Anatomical and Physical Properties of Three Lesser-known Timber Species from Malaysia

Nordahlia Abdullah Siam,[a,]* Shahlinney Lipeh,[a] Mohd Khairun Anwar Uyup,[a] Muhammad Amirul Aiman Ahmad Juhari,[b] Noraini Talip,[c] Che Nurul Aini Che Amri [d] and Nor Azahana Abdullah [d]

The purpose of this study was to determine the anatomical and physical properties of three lesser-known Malaysian timber species, *i.e.*, mahang (*Macaranga hosei*), medang (*Litsea costalis*), and terap (*Artocarpus scortechinii*). Correlation factors that influenced the density and shrinkage were also discussed. From the results obtained, terap wood had the longest fibre (1421 µm), followed by medang (1309 µm), and mahang (1161 µm). Terap, medang, and mahang were categorized as having very thin fibres. The density of terap, medang, and mahang had average values of 504 kg/m^3, 485 kg/m^3, and 474 kg/m^3, respectively. In addition, terap wood also showed the highest tangential shrinkage (3.8%), followed by mahang (2.2%) and medang (1.5%) wood. This present study showed that the density was significantly influenced by the fibre length, fibre wall thickness, vessel diameter, and number of vessels. In addition, the shrinkage was highly correlated with the density. Based on the conducted research, mahang, medang, and terap show potential as alternative raw material to fulfill demand in wood-based industries.

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Contact information: a: Forest Research Institute Malaysia, Kepong 52109 Selangor; b: Faculty of Forestry and Environment, University Putra Malaysia, Serdang 43400 Selangor; c: Faculty of Science and Technology, University Kebangsaan Malaysia, Bangi 43600 Selangor; d: Kulliyah of Science, International Islamic University Malaysia, Kuantan 25200 Pahang;
** Corresponding author: nordahlia@frim.gov.my*

INTRODUCTION

Timbers used by the wood industry in Malaysia can be divided into two groups, *i.e.*, commercial timber species and lesser-known timber species. Commercial timber species refer to well-known species and these trees dominate the forest. The commercial timber species in Malaysia mostly come from the Dipterocarpaceae family. Lesser-known timber species can be defined as species which are little known or known only locally and are not marketed or are marketed on a small scale only (Sosef *et al*. 1998). Lesser-known timber species have been used in the Malaysia timber industry in the form of mixed species or 'chap-char' for a long time (Lim *et al*. 2016). Lately, the trend of using lesser-known timber species in the timber market increased due to the decreasing supply of commercial timber species. This is due to some states already turning to second rotation forests for relogging, as stated by Samsudin *et al*. (2010) and Demies *et al*. (2019).

The National Forest Inventory 4 Report for Peninsular Malaysia in 2000-2002 by Forest Department Peninsular Malaysia (JPSM 2004), Samsudin *et al*. (2010), Isa *et al*.

(2015), Shima *et al*. (2018), and Demies *et al*. (2019) found that, second rotation forests are highly variable forests which consists of a higher composition of non-dipterocarp trees, *e.g.*, kelat (*Syzygium* spp.), terap (*Artocarpus* spp.), medang (Family of Lauraceae), perah (*Elateriospermum tapos*), sesenduk (*Endospermum malaccense*), mempening (*Lithocarpus* spp.), and mahang (*Macaranga* spp.). According to Samsudin *et al*. (2010) and Demies *et al*. (2019), Malaysia will face new challenges in forest management as the structure, composition, and productivity of the second growth forest could be quite different from the rich primary stands. This is due to the fact that if the second growth forests have lower stocking, lower valuable commercial species, and smaller sized timbers, then it will affect the income of states dependent on the forestry sector. It will also affect the supply of raw materials to wood-based industries, which were dependent on the commercial timbers species that came from the Dipterocarpaceae family.

Based on the shortage supply of commercial timber species, research needed to focus on the timber properties of alternative timber species, such as the lesser-known timber that come from the second rotation forests, and to explore their potential usage. Important timber properties include the timber anatomical and physical properties. Anatomical characteristics such as fibre length, fibre wall thickness, vessel diameter, number of vessels, ray height, and ray width, considerably affect the wood properties, *i.e.*, the density, shrinkage, and mechanical properties (Uetimane Jr. and Ali 2011; Chowdhury *et al*. 2012; Quartey 2015; Elaieb *et al*. 2019). Therefore, study on the anatomical properties is essential to provide indication of the wood properties. Besides that, based on the anatomical properties, the potential product of the timber could also be predicted, *e.g.*, timber with thickest fibre wall is usually related to a high density and mechanical properties, which will make the timber suitable for heavy duty purposes (Hamdan *et al*. 2020). In addition, the physical properties, including density and shrinkage, are also very important to study. Density is the best parameter to predict the mechanical properties and shrinkage (Leonardon *et al*. 2009; Miyoshi *et al*. 2018; Emmerich *et al*. 2019; Zhang *et al*. 2021). In addition, it is also important to understand the shrinkage properties of a wood since this property affects the wood quality (Bowyer *et al*. 2003).

