Qualitative and Quantitative Anatomical Characteristics of Four Tropical Wood Species from Moluccas, Indonesia

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Original Article

Qualitative and Quantitative Anatomical Characteristics of Four Tropical Wood Species from Moluccas, Indonesia[1]

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ABSTRACT

The objective of this study was to compare the wood anatomical characteristics of local tree species in Moluccas, Indonesia *i.e.*, Moluccan ironwood (*Intsia bijuga*), linggua (*Pterocarpus indicus*), red meranti (*Shorea parvifolia*), and gofasa (*Vitex cofassus*). Qualitative evaluation was conducted by observing the anatomical structure in cross, radial, and tangential sections of each sample. For the quantitative evaluation, the dimensions of vessels, rays, and fibers were measured. Qualitative evaluation showed that crystals were observed in Moluccan ironwood, linggua, and gofasa, while resin canals were only observed in red meranti. Tyloses were frequently observed in gofasa but infrequently observed in linggua and red meranti. Quantitative evaluation showed that Moluccan ironwood with the higher density had thicker fiber wall, higher quantity of ray number, and wider rays than the other species. Red meranti had higher values of ray height and fiber length than the other three species. The results also revealed that linggua showed the highest values of relative crystallinity and crystallite width. Red meranti and gofasa showed similar values of relative crystallinity and crystallite width, while Moluccan ironwood showed the lowest values. The basic qualitative and quantitative anatomical characteristics discussed could provide useful information for further utilizations of such wood species.

Keywords : anatomical characteristics, *Intsia bijuga*, Moluccan woods, *Pterocarpus indicus*, *Shorea parvifolia*, *Vitex cofassus*

1. INTRODUCTION

Moluccas (Indonesian Maluku) is located in the east part of Indonesia. In the Dutch era it was also known as the Spice Islands where nutmeg, mace, cloves and several other valuable spices were grown. Moluccas forest areas cover 5% (6.43 million ha) of the permanent forest (128.22 million ha) of Indonesia (Ministry of Environment and Forestry, Republic of

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Indonesia, 2015). The permanent forest areas of Moluccas are classified based on their main functions, *i.e.* conservation forest of 0.64 million ha, protection forest of 1.21 million ha, production forest of 2.69 million ha and conversion forest of 1.89 million ha (Ministry of Environment and Forestry, Republic of Indonesia, 2015). The forests in Moluccas are the home of valuable woods from the family of *Fabaceae*, *Calophyllaceae*, *Ebenaceae*, *Dipterocarpaceae, etc*.

Moluccan ironwood (*Intsia bijuga*), linggua (*Pterocarpus indicus*), red meranti (*Shorea parvifolia*), and gofasa (*Vitex cofassus*) are some of the important wood species in Moluccas. Moluccan ironwood is a slow growing hardwood tree which produces valuable timbers due to its beautiful color and texture (Soerianegara and Lemmens, 1993; Hu *et al.*, 2012). The wood is dense and has excellent durability, dimensional stability, and strength properties making it ideally suited for use as wood flooring and other outdoor applications (Marler, 2015; Hsiao *et al.*, 2016; Liao *et al.*, 2016). The ironwood trees are also planted in soil conservation projects due to its ability to fix nitrogen even in a highly saline mangrove environment (Eganathan *et al.*, 2000).

Linggua trees grow extensively in Philippines, New Guinea, Malaysia, and Indonesia. In Indonesia it is distributed in Moluccas, Java, Sulawesi, Bali, West and East Tenggara, and Papua (Orwa *et al.*, 2009). The tree is adaptable to a wide range of soil types including infertile, alkaline, stony soils to deep, fertile, loamy, alluvial soils (Lim, 2014). The wood has straight or irregularly wavy grain and sometimes forms a rare and valuable burl form known as Amboyna burl that is often used for high-class furniture, cabinets and decorative sliced veneer. The wood contains antifungal compounds but the resistance against termite is considered low to moderately resistant (Kusuma *et al.*, 2004; Febrianto *et al.*, 2015).

