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Anatomical, physical, and mechanical properties of four pioneer species in Malaysia

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Abstract

The purpose of this study is to evaluate the anatomical, physical, and mechanical properties of four pioneer species, i.e., batai (*Paraserianthes moluccana)*, ludai (*Sapium baccatum*), mahang (*Macaranga gigantea*), and sesendok (*Endospermum malaccense*). Correlation of factors influencing density, shrinkage, and mechanical properties were also discussed. Samples were obtained from the Forest Research Institute Malaysia (FRIM) campus. From the result obtained, these four pioneer species characterised by medium-to-large vessel with absent of tyloses and gum deposit, fine ray, thin walled fibre, runkel ratio less than 1.0, low in density, and mechanical properties. Sesendok has significantly higher value in fibre length, fibre diameter, fibre lumen diameter, fibre wall thickness, vessel diameter, density, MOR, MOE, compression parallel to grain, and shear parallel to grain compared to the other three pioneer species which were 2001 µm, 45 µm, 35 µm, 5.1 µm, 300 µm, 514 kg/m^3, 79.5 N/mm^2, 9209 N/mm^2, 38.7 N/mm^2, and 10.1 N/mm^2, respectively. Between these four pioneer species, ludai has significantly higher in runkel ratio which was 0.57, whereas mahang shows significantly higher in slenderness ratio and number of vessels/mm^2 which were 50.2 and 5 vessel/mm^2, respectively. On the other hand, batai has higher tangential, radial and longitudinal shrinkage compared to ludai, mahang, and sesendok which were 3.0%, 2.4%, and 0.8%, respectively. Based on the basic property study, batai, ludai, mahang, and sesendok could be suitable for pulp and paper, plywood, light construction, furniture, interior finishing, and general utility. Fibre length, fibre wall thickness, and vessel diameter correlated significantly with density and mechanical properties. Shrinkage and mechanical properties were significantly influenced by density.

Keywords: Anatomical properties, Physical properties, Mechanical properties, Pioneer species, Correlation, Low density

Introduction

Pioneer species is seen as an alternative material to the depleting resources of commercial timber from natural forest. It grows on previously disturbed land, such as areas of clear cutting, damage by the elements of nature, or in former agricultural land. These species adapted well to nutrient-depleted soils and colonize them more easily than other species. They are also known as successional species and make the soil more livable for species that are not good colonizers by putting nutrients back into the soil and providing shade for other plants [1]. Information on the availability of pioneer species was obtained from the National Forest Inventory 4 Report for Peninsular Malaysia conducted by the Forest Department Peninsular Malaysia (JPSM) in 2000–2002 [2]. According to [1], pioneer species such as batai, ludai, mahang, and sesendok have potential for the cellulosic industry due to its fast growth, relatively free from common or major known pests and diseases, and yet produce acceptable wood.

Study on the anatomical, physical, and mechanical properties need to be done on the pioneer species to explore the suitability of these species for various applications in wood-based industry such as in pulp and paper and also in plywood industry where the demands on this product are increased. Anatomical properties study such as the cell structure and fibre morphology are very important to determine the different areas of application. As an example, fibre morphology is an indicator

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on the suitability of timber for pulp and paper products [3]. Besides that, fibre length and fibre wall thickness are also a determinant to predict the density and mechanical properties [4]. On the other hand, vessel size is related to the treatment ability, where large vessel indicates the easy treatment compared to small vessels [5].

Physical properties such as density and shrinkage are related to wood quality. Density is correlated with shrinkage, drying, machining, and mechanical properties [6, 7]. Shrinkage of wood is another important physical property noted by Kiaei [8]. It is necessary to have good understanding on the shrinkage behavior of wood, since this property is associated with effects such as warping, cupping, checking, and splitting that will contribute to the most troublesome physical properties of the wood [9]. Mechanical properties would affect the wood quality, characterised the suitability of wood for structural applications, and also can be used as an indicator to the quality of sawn lumber [10, 11].