In this present study, the anatomical and physical properties of three lesser-known timber species, *i.e.*, mahang (*Macaranga hosei*) from the family Euphorbiaceae, medang (*Litsea costalis*) from the family Lauraceae, and terap (*Artocarpus scortechinii*) from the family Moracaeae, were determined. Correlation factors that influenced the density and shrinkage properties were also presented in this study. It is hoped that these basic properties will be useful to wood-based industries in terms of exploring suitable products from these lesser known-timbers species.

EXPERIMENTAL

Materials

Field sampling

Lesser-known timber species (18-years-old), *i.e.*, mahang (*Macaranga hosei*), medang (*Litsea costalis*), and terap (*Artocarpus scortechinii*), were randomly extracted based on availability from Rembau, Negeri Sembilan, Malaysia. Three trees from each species were felled at 15 cm above the ground. Two discs, approximately 5 cm in thickness, were cut from each tree at diameter breast height (DBH) and wrapped in plastic and stored in a freezer for later to study the anatomical and physical properties (Tan *et al*. 2010). The diameter at breast height (DBH) of mahang, medang, and terap were 28 cm, 32 cm, and 30 cm, respectively. Figure 1 shows the discs of mahang, medang, and terap.

Fig. 1. a) Mahang (*Macaranga hosei*), b) Medang (*Litsea costalis*), c) Terap (*Artocarpus scortechinii*)

Methods

Determination of the anatomical properties

The anatomical features study was conducted according to the method outlined in Schweingruber *et al*. (2006). A 10 mm x 10 mm x 10 mm wood block was taken from each wood disc. The blocks were boiled in distilled water until they were well soaked and sank. A sledge microtome (Reichert, Vienna, Austria) was used to cut thin sections from the transverse, tangential, and radial surfaces of each block. The thickness of the wood sections was approximately 25 µm. The transverse, tangential, and radial sections were kept in separate petri dishes for the staining process. Staining was carried out using 1% safranin-0 (Sigma, New Delhi, India). These sections were washed with 50% ethanol and dehydrated using a series of ethanol solutions with concentrations of 70%, 80%, 90%, and 95% (Merck, Selangor, Malaysia). Then, one drop of Canada Balsam (Merck, Darmsladt, Germany) was placed on top of the section and covered with a cover slip. The slides were oven-dried at a temperature of 60 °C for a few days.

The maceration technique was used to determine the fibre morphology (Wheeler *et al*. 1989). A wood block was split into matchstick size pieces before being macerated using a mixture of 30% hydrogen peroxide and glacial acetic acid at a ratio of 1 to 1 at a temperature of 45 °C, until all of the lignins had dissolved and the cellulose fibres appeared whitish. Microscopic observations and measurement of the wood anatomical features were carried out by using an optical microscope (Olympus Corporation, Tokyo, Japan). The descriptive terminology follows the International Association of Wood Anatomists (IAWA), as described in Wheeler *et al*. (1989) and Menon (1993). For all the anatomical properties measurements, 25 readings were taken randomly for each species, *i.e.*, mahang, medang, and terap. The slenderness ratio (fibre length to fibre diameter) and Runkel ratio (2 × wall thickness to lumen diameter) were also calculated (Singh and Mohanty 2007; Gülsoy *et al.* 2017).

Determination of some physical properties

The physical properties, *i.e.*, the density and shrinkage, were tested using BS standard 373 (1957). Samples that were 20 mm in the radial direction × 20 mm in the longitudinal direction × 40 mm in the tangential direction were cut from the wood samples for the analysis of the density and shrinkage. Density was determined on the basis of the oven dry weight and green volume.

The shrinkage test was conducted from green to air-dry conditions (wood MC=14 to 20%). The tangential, radial, and longitudinal sections of each sample were marked and measured with a pair of digital vernier calipers to the nearest 0.01 mm. A total of 90 specimens were used for each species, *i.e.*, mahang, medang, and terap, to determine the density and shrinkage. The shrinkage (S_a) was calculated using Eq.1,

$$S_a(\%) = \left(\frac{D_i - D_a}{D_i}\right) \times 100 \quad (1)$$

where S_a is the shrinkage (%) from the green to air-dry conditions, D_i is the initial dimension length (mm), and D_a is the air-dry dimension length (mm).

Statistical analysis

Statistical analysis was performed using Statistical Analysis System (SAS) software (version 9.1.3, SAS Institute, Cary, NC). Analysis of variance (ANOVA) was used to determine whether or not the differences in the means were significant. If the differences were significant, then the least significant difference (LSD) test was used to determine which of the means were significantly different from one another. The relationship between the properties was analyzed using simple correlation analysis. The correlation used the guide that Evans (1996) suggests for the absolute value of r: 00 to 0.19 is very weak; 0.20 to 0.39 is weak; 0.40 to 0.59 is moderate; 0.60 to 0.79 is strong; and 0.80 to 1.0 is very strong.