Red meranti is a native tree species of Southeast Asia occurring in the rainforests of Malaysia, Indonesia and the Philippines (Appanah and Turnbull, 1998). The tree is a relatively slow growing species. In intensively managed forest plantations, the annual diameter increment in red meranti is between 1.17-1.20 cm hence a rotation of 30 years is feasible for the production of commercial logs (Appanah and Weinland, 1993). The species is one of the most economically important woods in the *Dipterocarpaceae* family which is often used to make furniture, veneers, plywood, and other high value wood products (Widiyatno *et al.*, 2016).

Gofasa is native to Fiji, Indonesia, Malaysia, Papua New Guinea, Thailand, Vietnam (Orwa *et al.*, 2009). The wood is very strong and durable but difficult to treat with preservatives. Gofasa tree produces highly valued timber that is generally used for house construction, boats and domestics utensils such as bowls and platters.

Our previous investigations have reported the anatomical characteristics of fast growing species from Indonesia (Kim *et al.*, 2012), includ-

Table 1. General information on wood samples

Common name	Scientific name	Botanical family	Density (g/cm^3)	Shrinkage (%)	
				R	T
Moluccan ironwood	*Intsia bijuga* (Colebr.) Kuntze	Fabaceae	1.02	4.30	7.70
Linggua	*Pterocarpus indicus* Willd.	Fabaceae	0.64	2.90	5.00
Red meranti	*Shorea parvifolia* Dyer	Dipterocarpaceae	0.51	3.20	9.70
Gofasa	*Vitex cofassus* Reinw. ex Blume	Lamiaceae	0.79	4.20	8.00

Notes: R= radial direction, and T= tangential direction.

ing the physical, mechanical, combustion, natural durability, and weathering properties (Kim *et al.*, 2014; Park *et al.*, 2015; Febrianto *et al.*, 2015; Park *et al.*, 2016; Hidayat *et al.*, 2017). In this paper we discuss the qualitative and quantitative anatomical characteristics of four slow growing species from Indonesia as Moluccan ironwood, linggua, red meranti, and gofasa. The information and technical reports on the anatomical characteristics of the four wood species are available in some publications and online database (Soerianegara and Lemmens, 1993; Hillis, 1996; Richter and Dallwitz, 2000; Ogata *et al.*, 2008). However, they mostly discussed the qualitative anatomical characteristics of the woods. Therefore this study is important in providing the information on both the qualitative and quantitative anatomical characteristics of the woods for further development of woody bio-resources.

2. MATERIALS and METHODS

2.1. Materials

Four tropical hardwood species *i.e.* Moluccan ironwood, linggua, red meranti, and gofasa were used for this study. The scientific names, botanical families and some physical properties of the specimens used in this study are given in Table 1. The samples of the four wood species were obtained from the forest in Moluccas Island, Indonesia (3°42'18"S 128°10'12"E). The samples were conditioned at room temperature of 25℃ and a relative humidity of 65% for 2 weeks prior to evaluation of their properties.

2.2. Methods

2.2.1. Anatomical Characteristics

For the evaluation of anatomical characteristics, the wood samples were cut into small blocks. The blocks were then sliced using a sliding microtome (Nippon Optical works, Japan.) in cross, radial, and tangential sections with the thickness of 10-15 μm. The wood slices were then stained with safranin-astra blue according to the methods in the previous study (Qi *et al.*, 2016). After staining, slices were dehydrated by a series of alcohol (50%, 70%, 90%, 95% and 99%). Then, mounted sections with Canada balsam were observed by an optical microscope (Nikon Eclipse, E600).

For the qualitative evaluation, the wood struc-

tures in cross, radial, and tangential sections of each sample were observed. For the quantitative evaluation, the anatomical characteristics such as number and diameters of vessels, number, width, and height of rays, fiber wall thickness and length were measured and compared with the IAWA hardwood feature list (Wheeler *et al.*, 1989) using Total Imaging Isolation (IMT, I-solution Lite). Thirty random measurements were taken for each character to obtain a mean value.

For SEM observation, samples were cut with dimension of 5 × 5 × 5 mm^3, air-dried and coated with gold using a Gressington sputter coater (ULVAC G-50DA, Japan) and observed with a scanning electron microscope (JSM-5510, Japan).

