported at both ends over a span of 280 mm. A load was applied at mid-span at a constant speed of 6.6 mm min^{-1}. Specimens of 20 mm × 20 mm × 60 mm dimensions were used for the test of compression parallel to the grain. Each specimen was placed in a vertical position. The bottom end was placed on the flat surface of the hemispherical bearing of the strength tester, while a constantly applied load was introduced at the top end. Rate of loading was controlled at 0.6 mm min^{-1}. Load was applied at a constant rate of cross-head movement of 0.6 mm min^{-1}. The dimensions of specimens for shear parallel to the grain were 20 mm × 20 mm × 20 mm. The direction of shearing was parallel to the longitudinal direction of the grain. Tests were made on the tangential and radial planes of the samples. The total number of samples was 90 for each test. All tests were conducted using the 100 KN testing machine.

Statistical analysis

Statistical analysis was carried out using Statistical Analysis Software package. Analysis of variance (ANOVA) was use to determine whether differences in means were significant. If differences were significant, least significant difference (LSD) test was used to determine which means were significantly different from one another. Relationships between anatomical properties as well as density and mechanical properties were analysed using simple correlation analysis.

RESULTS AND DISCUSSION

Mechanical properties

Table 1 shows sapwood percentage, selected anatomical properties and density along the tree height and their variations between sapwood and heartwood. The mean value of the properties by the propagation technique is also shown. These properties affected the mechanical properties of sentang (Table 2). Their correlations are shown in Table 3. Ten-year-old sentang is considered juvenile wood. Thus, the wood has lower anatomical properties and density but higher sapwood percentage compared with mature wood (Bowyer et al. 2003). The anatomical structure of sentang wood at the bottom, middle and top positions as well as sapwood and heartwood portions are presented in Figure 2. Vessel diameter along tree height reduced in size upwards (Table 1). Vessel diameter was found to be larger in the sapwood compared with the heartwood (Table 1). Wood cut from trees grown from rooted cuttings and seedlings showed similar trend in vessel diameter.

Table 1 Sapwood percentage, selected anatomical properties and density along tree height and between disc proportion of 10-year-old sentang grown from seedlings and rooted cuttings

Propagation technique	Position	Sapwood percentage (%)	Fibre length (µm)	Fibre wall thickness (µm)	Vessel diameter (µm)	Fibre proportion (%)	Density (kg m^{-3})
Seedling	Height level of the tree						
	Bottom	48.3 b	1045 a	3.2 a	144 a	53.2 b	520 a
		(11.8)	(148)	(0.92)	(8.5)	(11.3)	(40.6)
	Middle	58.3 a	991 b	2.7 b	138 b	56.7 a	483 b
		(5.94)	(135)	(0.80)	(9.1)	(8.68)	(33.5)
	Top	63.0 a	890 c	2.5 c	137 b	56.8 a	484 b
		(6.47)	(144)	(0.80)	(8.9)	(10.7)	(23.3)
	Wood disc proportion						
	Sapwood	56.5 a	999 a	2.9 a	157 a	54.6 b	530 a
		(10.5)	(163)	(0.91)	(7.0)	(10.4)	(41.5)
	Heartwood	43.5 b	950 b	2.7 b	122 b	56.5 a	486 b
		(9.4)	(144)	(0.88)	(6.5)	(10.4)	(38.5)
	Mean	**56.5**	**975**	**2.8**	**140**	**55.6**	**496**
Rooted cutting	Height level of the tree						
	Bottom	52.5 b	1126 a	3.6 a	155 a	52.2 a	510 a
		(9.07)	(143)	(1.12)	(7.8)	(11.2)	(33.5)
	Middle	58.9 a	1083 b	3.2 b	154 a	52.1 a	476 c
		(5.71)	(143)	(0.99)	(7.5)	(11.2)	(26.3)
	Top	65.4 a	985 c	2.7 c	142 b	53.4 a	498 b
		(8.70)	(159)	(0.97)	(6.0)	(11.5)	(25.4)
	Wood disc proportion						
	Sapwood	58.6 a	1112 a	3.47 a	158 a	52.5 a	511 a
		(11.5)	(151)	(1.06)	(7.5)	(11.2)	(40.5)
	Heartwood	41.4 b	1018 b	2.84 b	133 b	52.7 a	489 b
		(9.1)	(155)	(1.03)	(7.1)	(11.35)	(38.0)
	Mean	**58.6**	**1064**	**3.2**	**150**	**526**	**495**