RESULTS AND DISCUSSION

Anatomical Properties

The anatomical features of the three lesser-known timber species (mahang, medang, and terap) are shown in Figs. 2 through 4. The anatomical features of these three lesser-known timber species are described for their identification and are an important indication on the suitability of the timber in terms of its potential usage. Figure 2 shows the anatomical features of mahang (*Macaranga hosei*) wood. The wood had a straight grain, and the growth ring boundaries were absent. The sapwood and heartwood were not clearly differentiated, and the colour was pale brown (as shown in Fig. 1a). The vessels were diffuse, solitary, and in radial multiples of 2 to 3, and the tyloses and deposits were absent in the heartwood vessels (Fig. 2a). In addition, the simple perforations plates and intervessel pits alternated (Fig. 2b). The tangential vessels diameter ranged from 112 µm to 252 µm and the frequency ranged from 6 per mm^2 to10 per mm^2. The axial parenchyma were in narrow bands. Rays 1 to 3 were seriated (Fig. 2c), the height ranged from 1559 µm to 2201 µm, and were heterocellular with procumbent and upright cells (Fig. 2d). The fibres were non-septate (Fig. 2d), 1055 to 1267 µm long and 2 to 4 µm thick. Crystals were present in the rays and axial parenchyma (Fig. 2e). However, silica grains were absent.

The anatomical features of medang (*Litsea costalis*) wood are shown in Fig. 3. The wood had a straight grain, and the growth ring boundaries were absent. The sapwood and heartwood were not clearly differentiated, and the colour was a light-brown (as shown in Fig. 1b). The vessels were diffuse, solitary, and in radial multiples of 2 to 4, while the tyloses and deposits were absent in the heartwood vessels (Fig. 3a). The simple perforations plates and intervessel pits alternated (Fig. 3b).

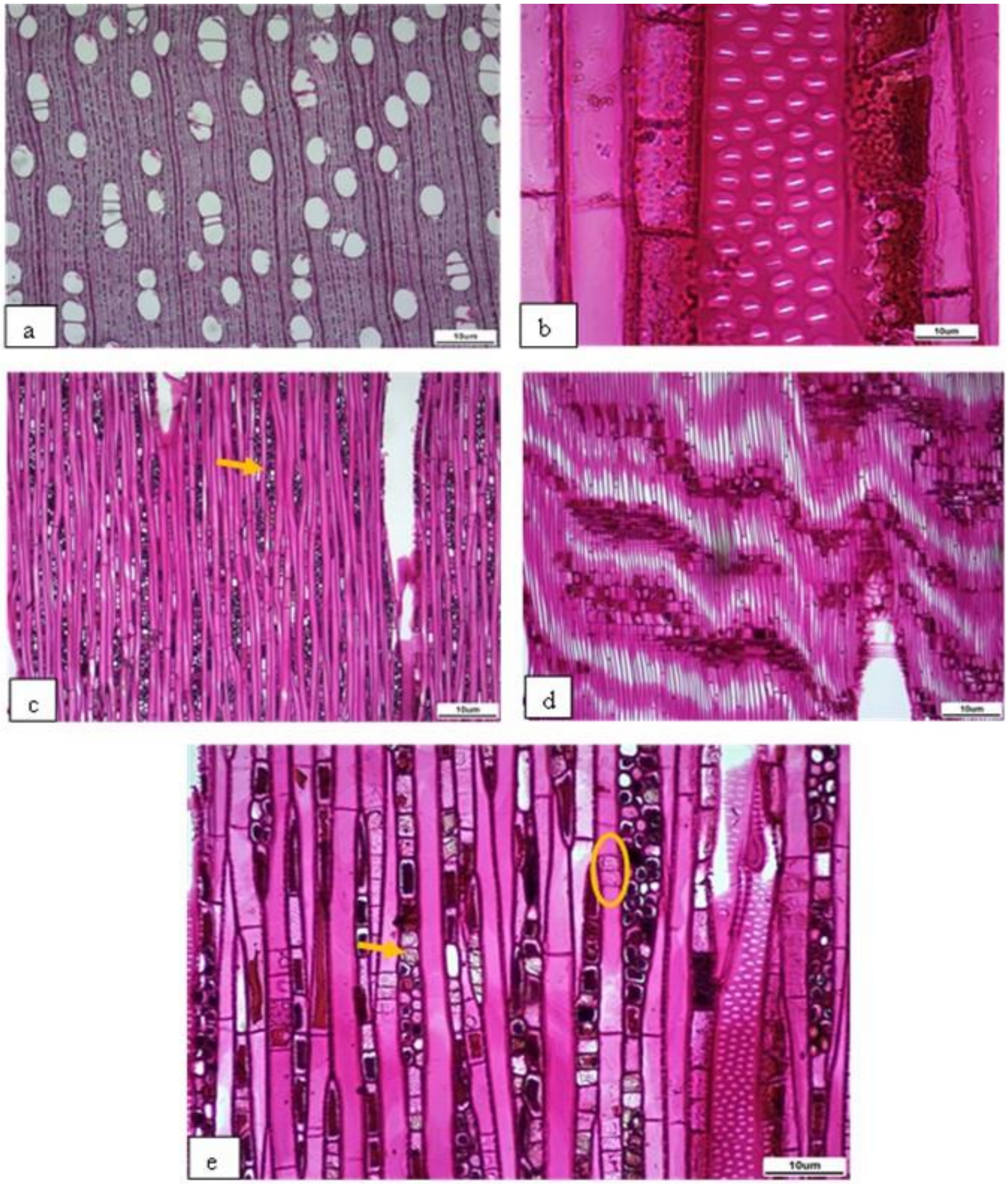

Fig. 2. Mahang (*Macaranga hosei*) wood: a) vessels absent of tylosis and deposits; b) intervessel pits alternated; c) rays 1 to 3 were seriated (arrow); d) heterocellular rays with procumbent and upright cells, and non-septate fibres; e) crystals present in the rays (arrow) and axial parenchyma (circle) (Note: Scale bars for a through e = 10 µm)