2.2.2. Crystalline Characteristics

An X-ray diffractometer (Rigaku DMAX2100V, Japan) equipped with a Cu target (λ = 0.1542 nm) was used for measuring the crystalline properties, at 40 kV and 40 mA. The relative crystallinity and crystallite width were calculated by Segal's method (Segal *et al.*, 1959) and Scherrer's equations (Alexander *et al.*, 1969), respectively.

3. RESULTS and DISCUSSION

3.1. Qualitative Anatomical Characteristics

3.1.1. Moluccan Ironwood

Moluccan ironwood had diffuse-porous with the vessels of solitary or radial multiples of 2-3 cells (Fig. 1A). The axial parenchyma aliform and confluent with broad wings and crystalliferous cells were present in the periphery of axial parenchyma (Fig. 1B). In radial section large amounts of crystals were observed in axial parenchyma (Fig. 1C), similar to the observation by Hillis (1987). Hillis (1996) also reported that the crystals contained in some vessels are a unique feature of the genus of Intsia, including *Intsia bijuga* and *Instia palembanica*. In addition, the specific crystals were reported as yellow crystals of pure robinetin (a flavonol). Ray cells mostly displayed the procumbent form. Vessel perforation plates were simple with alternated intervessel pits (Fig. 1D). The wood rays consisted mostly of 1-2- or 1-4-seriate cells (Fig. 1E). Inclusions were also found in the vessels on cross, radial, and tangential sections (Fig. 1B, D, F). The characteristics of Moluccan ironwood are in complete agreement with those observed in previous studies (Richter and Dallwitz, 2000; Ogata *et al.*, 2008).

3.1.2. Linggua

Linggua showed diffuse-porous and/or semi-ring porous (Fig. 2A). Axial parenchymas were present with bands or without bands. Vessels were solitary and radial multiple of 2-3 vessels. Tyloses were observed in the vessels but were infrequent (Fig. 2B). Ogata *et al.* (2008) also reported that tyloses were infrequently observed in the vessels of linggua. Crystals were observed in the axial parenchyma (Fig. 2C, D). Richter and Dallwitz (2000) reported the existence of crystals in the apo-