Values in parentheses are standard deviations; means followed by the same letter in the same column are not significantly different ($p \leq 0.05$)

Compression and shear parallel to the grain values were higher in wood from seedling trees (Table 2). Similar result was also reported by Sharma et al. (2005) who reported higher compression and shear in seedling wood than in coppiced wood of 10-year-old *E. tereticornis*. On the other hand, modulus of elasticity (MOE) was higher in wood from rooted-cutting trees (Table 2). However, there was no significant difference in modulus of rupture (MOR) between wood from seedling and rooted-cutting trees. The mechanical properties of the present study were almost comparable to or even better than 42-year-old sentang where the MOR, MOE, compression and shear were 83.9, 8655.0, 42.0 and 13.3 N mm^{-2} respectively (Lathsamy 1998). The present result showed higher mechanical property values compared with 12-year-old sesendok where the mean values of MOR, MOE, compression and shear were 48.2, 5618.0, 24.2 and 6.1 N mm^{-2} respectively (Khairul et al. 2010).

The higher values of compression and shear in wood from seedling trees could be due to higher fibre proportion found in wood of seedling trees (Table 1). The fibre proportion was also positively correlated with compression and shear as shown in Table 3. As stated by Bodig and Jayne (1982), fibre proportion is related to mechanical properties. On the other hand, MOE was higher in wood planted from rooted cuttings due to the longer fibres (Table 1). Some anatomical features are important in determining strength with stronger wood being frequently associated with longer fibre length (Desch & Dinwoodie

Table 2 Mechanical properties along tree height of 10-year-old sentang grown from seedlings and rooted cuttings