The purpose of this study is to evaluate the anatomical, physical, and mechanical properties of four pioneer species, i.e., batai (*Paraserianthes moluccana)*, ludai (*Sapium baccatum*), mahang (*Macaranga gigantea*), and sesendok (*Endospermum malaccense*). These four pioneer species were selected in this study to meet the needs of the wood industry that requires continuous supply and short-term raw materials. Therefore, batai, ludai, mahang, and sesendok were selected for the study due to their fast growth in which in 10 years which they are able to harvest. Correlation factors influencing density, shrinkage, and mechanical properties were also presented. It is hoped that these basic properties will be useful to the wood-based industry to explore the suitable products from the pioneer timbers species.

Materials and methods

Preparation of materials

Samples of batai (*Paraserianthes moluccana)*, ludai (*Sapium baccatum*), mahang (*Macaranga gigantea*), and sesendok (*Endospermum malaccense*) were obtained from the Forest Research Institute Malaysia (FRIM) campus. The trees were planted at a spacing of 3 × 3 m. Three trees from each species which age of 14 years were felled at 15 cm above the ground. Two discs approximately 3 cm in thickness and billets of 2 m length were cut. Discs were assigned for two different studies, viz., for anatomical and physical properties study, and billets of 2 m long were used for mechanical property study [12].

Determination of anatomical properties

The anatomical feature study was conducted according to the method by Schweingruber and Schulze [13]. A wood block 10 × 10 × 10 mm was each taken from the wood disc. The blocks were boiled in distilled water until they were well soaked and sank. The sledge microtome was used to cut thin sections from the transverse, tangential, and radial surfaces of each block. The thickness of wood sections must be in the range of between 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. These sections were washed with 50% ethanol and dehydrated using a series of ethanol solutions with concentrations of 70%, 80%, 90%, and 95%. Then, one drop of Canada Balsam was placed on top of the section and covered with a cover slip. The slides were oven-dried at 60 °C for a few days.

The maceration technique was used to determine the fibre morphology [14]. A wood block split into matchstick size pieces before being macerated using a mixture of 30% hydrogen peroxide:glacial acetic acid at a ratio of 1:1 at 45 °C for 2 to 3 h until all of the lignin had dissolved and the cellulose fibres appeared whitish. Microscopic observations and measurement of the wood anatomical features were carried out using the light microscope. The descriptive terminology follows the International Association of Wood Anatomists (IAWA) List of Microscopic Features for Hardwood Identification [14]. For all the anatomical property measurements, there were 25 readings which were taken randomly for each species of batai, ludai, mahang, and sesendok. The Slenderness ratio (fibre length/fibre diameter) and Runkel ratio (2 × wall thickness/lumen diameter) [15, 16] were also calculated.

Determination of physical and mechanical properties

Physical properties were tested using British Standard 373:1957 Methods of Testing Small Clear Specimens of Timber [17]. Samples of size 20 mm in radial × 20 mm in longitudinal × 40 mm in tangential directions were cut from the woods for the analyses of density and shrinkage. Density was determined on the basis of oven dry weight and green volume. The shrinkage test was conducted in green to air-dry conditions. The tangential, radial, and longitudinal sections of each sample were marked and measured with a pair of digital vernier callipers (Mitutoyo) to the nearest 0.01 mm. A total of 90 specimens were used for each species of batai, ludai, mahang, and sesendok. Shrinkage was calculated using the following equations:

$$S_a(\%) = \frac{D_i - D_a}{D_i} \times 100,$$

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

Samples for mechanical properties were tested in accordance with British Standard 373:1957 Methods of Testing Small Clear Specimens of Timber [17].

Types of tests that were conducted: static bending of modulus of rupture (MOR) and modulus of elasticity (MOE), compression, and shear parallel to the grain. The standard dimensions for static bending test were 300 × 20 × 20 mm. Dimensions of 20 × 20 × 60 mm specimens were used for the test of compression parallel to the grain. Each specimen was placed in a vertical position. The dimensions of specimens for shear parallel to the grain were 20 × 20 × 20 mm. The direction of shearing was parallel to the longitudinal direction of the grain. The test was made on the tangential and radial planes of the sample. The total number of specimens was 90 for each species of batai, ludai, mahang, and sesendok. All tests were conducted using the 100 KN Shimadzu testing machine.

Statistical analysis

Statistical analysis was performed using Statistical Analysis System (SAS) version 9.1.3 software. Analysis of variance (ANOVA) was used to determine whether or not the differences in means were significant. If the differences were significant, 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 analysed using simple correlation analysis.