The tangential vessels diameter ranged from 88 to 188 µm and the frequency ranged from 15 to 21 per mm^2. The axial parenchyma was vasicentric to aliform; however, sometimes banded parenchyma were present. Rays 1 to 4 were seriated (Fig. 3c), with a height ranging from 1020 to 1380 µm and were heterocellular with procumbent and upright cells (Fig. 3d). The fibres were non-septate (Fig. 3d), 1211 to 1407 µm long and 2 to 4 µm thick. Oil cells were present, which was associated with the axial parenchyma and rays (Fig. 3e). Crystals were absent, but silica grains were present in the rays (Fig. 3f).

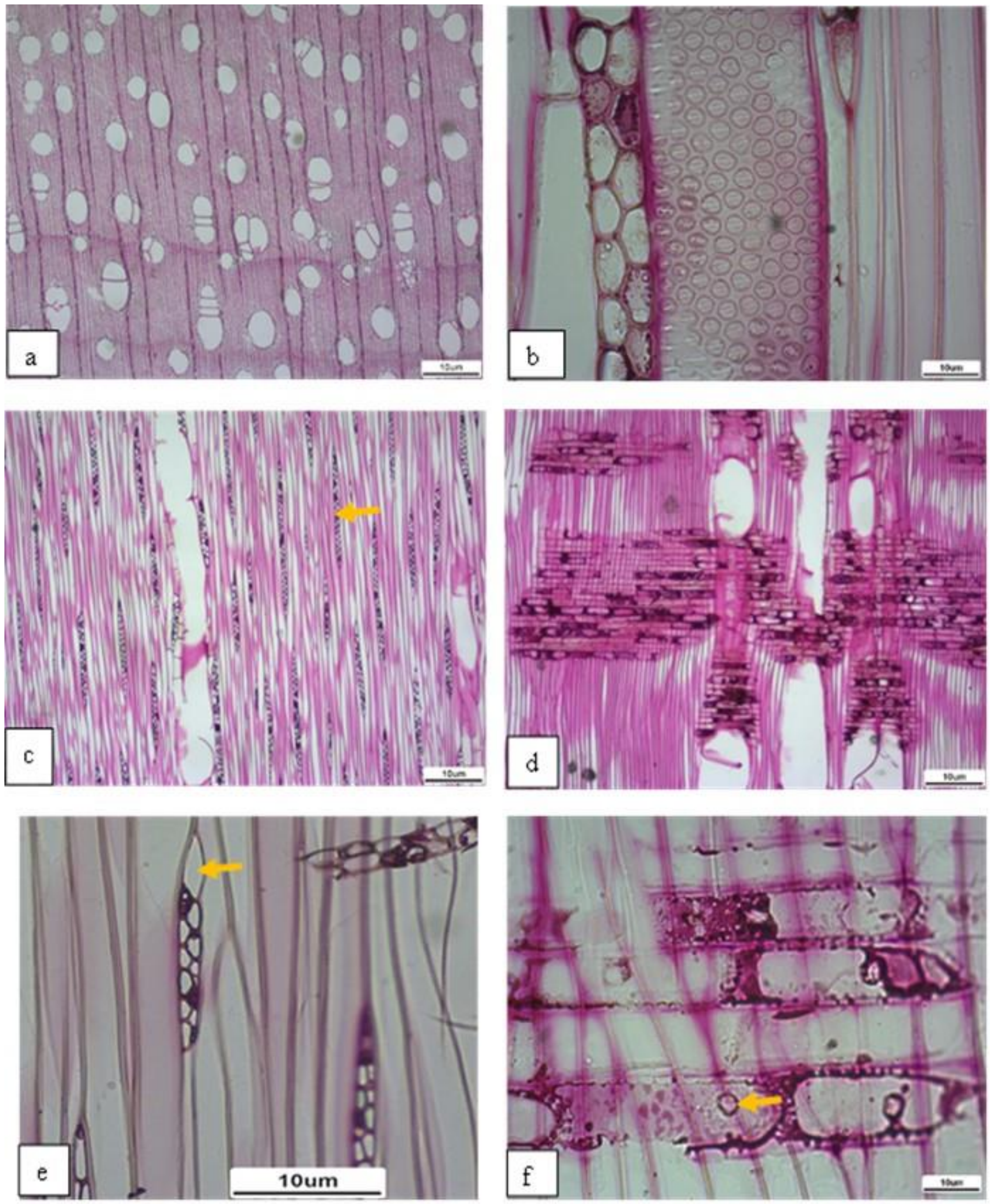

Fig. 3. Medang (*Litsea costalis*) wood: a) vessels absent of tylosis and deposits; b) intervessel pits alternate; b) intervessel pits alternated; c) rays 1 to 4 were seriated (arrow); d) heterocellular rays with procumbent and upright cells, and non-septate fibres; e) Oil cells present associated with ray (arrow); f) silica grains present in rays (arrow) (Note: Scale bars for a through f = 10 µm)

Figure 4 shows the anatomical features of terap (*Artocarpus scortechinii*) wood. The wood had an interlocked grain, and the growth ring boundaries were absent. The sapwood and heartwood were not clearly differentiated, and the colour was yellow-brown (Fig. 1c).