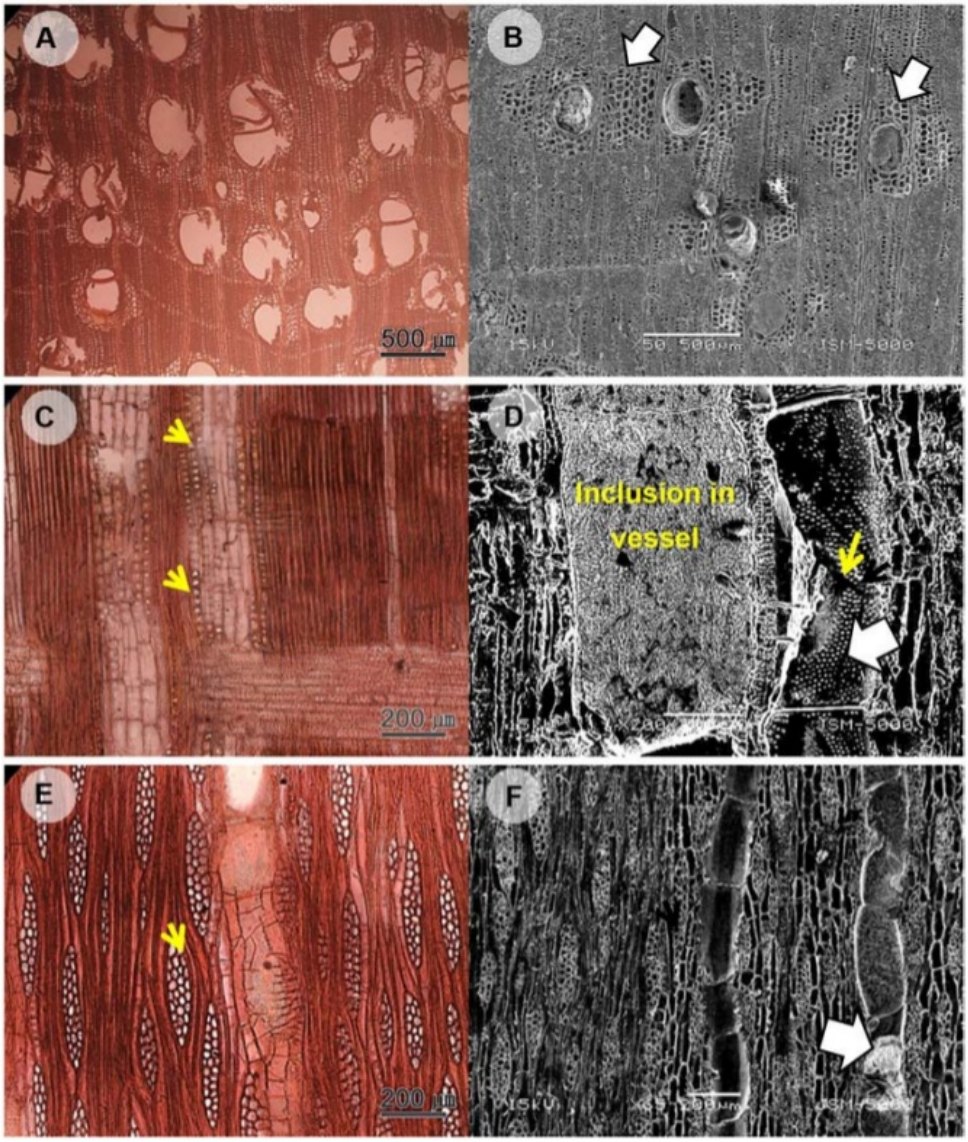

Fig. 1. Optical (left) and scanning electron micrographs (right) of Moluccan ironwood: (A) diffuse-porous; (B) arrows show axial aliform and confluent parenchyma with broad wings; (C) arrows show crystals in axial parenchyma; (D) inclusion in vessel; simple perforation (white arrow) and alternated intervessel pits (yellow arrow); (E) rays composition; (F) arrow shows inclusion in vessel.

trachealaxial parenchyma. Ogata *et al.* (2008) also observed crystals in chambered axial parenchyma cells and scattered crystals among fibers and parenchyma. However they could not observe crystals in rays. Ray cells were of the procumbent form (Fig. 2C). Ray width was ex-