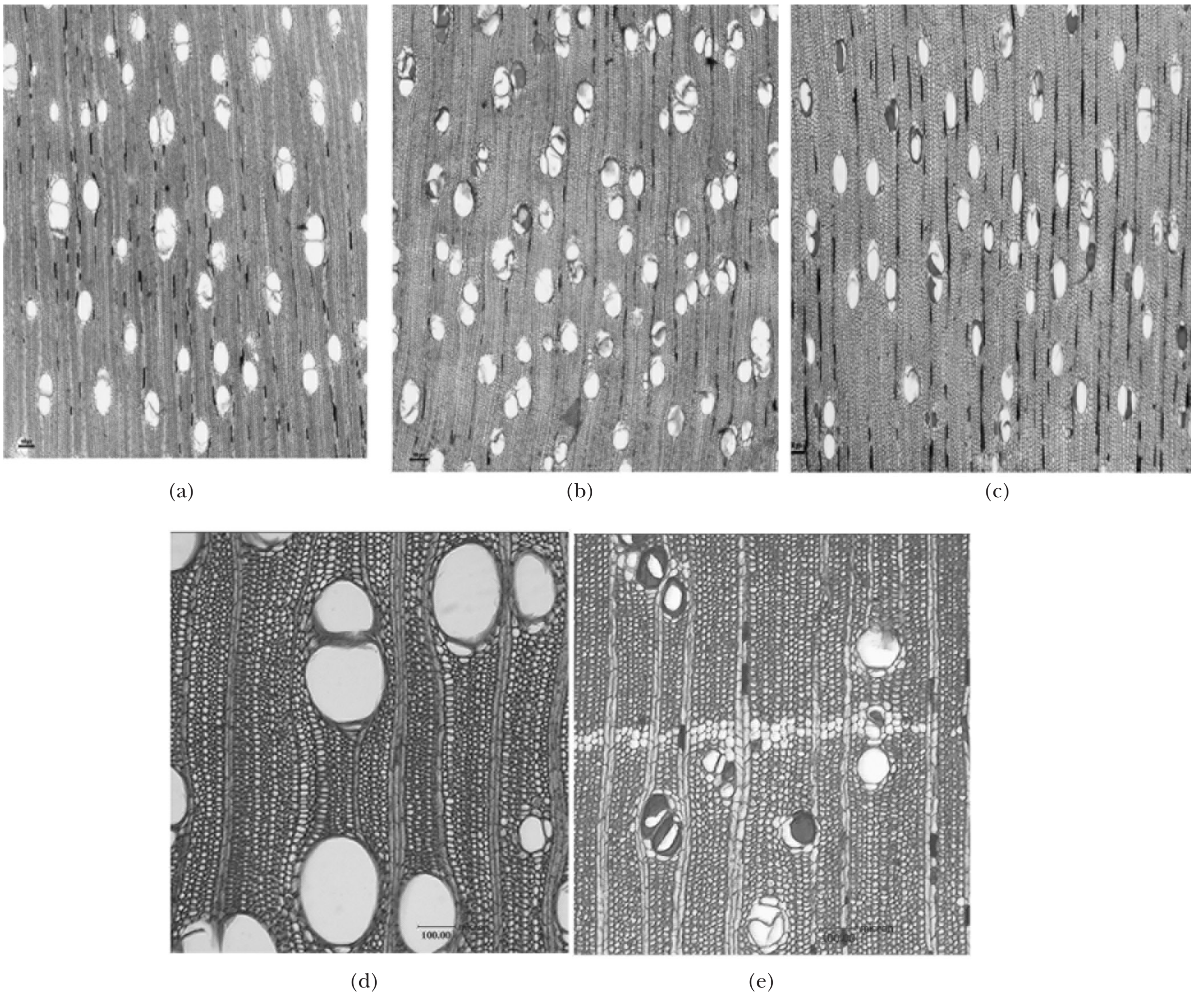
Property	Height position	Propagation technique	
		Seedling	Rooted cutting
Modulus of rupture (N mm^{-2})	Bottom	81.3 b	77.2 b
		(8.09)	(6.53)
	Middle	85.2 a	84.7 a
		(9.53)	(10.2)
	Top	83.0 a	86.3 a
		(10.3)	(7.82)
	Mean	83.1 a	82.7 a
Modulus of elasticity (N mm^{-2})	Bottom	8229 b	8737 b
		(1283)	(880)
	Middle	9090 a	9515 a
		(1750)	(813)
	Top	9100 a	9589 a
		(1187)	(667)
	Mean	8806 b	9280 a
Compression parallel to grain (N mm^{-2})	Bottom	42.3 b	37.4 b
		(3.66)	(3.16)
	Middle	47.4 a	40.1 b
		(4.48)	(5.23)
	Top	46.9 a	43.6 a
		(3.94)	(3.89)
	Mean	45.5 a	40.4 b
Shear parallel to grain (N mm^{-2})	Bottom	13.8 a	10.1 b
		(1.53)	(0.96)
	Middle	13.8 a	11.4 b
		(1.57)	(1.04)
	Top	13.4 a	13.1 a
		(1.20)	(1.27)
	Mean	13.7 a	11.5 b

Means followed by the same letter in the same column are not significantly different at $p \leq 0.05$; values in parentheses are standard deviations

Table 3 Correlations between selected anatomical properties as well as density and mechanical properties of 10-year-old sentang grown from seedlings and rooted cuttings

Propagation technique	Parameter	MOR	MOE	Compression	Shear
Seedling	Fibre length	-0.25*	0.10 ns	-0.09 ns	-0.42**
	Fibre wall thickness	-0.11*	0.09 ns	-0.16*	-0.08 ns
	Vessel diameter	-0.17*	-0.33**	-0.11*	-0.24*
	Fibre proportion	0.13*	0.11*	0.10*	0.12*
	Density	-0.05 ns	-0.03 ns	-0.33*	-0.12*
Rooted cutting	Fibre length	-0.16 ns	0.16*	-0.20*	-0.07 ns
	Fibre wall thickness	-0.10 ns	0.28*	-0.10 ns	-0.55**
	Vessel diameter	-0.34*	-0.12*	-0.48**	-0.23*
	Fibre proportion	0.18*	0.11*	0.10*	0.10*
	Density	-0.12 ns	-0.33*	-0.19 ns	-0.11 ns

MOR = modulus of rupture, MOE = modulus of elasticity; * significant at p ≤ 0. 05, ** significant at p ≤ 0.01, ns = not significant


(a) (b) (c)

(d) (e)

Figure 2 Microscopic characters of cross-sections of sentang wood from different tree heights: (a) bottom, (b) middle and (c) top as well as from different disc portions: (d) sapwood and (e) heartwood; scale bar = 100 µm

1996). The higher MOE in wood from rooted-cutting trees could also be associated with thicker fibre wall (Table 1). This was in good agreement with Bhat and Priya (2004) who reported that thicker fibre wall gave higher MOE in 21-year-old teak. Fibre length and fibre wall thickness were positively correlated with MOE in wood from rooted-cutting trees (Table 3).