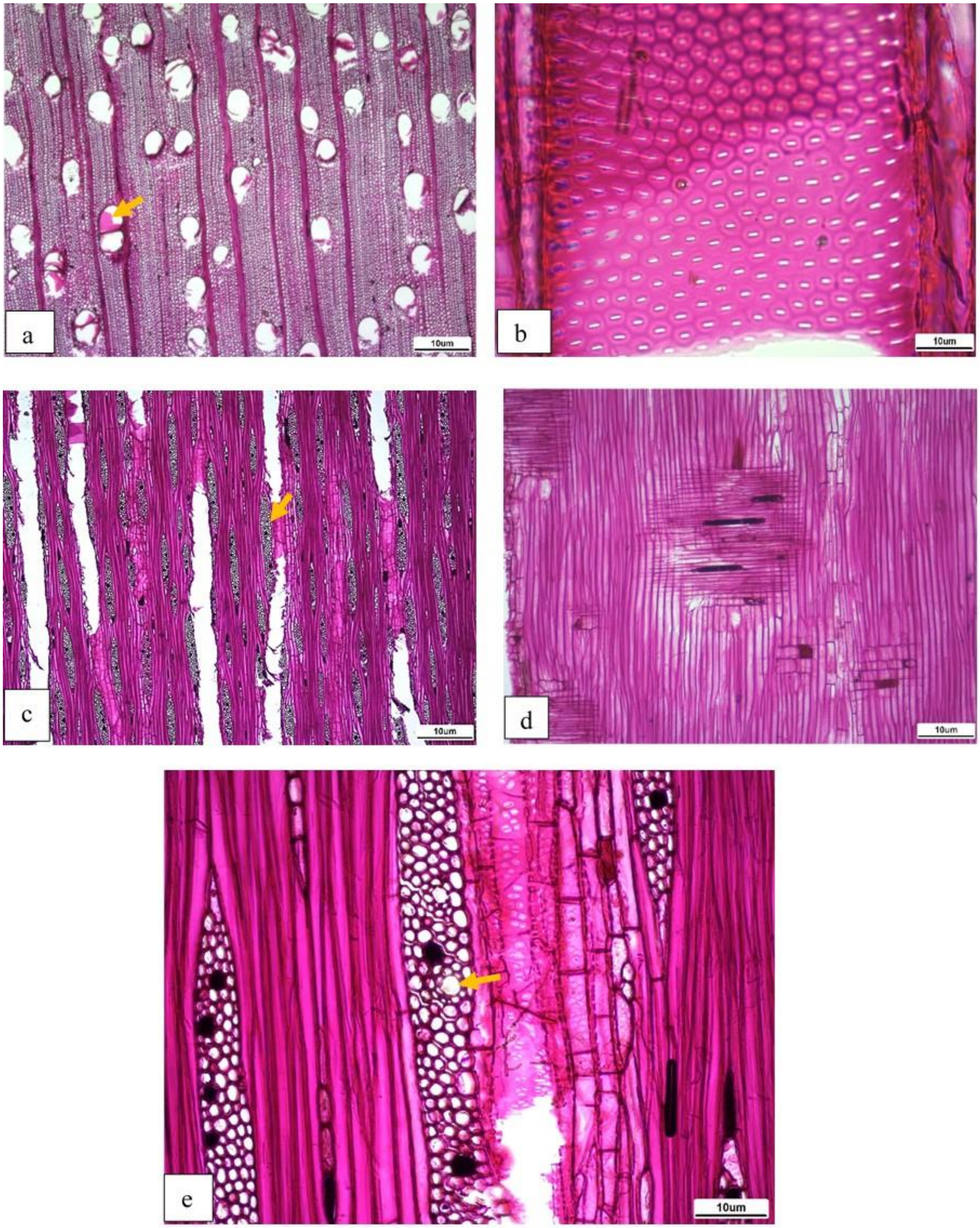

Fig. 4. Terap (*Artocarpus scortechinii*) wood a) vessels present of deposits (arrow); b) intervessel pits alternated; c) rays 2 to 6 were seriated (arrow); d) heterocellular rays with procumbent and upright cells, and non-septate fibres; e) latex tubes present in ray (arrow)
(Note: Scale bars for a through e = 10 µm)

The vessels were diffuse, solitary, and in radial multiples of 2 to 3, and the tyloses were absent, but white colored deposits were present in the heartwood vessels (Fig. 4a). The simple perforations plates and intervessel pits alternated (Fig. 4b). The tangential diameter ranged from 124 to 306 µm, and the frequency ranged from 6 per mm^2 to 10 per mm^2. The axial parenchyma were vasicentric to aliform and were sometimes confluent. Rays 2 to 6 were seriated (Fig. 4c), the height ranged from 1205 to 1695 µm, and were heterocellular with procumbent and upright cells (Fig. 4d). The fibres were non-septate (Fig. 4d) and were 1305 to 1537 µm long and 4 to 7 µm thick. Latex tubes were present in some rays (Fig. 4e), but crystals and silica grains were absent.