Results and discussion

Anatomical properties

Anatomical features of batai, ludai, mahang, and sesendok are shown in Figs. 1, 2, 3, and 4. The anatomical features of these four pioneer species are described for their identification and an important indication on the suitability of the timber for its potential usage. Figure 1 shows the anatomical features of batai. It shows that the vessels are predominantly solitary and in radial multiples of 2–4 with simple perforation. The tangential diameter ranges from 282 to 299 µm and the frequency is 1–3/mm^2. Tyloses and deposit are absent. The axial parenchyma is vasicentric and diffuse but visible as white dots in cross section when observe with a hand lens than in the microscope. Its rays are usually uniseriate although sometimes present as biseriates with cell height at 310–550 µm and homocellular with procumbent cells. Fibres are non-septate, while crystal is present in chambered axial parenchyma but silica grains absent.

Anatomical features of ludai (Fig. 2) show that the vessels are predominantly solitary and in radial multiples

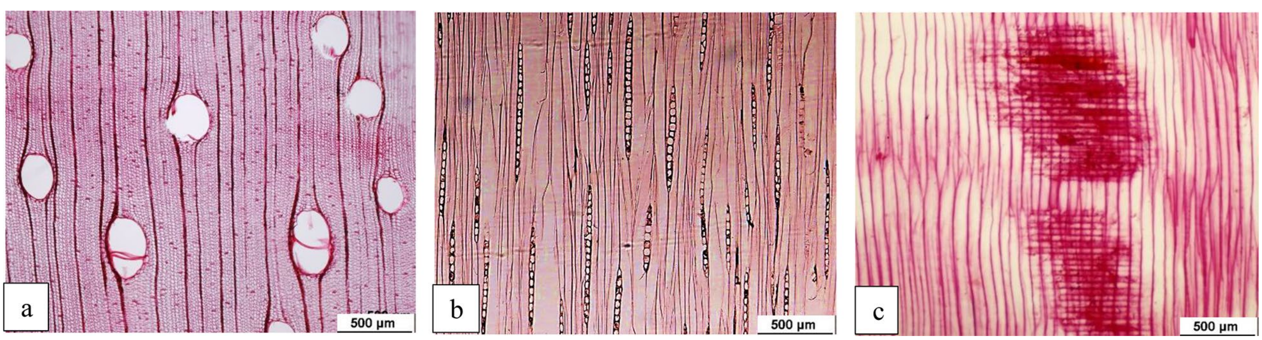

Fig. 1 Batai: (**a**) tranverse section, (**b**) tangential section, and (**c**) radial section

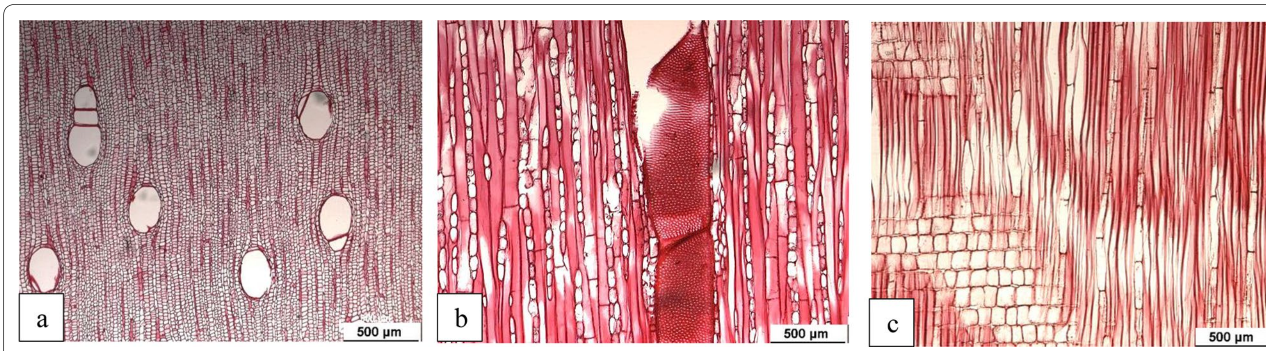

Fig. 2 Ludai: (**a**) tranverse section, (**b**) tangential section, and (**c**) radial section