Variations in mechanical properties along tree height and between sapwood and heartwood

Basically, both types of wood showed increasing trend of mechanical properties from bottom to top (Table 2). This finding contradicted that of 42-year-old sentang in which the mechanical properties decreased from bottom to top of the tree and the trend was influenced by density which also decreased towards the top (Lathsamy 1998). Higher mechanical properties towards the top might be due to increasing fibre proportion and decreasing vessel diameter towards the top (Table 1).

This finding was similar to that of Bhat and Priya (2004) who reported that higher fibre proportion and smaller vessel contributed to higher mechanical properties of teak. Not all mechanical properties are influenced by density but possibly by anatomical structure (Desch & Dinwoodie 1996, Onilude & Ogunsanwo 2002). Increased mechanical properties towards the top of the tree were also observed in other plantation species such as 7-year-old *Macaranga gigantifolia*, 7-year-old *Pinus radiata* and 6-year-old *G. arborea* (Helmer et al. 2000, Hsu et al. 2003, Karlinasari et al. 2008). These researchers opined that increase in mechanical properties towards the top was associated with anatomical properties. Juvenility of wood could be one of the factors that contributed to the abnormality in variations of mechanical properties along tree height in the present study. As reported by Zobel and Van Buijtenan (1989) as well as Bowyer et al. (2003), juvenile wood could affect the abnormality of wood properties and also their variations within the tree.

MOE in wood from seedling trees was not significantly different between sapwood and heartwood (Figure 3). However, in wood from rooted-cutting trees, it was significantly higher in the heartwood. MOR, shear and compression parallel to the grain were significantly higher in the heartwood (Figure 4). Factors which might give rise to better mechanical properties in heartwood were anatomical properties. Some of these anatomical properties were related to mechanical properties such as fibre proportion was higher in the heartwood compared with the sapwood in wood from seedling and rooted-cutting trees (Table 1). Some species do not follow a simple relationship based on specific gravity or density as the presence of silica or other mineral deposits in cells and anatomical properties could cause disparity in the relationship between specific gravity or density and mechanical properties of wood (Okai et al. 2004).

Correlations between anatomical properties as well as density and mechanical properties

The correlation coefficients between anatomical properties as well as density and mechanical properties of wood obtained from seedling and rooted-cutting trees are given in Table 3. Generally density is strongly related to mechanical properties as reported by Bowyer et al. (2003) and Fuwape and Fabiyi (2003). However, the present study found only shear and compression in seedling wood and MOE in rooted-cutting wood to be correlated with density (Table 3). The correlations were negative and very small. A similar result was observed by McKinley et al. (2002) and Okai et al. (2004). This study found that most of the mechanical properties were correlated with anatomical properties rather than with density. Fibre proportion and vessel diameter were correlated with MOR, MOE, compression and shear in both types of wood (Table 3). These findings concurred with those of Bhat and Priya (2004) as well as Okai et al. (2004).

CONCLUSIONS

Rooted cutting technique could produce almost comparable wood properties with wood from