Table 1 compares the anatomical properties of mahang, medang, and terap wood with other commercial timbers, *i.e.*, light red meranti (*Shorea* spp.) and mersawa (*Anisoptera* spp.) from the Dipterocarpaceae family. From the results obtained, the fibre length of terap (1421 µm) was significantly longer than the other fibres, *i.e.*, medang (1309 µm) and mahang (1161µm). However, the fibre wall of terap was the thickest (5.2 µm), followed by medang (3.1µm), and mahang (2.8 µm). Terap, medang, and mahang were categorized as very thin fibre walled, which is when the fibre lumen is 3 times wider than the double wall thickness.

Table 1. Anatomical Properties of Mahang, Medang, and Terap Wood in Comparison to Other Commercial Timbers

Anatomical Features	Lesser-known Timber Species			Commercial Timbers	
	Mahang	Medang	Terap	Light red meranti	Mersawa
Grain	Straight	Straight	Interlocked	Interlocked	Interlocked
Ray width cells	1 to 3	1 to 4	2 to 6	1 to 6	1 to 9
Ray height (µm)	1880^a (321)	1200^c (180)	1450^b (245)	1000 to 2500	1200 to 2900
Extractive in heartwood vessels	Absent	Absent	Present	Absent	Absent
Tyloses	Absent	Absent	Absent	Present	Present
Fibre length (µm)	1161^c (106)	1309^b (98)	1421^a (116)	1300	1900
Fibre diameter (µm)	32^b (5.1)	34^b (4.3)	40^a(4.0)	15-30	15-30
Fibre lumen diameter (µm)	27^b (4.1)	28^b (3.3)	30^a (2.7)	-	-
Cell wall thickness (µm)	2.8^b (1.2)	3.1^b (0.8)	5.2^a (1.5)	2 to 6	6- to 0
Runkel ratio	0.21^b (0.11)	0.22^b (0.10)	0.35^a (0.26)	-	-
Slenderness ratio	36.3^b (5.1)	38.5^a (3.8)	35.5^b (4.2)	-	-
Vessel diameter (µm)	182^b (70)	138^c (50)	215^a (91)	250 to 330	200 to 300
Number of vessels (per mm^2)	8^b (2.2)	18^a (3.1)	8^b (2.6)	3 to 7	6 to 9

Note: Values in parentheses are standard deviations. Cell values differing by a letter (a,b,c) in the superscript in each row are significantly different at the 0.05 probability level.
Source of commercial timbers: Ogata *et al*. (2008)

The Runkel ratio of these three lesser-known timber species was less than 1.0. The vessel diameter of terap wood was categorized as large, whilst mahang and medang wood were categorized as medium sized vessel. The number of vessels present for these three lesser-known timber species were categorized as moderately few to moderately numerous. The widest ray was observed in terap wood, whilst mahang had the significantly highest ray. In comparison to other commercial timbers (Table 1) these three lesser-known timber species showed comparable values in terms of the anatomical properties.

The anatomical microscopic features are shown in Figs. 1 through 3 and in Table 1. Based on these, the timber properties can be predicted. Mahang and medang woods have a straight grain, which allows for a smooth surface upon sawing and planing. However, terap tends to be rough at the radial surface due the presence of an interlocked grain. Lim *et al*. (2016) stated that a roughed surface is caused by picking-up the grain, due to the presence of an interlocked grain. According to Hamdan *et al*. (2020), the fibre thickness is related to the density and strength. As shown in the Table 1, mahang, medang, and terap have a thinner fibre wall, which indicated a lower density. Mahang, medang, and terap have average fibre lengths of 1161 µm, 1309 µm, and 1421 µm, respectively, which are much lower than the values of softwood fibres reported by Bowyer *et al*. (2003), *i.e.*, an average range of 3000 µm to 4000 µm. However, the fibre length of mahang, medang, and terap were comparable to *Eucalyptus grandis* (1110 µm), which was reported by Palermo *et al*. (2015). *Eucalyptus* has been recognized as an extensively-planted species for pulp production in numerous countries (Ganis *et al*. 2016). Based on the result obtained (Table 1), the mean Runkel ratios of all three lesser known timber species studied were less than 1.0. As stated by Takeuchi *et al*. (2016), a Runkel ratio less than 1.0 indicating that the fibres from the timber would produce good quality paper. Results showed the slenderness ratio of mahang, medang, and terap were 36.3, 38.5, 35.5, respectively. This result is comparable to the study of *Eucalyptus grandis* which was 51 (Palermo *et al*. 2015). These three lesser known timber species might have potential for pulp and paper since they have comparable fibre length as *Eucalyptus grandis*, which is widely used for pulp and paper and has a Runkel ratio less than 1.0.