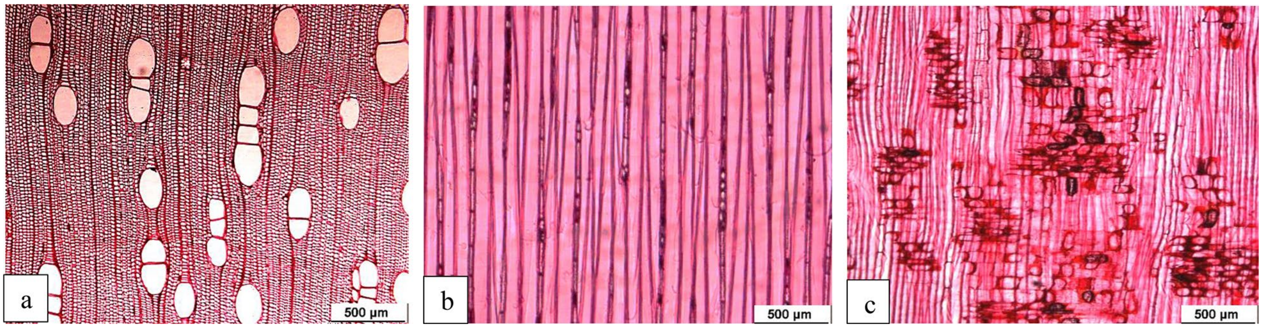

Fig. 3 Mahang: (**a**) tranverse section, (**b**) tangential section, and (**c**) radial section

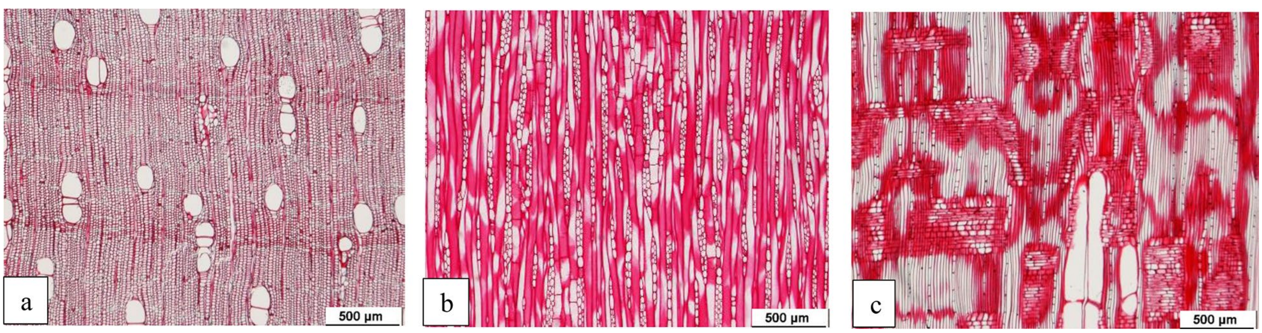

Fig. 4 Sesendok: (**a**) tranverse section, (**b**) tangential section, and (**c**) radial section

of 2–6 with simple perforation. The tangential diameter ranges from 243 to 257 µm and frequency is at 3–5/mm^2. Tyloses and deposit are absent. Axial parenchyma is irregularly wavy, narrow bands, more distinct with hand lens than in the microscope due to lack of contrast with fibres. Rays are exclusively uniseriate, height ranging from 2500 to 8000 µm, homocellular cells. Fibres are non-septate, while silica grains are present in rays and axial parenchyma.

Anatomical features of mahang (Fig. 3) show that the vessels are solitary and in radial multiples of 2–3 with simple perforations. Tangential diameter ranges from 155 to 167 µm and frequency 4–7/mm^2. Tyloses and deposit are absent. Axial parenchyma is in narrow bands. Rays 1–3 seriate, height ranging from 1700 to 3100 µm, heterocellular with procumbent and upright cells. Fibres are non-septate. Crystal is often present in rays or axial parenchyma. Silica grain is absent.

Anatomical features of sesendok (Fig. 4) show that the vessels are predominantly in radial pairs and multiples of 2–7 in a series and occasional clusters with simple perforation. Tangential diameter ranges from 291 to 309 µm and the frequency is 1–3/mm^2. Tyloses and deposit are distinctly absent. Axial parenchyma is regularly spaced apotracheal bands, more distinct with hand lens than observing under the microscope. Rays are 1–2 seriate, height of 500–1500 µm, heterocellular with procumbent and upright cells. The fibres are non-septate, while crystal and silica grains are absent.