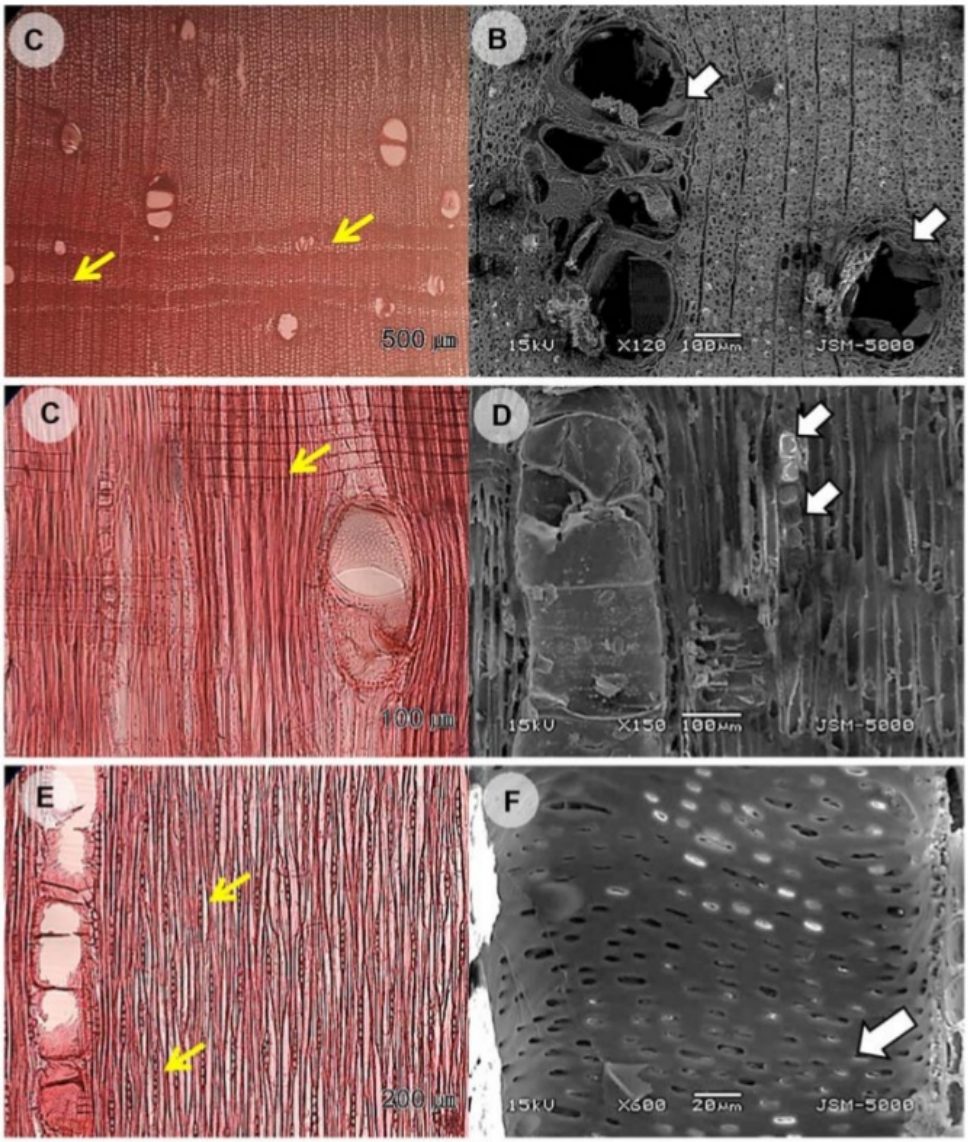

Fig. 2. Optical (left) and scanning electron micrographs (right) of linggua: (A) banded axial parenchyma (arrows); (B) tyloses in the vessels; (C) procumbent form of ray cells; (D) arrows show crystals in axial parenchyma; (E) ray composition exclusively uniseriate; (F) arrows show alternated intervessel pits with coalescent apertures.

clusively uniseriate (Fig. 2E). Perforation plates were simple with alternated intervessel pits (Fig. 2D, F).

3.1.3. Red Meranti

Red meranti had diffuse-porous with the vessels were arranged in no specific pattern; some