Mahang, medang, and terap can be categorized as having medium to large sized vessels (Table 1), which indicated they were light timbers and had a course texture which is suitable for general usage. The presence of deposits and extractives in terap wood indicated that the timbers would be difficult to treat. According to Uetimane Jr. *et al*. (2009), this difficulty in treatment will especially occur in the heartwood, since the deposits and extractives are abundance in this part. Mahang and medang woods were categorized as having medium size vessels with the absent of tylosis and deposits, which indicated these timbers were easily treated with preservatives. This was in line with the previous study by Uetimane Jr. *et al*. (2009) and Sint *et al*. (2011, 2013), who also observed that timbers with medium to large sized vessels and the absent of tylosis, deposits, and extractives were easily treated.

Based on the anatomical features, these three lesser-known timber species have narrow rays, which indicated they would have excellent nailing properties. Lim *et al*. (2016) found that, timbers with presence of silica, *e.g.*, white meranti (*Shorea* spp.) and mersawa (*Anisoptera* spp.), would cause difficulty in processing the timbers and a negative effect on the sawteeth. This present study also observed the presence of silica in medang wood, which indicated that it would be difficult to process in this timber and would cause a blunting effect on the sawteeth. Therefore, precautions should be taken when processing this timber. Mahang and medang wood would be potential for plywood due to the absence of deposits. As reported by Adeniyi *et al*. (2013), timber for plywood should be free from deposits, as it would interfere with wood gluability.

Density and Shrinkage

Table 2 presents the results of density and shrinkage analysis of mahang, medang, and terap wood, as well as a comparison with other commercial timbers. All the three lesser-known timber species were classified as a light hardwood timber, which are comparable to light red meranti and mersawa. The results showed that terap has the highest density, followed by medang and mahang, with an average of 504, 485, and 474 kg/m^3, respectively. The higher density in terap wood could be related to the longest and thickest fibres out of the three in this species. Similar results were also reported by Martińez-Cabrera *et al*. (2009), who found that density was correlated with fibre properties. The wood density obtained from this study was also comparable with the study by Wong (2019) that recorded the wood density ranging from 400 to 560 kg/m^3 (terap), 350 to 880 kg/m^3 (medang), and 270 to 495 kg/m^3 (mahang). Based on the relatively low densities of terap, medang, and mahang, they are suitable for light construction, furniture, cabinet making, picture frames, and other general usage. The potential usages of mahang, medang, and terap wood are summarized in Table 2, which are based on the anatomical properties (Table 1) and density. However, their appearance, colour, strength, and durability should also be considered.

Table 2. Density, Shrinkage, and Potential Usages of Mahang, Medang, and Terap Wood in Comparison to Other Commercial Timbers

Properties		Lesser-known Timber Species			Commercial Timbers	
		Mahang	Medang	Terap	Light red meranti	Mersawa
Density (kg/m^3)		474^c (20)	485^b (29)	504^a (23)	545	460 to 850
Shrinkage (%)	Tangential	2.2^b (0.7)	1.5^c (1.1)	3.8^a (1.5)	5.4	3.2
	Radial	1.5^b (1.0)	0.9^c (0.2)	1.8^a (1.3)	1.5	1.4
	Longitudinal	0.5^a (0.2)	0.2^b (0.1)	0.2^b (0.1)	-	-
Uses		furniture, wall paneling, picture frames, veneer, and plywood	furniture, wall paneling, veneer and plywood, and cabinet making	picture frame, general planking, strip flooring, and light construction	furniture, wall paneling, skirting, veneer and plywood, cabinet making, and door and window frames	light construction, door and window frames, flooring, furniture, and curtain rails

Note: Values in parentheses are standard deviations. Cell values differing by a letter (a,b,c) in the superscript in each row are significantly different at the 0.05 probability level.
Source of commercial timbers: Wong (2019).

In terms of shrinkage (Table 2), terap had the significantly highest shrinkage for the tangential (3.8 %) and radial (1.8%) directions. The highest shrinkage value in terap could be due to the larger rays in this species compared to the other species. This was in line with the previous study by Elaieb *et al*. (2019), who found that larger rays could result in a higher shrinkage. These values were followed by mahang, which had tangential and radial shrinkage of 2.2% and 1.5%, respectively. In addition, medang had the significantly lowest tangential (1.5%) and radial shrinkage (0.9%). The longitudinal shrinkage was highest in mahang wood, *i.e.*, 0.5%, whilst there was no significant difference in the longitudinal shrinkage between the medang and terap wood. The percentage of shrinkage for terap wood was rated as high, whilst the percentage of shrinkage for mahang and medang wood was rated as average. The shrinkage rating for these three lesser-known timber species was based on the percentage shrinkage in the tangential direction from green to air dry (Wong 2019).