Table 1 summarizes the result of anatomical properties of batai, ludai, mahang, and sesendok with comparison to other well-known plantation timbers. Results showed that the fibre lengths are significantly different at ($p \leq 0.05$), with sesendok having the longest fibre as compared to the other three pioneer species. This present result is similar with the finding by [18] who also found in his study that sesendok has the longest fibre which is very long for hardwood and could be suitable for the pulp and paper. In comparison to other well-known plantation timbers, i.e., rubberwood (*Hevea brasiliensis*) and *Eucalyptus grandis*, these four pioneer species show comparable value in terms of fibre length. The fibre wall of sesendok is the thickest at 5.1 µm followed by mahang, ludai, and batai. Fibre wall thickness of these four pioneer species categorised as very thin fibre walled which is the fibre lumen is three times wider than the double wall thickness. Runkel ratio of batai, ludai, mahang, and sesendok is less than 1.0 which were 0.27, 0.57, 0.38, and 0.28, respectively, whilst the slenderness ratio for batai, ludai, mahang, and sesendok were 36.4, 43.2, 50.2, and 45.6, respectively. On the other hand, vessel diameter of batai, ludai, and sesendok is categorised as large with

Table 1 Anatomical properties of batai, ludai, mahang, and sesendok in comparison with other well-known plantation timbers

Species	Fibre length (μm)	Fibre diameter (μm)	Fibre lumen diameter (μm)	Fibre wall thickness (μm)	Runkel ratio	Slenderness ratio	Vessel diameter (μm)	Number of vessels/mm^2
Batai	1182[d]	33[c]	27[c]	3.0[c]	0.27[c]	36.4[c]	290[a]	2[b]
(Paraserianthes *moluccana*)	(116)	(5.2)	(5.4)	(1.4)	(0.13)	(4.8)	(8.5)	(0.5)
Ludai	1512[c]	37[b]	23[d]	3.0[c]	0.57[a]	43.2[b]	250[b]	4[a]
(Sapium baccatum)	(188)	(7.5)	(6.3)	(1.2)	(0.21)	(8.0)	(7.2)	(1.2)
Mahang	1660[b]	39[b]	30[b]	4.4[b]	0.38[b]	50.2[a]	161[c]	5[a]
(*Macaranga gigantea*)	(256)	(8.0)	(6.1)	(1.5)	(0.26)	(6.7)	(6.2)	(1.0)
Sesendok	2001[a]	45[a]	35[a]	5.1[a]	0.28[c]	45.6[b]	300[a]	2[b]
(*Endospermum malaccense*)	(129)	(4.6)	(3.8)	(0.8)	(0.10)	(4.5)	(8.9)	(0.8)
Rubberwood*	1249	29.6	20.3	4.7	–	–	177	5
(*Hevea brasiliensis*)								
Eucalyptus grandis **	1110	22	14	4.0	0.56	42.6-59.8	141	6

Values in parentheses are standard deviations. Cell values differing by a letter (a,b,c,d) in the superscript in each column are significantly different at the 0.05 probability level

*[41], ** [22]

sesendok having the significantly largest vessel diameter. Vessel diameter for mahang is the smallest as compared to the other three pioneer species and categorised as medium-sized vessel. A number of vessels present for these four pioneer species are categorised as very few.

The suitability of the timber for papermaking is based on the runkel ratio. Fibres with a runkel ratio of less than 1.0 are suitable for use as pulp with good strength properties [3]. High runkel ratio indicates inferior raw material for papermaking where the fibre is stiff, less flexible and forms bulkier paper with lower bonded area [19]. Based on the result obtained (Table 1), the mean runkel ratios of all four pioneer species studied were less than 1.0, indicating that the fibres from the timber would produce good quality paper. Besides that, the tearing strength and folding endurance of paper are indicated by the slenderness ratio [20]. Larger slenderness ratio results are better for paper making where it indicates a better formed and well-bonded paper [19, 21]. Present results showed that the slenderness ratio of the four pioneer species is in the range of 36.4–50.2. This result is comparable to the study for *Eucalyptus grandis,* as shown in Table 1, which ranges from 42.6 to 59.8 [22]. Batai, ludai, mahang, and sesendok also show thin fibre wall and large fibre lumen diameter which, according to [5] this features, contributes to the good adhesive penetration.