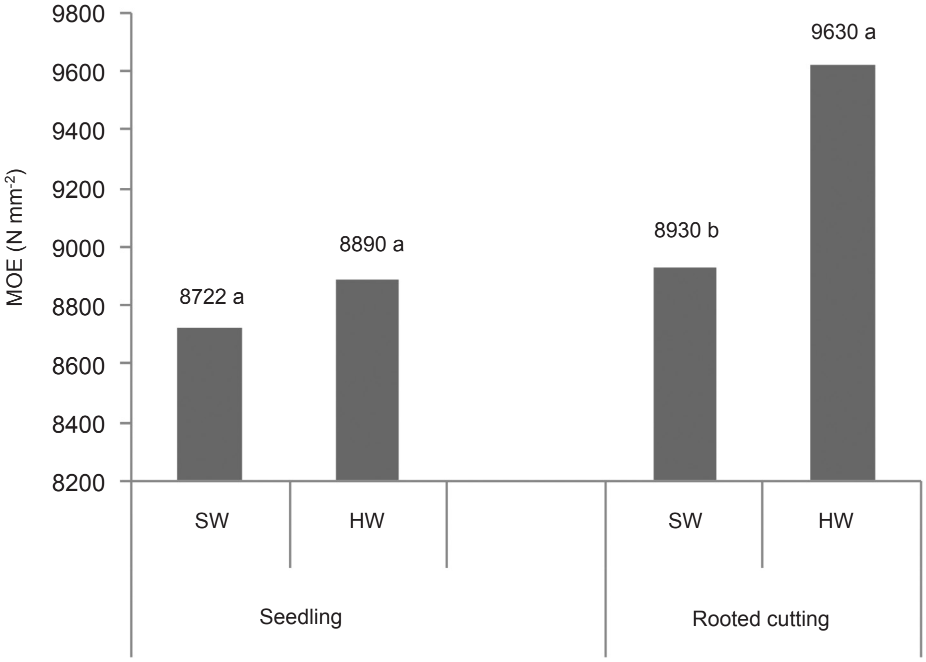


Figure 3 Variations in modulus of elasticity (MOE) between sapwood and heartwood of 10-year-old sentang grown from seedlings and rooted cuttings; means followed by the same letter in the same group are not significantly different at $p \leq 0.05$; SW = sapwood, HW = heartwood

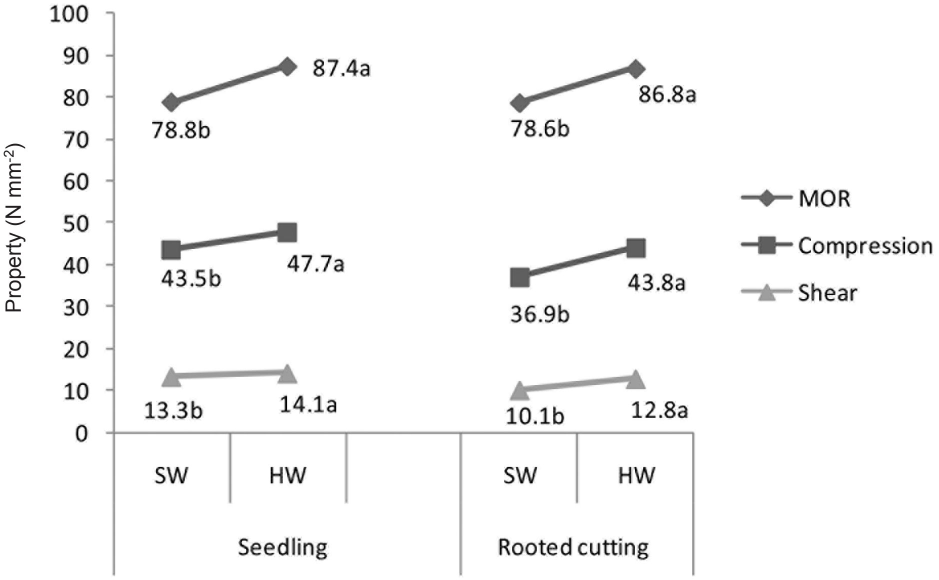


Figure 4 Variations in modulus of rupture (MOR), compression and shear between sapwood and heartwood of 10-year-old sentang grown from seedlings and rooted cuttings; means followed by the same letter in the same group are not significantly different at $p \leq 0.05$; SW = sapwood, HW = heartwood

seedling trees. Therefore, this technique could be a promising method for planting sentang and has the potential to be established on an extensive scale. Besides, rooted-cutting technique could provide a regular supply of planting stock in large quantities. Further research is needed to determine the wood mechanical properties of mature trees propagated from rooted cuttings since the 10-year-old trees examined in this study are considered juvenile. From the mechanical property results, 10-year-old sentang grown from seedlings and rooted cuttings would be suitable for furniture component, panelling, veneer and plywood and potentially useful for light flooring.

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