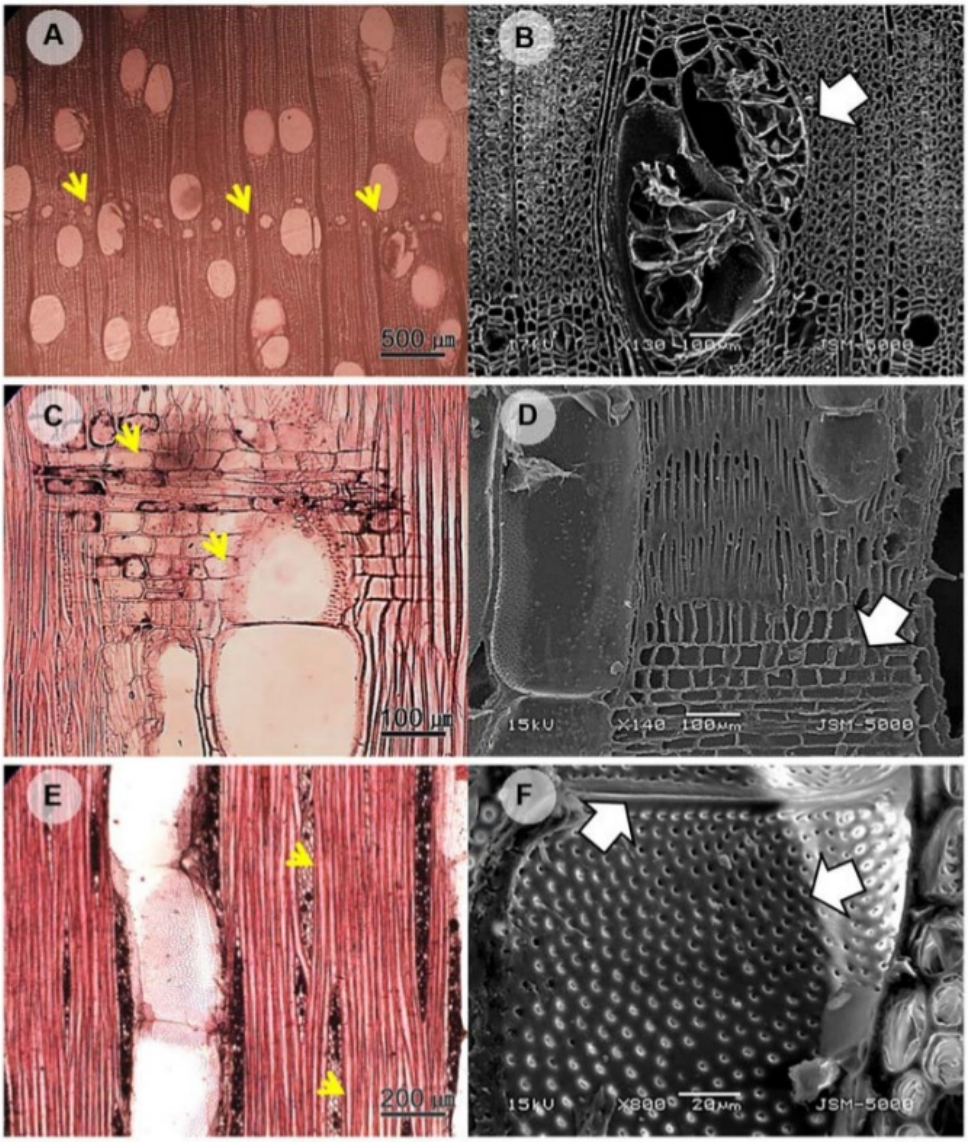

Fig. 3. Optical (left) and scanning electron micrographs (right) of red meranti: (A) axial resin canals in a concentric line; (B) tyloses in the vessels; (C, D) ray composition in radial section; (E) arrows show rays with 2-6-seriate cells; (F) simple vessel perforation with alternated intervessel pits.

were solitary and radial multiples of 2-3 cells (Fig. 3A, 3B). Axial resin canals in a concentric line were observed. Sass *et al.* (1995) also observed similar characteristics in *Shorea leprosula.* They observed abundant resin canals mostly in tangential bands together with parenchyma, thus giving the impression of growth boundaries. Ray cells displayed the procumbent

Table 2. Quantitative anatomical characteristics of the four Moluccan wood species

Characteristics	Species				IAWA list
	Moluccan ironwood	Linggua	Red meranti	Gofasa	
Vessel number/mm^2	2.2 (0.9)*	1.9 (0.8)*	2.0 (0.8)*	16.3 (2.4)**	*Feature 46: ≤ 5 per mm2 **Feature 47: 5-20 per mm^2
Vessel diameter (μm)	223.5 (19.3)**	196.4 (16.4) *	249.8 (16.6)**	143.8 (24.2)*	*Feature 42: 100-200 μm **Feature 43: ≥ 200 μm
Ray number/mm^2	9.5 (1.5)**	4.8 (1.2)**	2.4 (0.9)*	9.6 (1.7)**	*Feature 114: ≤ 4 per mm^2 **Feature 115: 4-12 per mm^2
Ray width (μm)	65.6 (7.1)	12.7 (2.3)	52.7 (3.7)	37.5 (6.2)	-
Ray width	1-3**	uniseriate*	2-6***	1-3**	*Feature 96: ray exclusively uniseriate **Feature 97: 1 to 3 cells ***Feature 98: 4- to 10-seriate
Ray height (μm)	421.9 (88.9)	160.1 (15.6)	760.1 (137.7)	321.1 (100.6)	-
Fiber wall thickness (μm)	10.2 (1.9)	7.1 (3.2)	8.1 (2.4)	8.7 (1.6)	-
Fiber length (μm)	1318.6 (90.8)	901.8 (75.7)	1457.4 (94.8)	1108.6 (47.9)	Feature 72: 900-1600 μm

and square form (Fig. 3C). Tyloses were present but infrequently observed (Fig. 3D). The wood rays were 2-6 cells wide (Fig. 3E). Vessel perforation plates were simple with alternated intervessel pits (Fig. 3F).