Observation on the anatomical features of the four pioneer species shows that all the timbers can be categorised as having medium-to-large vessel according to the vessel category by [14]. Karl [23] stated that wood species with medium-to-large vessel may not be good for printing papers, while [24] reported that generally species with medium-to-large pores are light with course texture which is suitable for general usage. These four pioneer species have larger vessel, absent of tylosis, and gum deposit, which have uniseriate and fine rays which according to [5, 25, 26], and these characteristics make them easy to be impregnated to enhance the wood properties. The absence of gum deposits in batai, ludai, mahang, and sesendok would also make these timbers suitable for veneering into plywood. Adeniyi et al. [5] further reported that timber for plywood should be free from gum deposits as it would interfere with wood gluability. The anatomical features show that these four pioneer species mostly have uniseriate rays which could contribute to the excellent nailing property. As reported by [27], wood with multiseriate rays is poor in nailing property as it has a tendency to split when nailed. However, the presence of silica in ludai would cause a blunting effect on sawteeth. This is also reported by [28] where silica that present in *Coelostegia griffithii* and *Durio griffithii* cause a blunting effect on sawteeth.

Physical and mechanical properties

Results of physical and mechanical properties are tabulated in Table 2. Based on the density, batai, ludai, mahang, and sesendok are classified as light timber, which are comparable to rubberwood and *Eucalyptus grandis*. From the result obtained, sesendok has the highest density, followed by mahang, ludai, and batai. From

Table 2 Physical and mechanical properties of batai, ludai, mahang, and sesendok in comparison with other well-known plantation timbers

Species	Density (kg/m^3)	*T*	*R*	*L*	MOR (Nm m^{-2})	MOE (Nm m^{-2})	Compression parallel to grain (Nm m^{-2})	Shear parallel to grain (Nm m^{-2})
Batai	293^d	3.0^a	2.4^a	0.8^a	36.9^d	5143^d	22.9^c	5.8^d
(Paraserianthes *moluccana*)	(78.0)	(0.9)	(0.9)	(0.4)	(14.1)	(1453)	(4.8)	(1.3)
Ludai	438^c	2.4^b	1.1^c	0.3b	65.9^c	7582^c	32.0^b	7.6^c
(Sapium baccatum)	(38.0)	(0.6)	(0.3)	(0.1)	(7.5)	(885.3)	(2.8)	(1.3)
Mahang	493^{ab}	2.4^b	1.5^b	0.5^b	74.0^b	8056^b	32.4^b	8.7^b
(*Macaranga gigantea*)	(35.0)	(0.6)	(0.8)	(0.1)	(9.0)	(938)	(3.9)	(1.4)
Sesendok	514^a	2.7^{ab}	1.7^b	0.8^a	79.5^a	9209^a	38.7^a	10.1^a
(*Endospermum malaccense*)	(50.5)	(0.8)	(0.8)	(0.3)	(8.8)	(1229)	(3.4)	(1.9)
Rubberwood* (*Hevea brasiliensis*)	503-553	–	–	–	81.3	8564	33.6	12.5
Eucalyptus grandis **	517	–	–	–	84.0	8412	52.0	8.0

Values in parentheses are standard deviation. Cells value differing by a letter (a,b,c,d) in the superscript in each column are significantly different at the 0.05 probability level

T tangential, *R* radial, *L* longitudinal

* [27], ** [42, 43]

this result, the trend of density in four pioneer species could be related with the fibre length, fibre wall thickness, and vessel diameter. Longest fibre and thickest fibre wall found in sesendok (Table 1) are directly related to the highest density among the four species studied. On the other hand, batai has the shortest, thinnest fibre, and large vessel diameter (Table 1) which contribute to the lower density. Similar result was also reported by [29] and [30] where density is correlated to the fibre length, fibre wall thickness, and vessel diameter.

In terms of shrinkage (Table 2), batai and sesendok have the highest shrinkage for tangential, radial, and longitudinal. Ludai and mahang shows no significant difference in tangential and longitudinal shrinkage between them. Percentage of shrinkage for sesendok and batai are rated as high, whilst ludai and mahang rated as average. The shrinkage rating is based on the percentage shrinkage of tangential from green to air dry as reported by [31]. The Sesendok shows significantly higher value in MOR, MOE, compression, and shear parallel to grain, followed by mahang, ludai, and the lowest mechanical properties of batai. Van Gelder [32] reported that pioneer species had a significantly lower wood density, MOR, and compression strength.