Correlation Factors Influencing Density and Shrinkage

The correlation factors influencing the density and shrinkage of mahang, medang and terap wood are shown in Table 3. It was found that the density was positively correlated with the fibre length and fibre wall thickness with strong to very strong correlation in mahang, medang, and terap. The density was also negatively correlated with the vessel diameter and number of vessels in all species studied, where the correlation was weak to strong. This indicated that smaller vessels and lower numbers of vessels resulted in a higher density.

Table 3. Correlation Factors Influencing the Density and Shrinkage of Mahang, Medang, and Terap Wood

Lesser-known timber species	Properties	Density	Shrinkage (%)		
			Tangential	Radial	Longitudinal
Mahang	Fibre length	0.685**	-0.562**	-0.411**	-0.031ns
	Fibre diameter	0.109ns	0.412**	0.303*	0.131ns
	Fibre lumen diameter	-0.122ns	-0.032ns	-0.015ns	-0.023ns
	Cell wall thickness	0.700**	0.411*	0.341*	0.518**
	Vessel diameter	-0.804**	0.022ns	0.141ns	0.018ns
	Number of vessels	-0.436**	0.073ns	0.106ns	0.025ns
	Density	1	0.480*	0.542**	0.715**
Medang	Fibre length	0.762**	-0.512**	-0.324*	-0.412**
	Fibre diameter	0.141ns	0.116ns	0.017ns	0.235ns
	Fibre lumen diameter	-0.109ns	-0.092ns	-0.181ns	-0.020ns
	Cell wall thickness	0.614**	0.384*	0.437**	0.551**
	Vessel diameter	-0.783**	0.043ns	0.092ns	0.145ns
	Number of vessels	-0.375*	0.017ns	0.018ns	0.011ns
	Density	1	0.350*	0.655**	0.490**
Terap	Fibre length	0.911**	-0.380*	-0.177ns	-0.509**
	Fibre diameter	0.100ns	0.427**	0.044ns	0.271ns
	Fibre lumen diameter	-0.317**	-0.065ns	-0.141ns	-0.169ns
	Cell wall thickness	0.857**	0.411**	0.579**	0.341*
	Vessel diameter	-0.770**	0.185ns	0.086ns	0.110ns
	Number of vessels	-0.303*	0.098ns	0191ns	0.059ns
	Density	1	0.490**	0.621**	0.510**

Note:* = significant at $p \leq 0.05$, **= significant at $p \leq 0.01$, ns = not significant.
25 readings were taken randomly for each species of mahang, medang and terap for the anatomical properties measurements; 90 specimens were used for each species of mahang, medang and terap for density and shrinkage study

Terap wood showed the density was negatively and weak correlated with the fibre lumen diameter (r = -0.317). It was clearly shown from this present study that the anatomical properties which significantly influence the density are the fibre length, fibre wall thickness, vessel diameter, and number of vessels. This was also confirmed by previous studies by Martińez-Cabrera *et al*. (2009), Toong *et al*. (2014), and Longui *et al*. (2017).

Based on the obtained results, shrinkage was highly correlated with the density in mahang, medang and terap wood, with a weak to strong correlation. This was in good agreement with the conclusions reached by de Almeida *et al*. (2015), Schulgasser and Witztum (2015), and Tonouéwa *et al*. (2020), who also reported that the factor that primarily affected the shrinkage behavior of wood was density, where a denser wood generally shrinks more. In addition, shrinkage was also affected by other anatomical properties, *i.e.*, fibre length, fibre diameter, and wall thickness, with weak to moderate correlation. Similar results were also observed by Toong *et al*. (2014) and Hamdan *et al*. (2020) during the study of commercial Malaysian timbers and pioneer species, respectively.

CONCLUSIONS

1. Mahang and medang straight grain provided smooth surfaced wood after sawing and planing, whereas terap wood tended to be roughed due the presence of an interlocked grain. The three lesser known-timber species had a thinner fibre wall and medium to large sized vessels, which indicated a lower density.
2. Based on the anatomical properties of mahang and medang wood, they indicate that these timbers can easily be treated due to the medium sized vessels and absence of deposits. The absence of deposit also made these timbers suitable for plywood. However, the presence of deposits in terap indicates that it might be more difficult to treat with preservatives.
3. The narrow rays present in these three lesser-known timber species indicate that they might have excellent nailing properties. However, the presence of silica in medang wood might cause a blunting effect on the sawteeth during the process.
4. Mahang, medang and terap wood are classified as a light hardwood timber that is suitable for light construction, furniture, cabinet making, picture frames, and other general usages. In terms of shrinkage, terap had the highest shrinkage, followed by mahang and medang wood.
5. From this study, the anatomical properties, *i.e.*, fibre length, fibre wall thickness, vessel diameter, and number of vessels, significantly affected the density. The obtained results demonstrated that shrinkage was highly correlated with the density in mahang, medang, and terap wood. In addition, shrinkage was also affected by the fibre length, fibre diameter, and fibre wall thickness in these three lesser-known timber species.
6. In summary, three lesser-known timber species, *i.e.*, mahang, medang, and terap wood, have a potential to be an alternative timber to replenish the lack of raw materials in the form of commercial timber species. However, further research

should be done, including the strength properties and a durability test, to shed further light on the wood quality of these lesser-known timber species.

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