3.1.4. Gofasa

Gofasa had diffuse-porous (Fig. 4A). The vessels were arranged in no specific pattern, including solitary and radial multiples of 2-4 cells. Abundant tyloses were observed in vessels (Fig. 4B). Tyloses affected the permeability of wood which resulted in difficulty drying and preservative impregnation (Shmulsky and Jones, 2011). The existence of tyloses is the reason why gofasa is preferred for traditional boat building in Sulawesi, Indonesia (Kurniawan, 2013). Ray cells displayed the procumbent form (Fig. 4C). Radial section also showed the presence of small crystals in ray cells (Fig. 4D), which had also been observed in the previous studies (Richter and Dallwitz, 2000; Ogata *et al.*, 2008). The wood rays consisted of 1-2- to 1-3-seriate (Fig. 4E, F). Vessel perforation plates were simple with alternated intervessel pits.

3.2. Quantitative Anatomical Characteristics

The quantitative anatomical characteristics of the four wood species are summarized in Table 2. Gofasa had the most vessel number per mm^2, while Moluccan ironwood, linggua, and red meranti had a similar vessel number. Moluccan ironwood, linggua, and red meranti also had similar values of vessel diameter which were

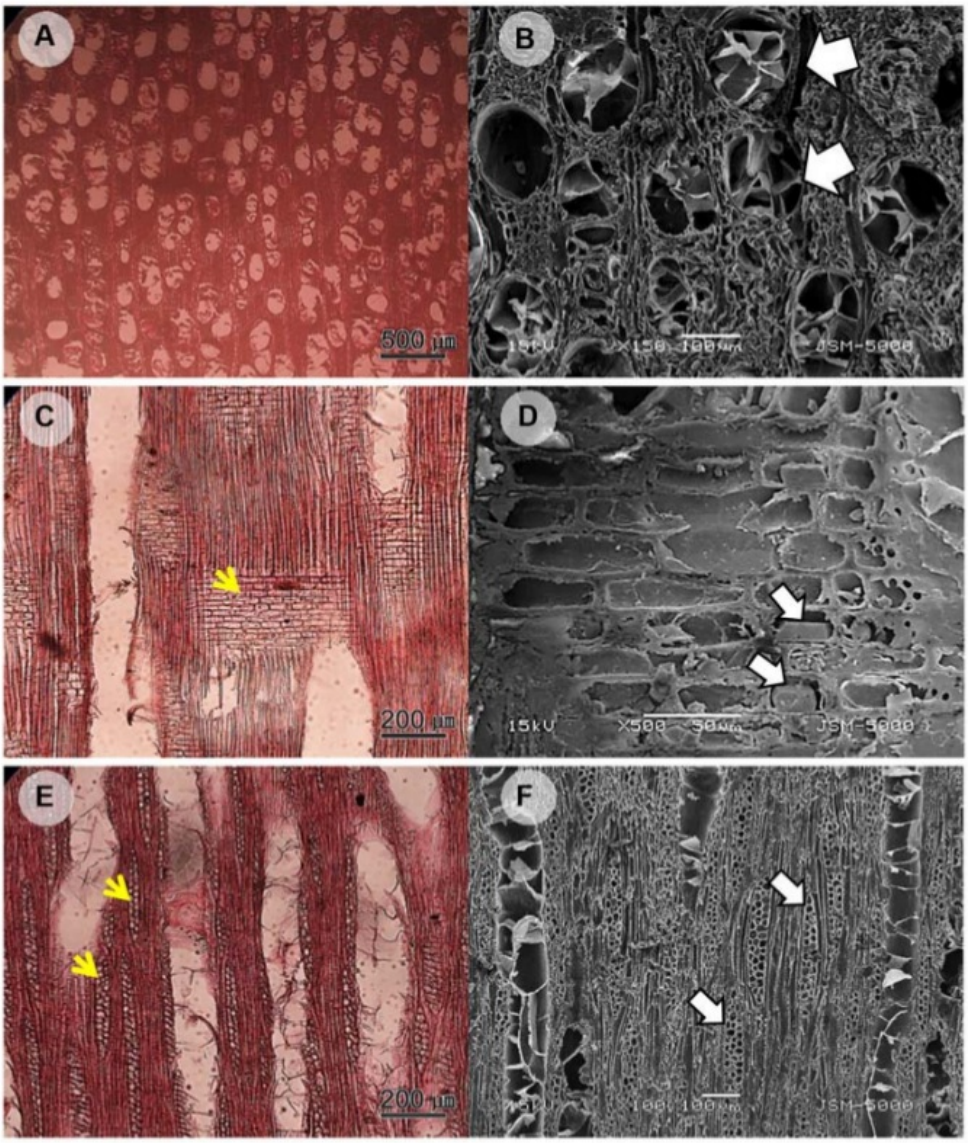

Fig. 4. Optical (left) and scanning electron micrographs (right) of gofasa: (A) diffuse-porous; (B) tyloses in the vessels; (C) procumbent form of ray cells; (D) arrow shows crystals in ray cells; (E, F) rays composition in tangential section.