Correlation factors influencing density, shrinkage, and mechanical properties

Table 3 presented the correlation factors influencing density, shrinkage, and mechanical properties of batai, ludai, mahang, and sesendok. Based on the results, density was positively correlated with fibre length except in batai, where the correlation is moderate-to-strong. Fibre diameter is weakly correlated with density in batai ($r = 0.229$) and mahang ($r = 0.325$). Density is positively correlated with fibre wall thickness in all species study with weak-to-moderate correlation. Vessel diameter also significantly correlates with the density with negative and weak-to-moderate correlation in all species. In terms of shrinkage, it shows significantly correlation with fibre length and fibre wall thickness in batai, ludai, mahang, and sesendok. Shrinkage is highly affected by density compared to other anatomical properties with positive and very weak-to-very strong correlation in all species. On the other hand, mechanical properties are significantly correlated with fibre length, fibre wall thickness, and vessel diameter with positive correlation in batai, ludai, mahang, and sesenduk. Among the properties, density is the best factor to be correlated with MOR, MOE, compression parallel to grain, and shear parallel to grain which shows positive and weak-to-strong correlation. Fibre dimeter and fibre lumen diameter are also significantly correlated with some properties, as shown in Table 3.

This study found the anatomical properties that significantly affect the density and mechanical properties are fibre length, fibre wall thickness, and vessel diameter. Similar findings were also observed by [4, 33] in *Pseudolachnostylis maprounaefolia* and *Azadirachta excelsa,* respectively. [5] further stated that strong wood has smaller size of vessel diameter and thick fibre wall. On the other hand, shrinkage was affected significantly by the anatomical properties, namely, fibre length and fibre wall thickness. Significant correlation of fibre with

Table 3 Correlation factors influencing density, shrinkage and mechanical properties of batai, ludai, mahang, and sesendok

Species	*P*	Density	*T*	*R*	*L*	MOR	MOE	*C*	*S*
Batai	FL	0.079 ns	− 0.701**	− 0.537**	− 0.231*	0.401**	0.332**	0.562**	0.266*
	FD	0.229*	0.357**	0.019 ns	0.396**	0.109 ns	0.033 ns	0.091 ns	0.041 ns
	FLD	− 0.429**	− 0.244*	− 0.361**	− 0.106 ns	− 0.008 ns	− 0.013 ns	− 0.640**	− 0.102 ns
	CWT	0.385**	0.099 ns	0.227*	0.267*	0.342**	0.380**	0.440**	0.223*
	VD	− 0.250*	0.100 ns	0.100 ns	0.217*	− 0.397**	− 0.332*	− 0.018 ns	− 0.288*
	VF	0.029 ns	0.024 ns	0.430**	− 0.040 ns	− 0.088 ns	− 0.018 ns	− 0.093 ns	− 0.024 ns
	Density	1	0.131*	0.317**	0.387**	0.253*	0.603**	0.262*	0.310**
Ludai	FL	0.680**	− 0.260*	− 0.016 ns	− 0.370**	0.259*	0.378**	0.333**	0.454**
	FD	0.025 ns	0.083 ns	0.221*	0.478**	0.066 ns	0.401**	0.085 ns	0.551**
	FLD	− 0.063 ns	− 0.081 ns	− 0.359**	− 0.037 ns	− 0.013 ns	− 0.108 ns	− 0.026 ns	− 0.404**
	CWT	0.418**	0.067 ns	0.116*	0.801**	0.399**	0.336**	0.362**	0.380**
	VD	− 0.221*	0.482**	0.066 ns	0.071 ns	− 0.195*	− 0.082 ns	− 0.262*	− 0.169*
	VF	0.062 ns	0.052 ns	0.020 ns	− 0.559**	− 0.077 ns	− 0.078 ns	− 0.025 ns	− 0.017 ns
	Density	1	0.243*	0.294*	0.153*	0.528**	0.550**	0.585**	0.721**
Mahang	FL	0.468**	− 0.221*	− 0.052 ns	− 0.370**	0.352**	0.258*	0.205*	0.242*
	FD	0.325**	0.042 ns	0.108 ns	0.395**	0.092 ns	0.103 ns	0.106 ns	0.082 ns
	FLD	− 0.080 ns	− 0.778**	− 0.763**	− 0.020 ns	− 0.043 ns	− 0.101 ns	− 0.287*	− 0.095 ns
	CWT	0.504**	0.673**	0.784**	0.205*	0.211*	0.239*	0.373**	0.268*
	VD	− 0.360**	0.558**	0.658**	0.034 ns	− 0.370**	− 0.138*	− 0.221*	− 0.146*
	VF	0.060 ns	0.078 ns	0.069 ns	− 0.040 ns	− 0.103 ns	− 0.081 ns	− 0.257*	− 0.089 ns
	Density	1	0.189*	0.204*	0.370**	0.330**	0.219*	0.576**	0.320**
Sesendok	FL	0.488**	− 0.213*	− 0.522**	− 0.379**	0.221*	0.234*	0.323**	0.198*
	FD	0.035 ns	0.092 ns	0.106 ns	0.078 ns	0.043 ns	0.040 ns	0.060 ns	0.086 ns
	FLD	− 0.027 ns	− 0.050 ns	− 0.015 ns	− 0.070 ns	− 0.022 ns	− 0.047 ns	− 0.032 ns	− 0.025 ns
	CWT	0.413**	0.358**	0.344*	0.416**	0.212*	0.310**	0.322**	0.267*
	VD	− 0.484**	0.072 ns	0.320*	0.057 ns	− 0.215*	− 0.197*	− 0.215*	− 0.106 ns
	VF	0.077 ns	0.378*	0.400*	− 0.106 ns	− 0.010 ns	− 0.011 ns	− 0.026 ns	− 0.012 ns
	Density	1	0.521**	0.335*	0.879**	0.770**	0.424**	0.353**	0.387**

25 readings were taken randomly for each species of batai, ludai, mahang, and sesendok for the anatomical properties measurements

90 specimens were used for each species of batai, ludai, mahang, and sesendok for physical and mechanical properties

T tangential, *R* radial, *L* longitudinal, *FL* fibre length, *FD* fibre diameter, FLD fibre lumen diameter, *CWT* fibre wall thickness, *VD* vessel diameter, *VF* number of vessels per mm^2, *C* compression parallel to grain, *S* shear parallel to grain, *P* properties

* Significant at $p \leq 0.05$, ** significant at $p \leq 0.01$, ns not significant

shrinkage was also reported by [34] in *Gmelina arborea*. Based on the result obtained (Table 3), the number of vessels per mm^2 does not significantly influenced the density, shrinkage, and mechanical properties which was also confirmed by [4].

Thus, it can be inferred from the results of this study that shrinkage and mechanical properties are highly dependence on density. Wood with higher density has higher shrinkage and mechanical properties. This is in good agreement with [35–37] who also reported significant relationship between density and shrinkage in *Melia azedarach*, *Azadiractha indica*, and *Pinus pinaster*, respectively. Whilst, correlation between density and mechanical properties was also observed by [38–40] in *Acacia mangium*, *Acacia melanoxylon*, and *Tectona grandis*, respectively.

Conclusions

Based on the result obtained, sesendok have the largest vessel, longest and thickest fibre, highest in density, and mechanical properties compared to batai, ludai, and mahang. These four pioneer species could be suitable for pulp and paper, since they have longer fibre and a runkel ratio less than 1.0. The absence of gum deposit made the timbers suitable for plywood. Besides that, these four pioneer species have low density and mechanical properties which makes them suitable for light construction, furniture, interior finishing, and general utility. Batai, ludai, mahang, and sesendok have excellent nailing property and could be easily treated. In terms of correlation, fibre length, fibre wall thickness, and vessel diameter are significantly correlated to density and mechanical properties. In this present study, density is a good indicator for predicting shrinkage and mechanical properties. Generally, batai, ludai, mahang, and sesendok could be a promising timber species as an alternative material to the depleting resources of commercial timber.

Abbreviations
MOR: modulus of rupture; MOE: modulus of elasticity.

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Authors' contributions
All authors have participated sufficiently in the study of wood properties and are responsible for the entire contents. The author read and approved the final manuscript.

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Competing interests
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