significantly higher than gofasa. The Moluccan ironwood with higher density had thicker fiber wall, higher quantity of ray number, and wider rays than the other species, while red meranti had higher values of ray height and fiber length than the other three species. The fiber length of Moluccan ironwood varies a little from earlier descriptions by Baar *et al.* (2013) who reported

Table 3. Crystalline characteristics of the four Moluccan wood species

Species	Relative crystallinity (%)	Crystallite width (nm)
Moluccan ironwood	50.1	2.76
Linggua	71.7	3.27
Red meranti	68.3	3.02
Gofasa	64.4	2.89

an average dimensions of 1392 µm. However, the ray height and ray width varies significantly from the results of Baar *et al.* (2013), they reported average dimensions of 273 µm and 27.4 for ray height and ray width, respectively. Fiber length is an important wood quality attribute for the pulp and paper industry, in which longer fibers are necessary to make stronger paper (Shmulsky and Jones, 2011).

3.3. Crystalline Characteristics

The crystalline characteristics of the four wood species are shown in Table 3 and the associated X-Ray diffractograms are shown in Fig. 5. Linggua had the highest values of relative cristallinity of 71.7% and crystallite width of 3.27 nm. Red meranti and gofasa had comparable values of relative crystallinity and crystallite width, while the lowest values were observed in Moluccan ironwood with of 50.1% of relative crystallinity and 2.76 nm of crystallite width. In Figure 5, we can find the peaks from calcium crystals at 2θ = 15, 21 and 24 degree.

The relative crystallinity correlated with the physical, chemical and mechanical properties of cellulosic materials. Lee (1961), and Wang and Chu (1990) reported the effects of crystallinity on the wood properties, *i.e.* Young's modulus,

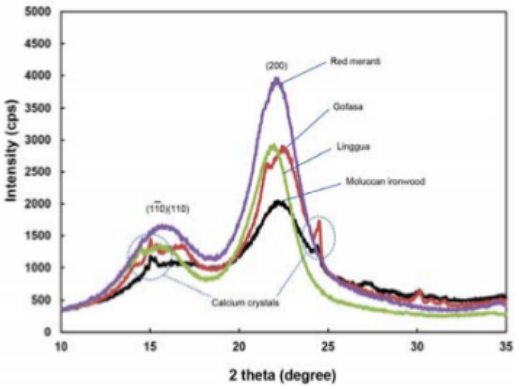

Fig. 5. X-Ray diffractograms of the four Moluccan wood species.

hardness, density and dimensional stability increased and moisture adsorption, flexibility and chemical reactivity decreased with increasing crystallinity. However, beside crystallinity, the strength properties of wood are also affected by other factors and the complex combination of the affecting factors such as density, moisture content, slope of grain, knots, reaction wood, extractive, etc (Shmulsky and Jones, 2011). The exception among the four species can be seen in Moluccan ironwood. The wood had higher mechanical properties such as Young's modulus and hardness compared to the other three species (Richter and Dallwitz, 2000), but had the lowest crystallinity in this study.

4. CONCLUSION

The four tropical woods from Moluccas, Indonesia showed some qualitative and quantitative differences on anatomical characteristics. The inclusions in vessels were only found in Moluccan ironwood. The crystals were observed in Moluccan ironwood, linggua, and gofasa, while resin canals were only displayed in red meranti. Tyloses were frequently observed in gofasa, but infrequently observed in linggua and red meranti. Moluccan ironwood with the higher density had thicker fiber wall, higher quantity of ray number, and wider rays than the other species, while red meranti had higher values of ray height and fiber length than the other three species. Linggua showed the highest values of relative crystallinity and crystallite width. Red meranti and gofasa showed similar values, while Moluccan ironwood showed the lowest relative crystallinity and crystallite width.

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