Original Article

Anatomical Structures and Fiber Quality of Four Lesser-Used Wood Species Grown in Indonesia[1]

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ABSTRACT

This study aimed to investigate the anatomical structure and fiber quality of four lesser-used wood species namely Benuang (*O. sumatrana*), Duabanga (*D. moluccana*), Pisang Merah (*H. hellwigii*), and Terap (*A. odoratissimus*). This study evaluated its suitability for raw material in pulp and paper manufacturing. The anatomical structure was observed macro- and microscopically. Macroscopic structures were observed directly to the wood samples, while microscopic characteristics were observed through microtome specimens. Fiber dimension was measured through macerated specimens and fiber quality was analyzed following the Rachman and Siagian's method. Results showed that these four timber species have similarity in the indistinct growth ring, diffuse porous in a radial pattern, rounded solitary vessel outline, 1 to 3 cells of ray width, deposits within the rays, fiber length, and cell wall thickness. Differences were found on vessel diameter, vessel grouping, vessel frequency, tyloses existence, type of axial parenchyma, and ray height. Based on fiber length and its derived values, the wood fibers of all species studied are suitable for pulp and paper manufacturing. They belong to the II quality class. The produced pulp and paper would have good quality, especially in tensile, folding, and tear strength. To promote their utilization, silviculture aspect of these four species has to be well understood.

Keywords: anatomical structure, *Artocarpus odoratissimus*, *Duabanga moluccana*, fiber quality, *Horsfieldia hellwigii, Octomeles sumatrana*

1. INTRODUCTION

In Indonesia, the forestry sector has an essential role in many aspects. The Indonesian forestry sector had relied on wood industries especially plywood, sawn timber, and others from 1970 to 1990. At that time, Indonesia was well known as the biggest plywood producer and exporter. However, since the last two decades, wood industries were replaced by pulp and paper industries. According to Statistics Indonesia (BPS 2014a; 2014b; 2015; 2016; 2017), the Indonesian export volume of pulp and paper increased significantly from 4.8 to 6.0 million ton during the last five years, while the productivity of timber industries decreased.

Pulp and paper industries in Indonesia highly depend on wood from plantation forests in the last twenty years.

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The forest was established either by local people or corporation using fast-grown tree species, especially Mangium (*Acacia mangium*), Sengon (*Falcataria moluccana*), and Eucalyptus (*Eucalyptus* spp.). Though pulpwood from plantation forests increases every year, some species from the natural rainforest are still needed to improve the characteristic of pulp and paper produced. However, the suitability of the species has not been proven scientifically. Wood characteristics, especially in anatomical structure and fiber quality, have to be properly investigated to improve the quality of pulp and paper (Hidayat *et al.*, 2017).

According to Soerianegara et al. (1993) and Mandang (2013), there are approximately 4000 potential wood species in Indonesian tropical rainforest, and only less than 10% has been utilized. There is a lot of wood species that can be selected and used for the candidate. Benuang (*Octomeles sumatrana*), Duabanga (*Duabanga moluccana*), Pisang Merah (*Horsfieldia hellwigii*), and Terap (*Artocarpus odoratissimus*) which are categorized as lesser-used wood species are a prospective source because of its abundance in natural forests. Understanding of these species' characteristics will lead to the evaluation of its potential in wood markets. Some researchers have done a similar project. They characterized some lesser-known and lesser-used wood species to promote the utilization (Poku *et al.*, 2001; Olson, 2003; Ishengoma *et al.*, 2004; Shupe *et al.*, 2005; Grünewald *et al.*, 2009; Junior *et al.*, 2009; Ali, 2011; Ogunwusi, 2012). These characteristics, which are varied among species as well as within and among the trees, can be used to predict an appropriate processing and proper utilization of the wood (Barnett and Jeronimidis, 2003; Wahyudi, 2013; Hidayati *et al.*, 2017; Park *et al.*, 2017; Yang *et al.*, 2017; Park *et al.*, 2018; Purusatama *et al.*, 2018). Hence, it is important to characterize the properties of lesser-used wood species to predict the appropriate processing technique and proper utilization.

This study aimed to characterize the four lesser-used wood species, especially their anatomical structures and fiber quality to evaluate its suitability in pulp and paper manufacturing. An evaluation was conducted by comparing the characteristics of experimental species with general raw materials in pulp and paper manufacturing (Mangium, Sengon, and Eucalyptus).

2. MATERIALS and METHODS

2.1. Brief description of the experimental wood species

2.1.1. Benuang (*O. sumatrana*, Datiscaceae)

The trees are large to very large, dioecious evergreen, 45–60 m tall, and about 90–250 cm in diameter. The trunk is straight, cylindrical, branchless up to 30 m, and buttressed 3–6 m high. The outer bark is thick up to 5 mm, greyish brown color, and has shallow streaks. The natural distribution of this species ranges from the Philippine, Sumatera, Kalimantan, Sulawesi, Moluccas, and New Guinea. In Indonesia, it grows on low altitude riverside land up to 1000 m asl. (Martawijaya *et al.*, 2005; ITTO's site; Ogata *et al.*, 2008). According to Martawijaya et al. (2005), Ogata et al. (2008), and Susila (2010), Benuang belongs to the fast-growing and pioneer species.

2.1.2. Duabanga (*D. moluccana*, Sonneratiaceae)

The genus of Duabanga consists of two species, *D. molucanna* in Kalimantan, Java, Timor, the Philippine, Sulawesi, the Moluccas, and New Guinea; and *D. grandiflora* from the Himalayas to Southern China, Andaman Islands, and Malaya. The trees are medium to fairly large, 35–45 m tall, and up to 100 cm in diameter. The trunk is straight, cylindrical, without buttress (ITTO's site; Ogata *et al.*, 2008). According to ITTO's site, the trees growing in the forest along

streams at a low altitude up to 1200 m asl. and frequently present in regrowth and riverside areas.

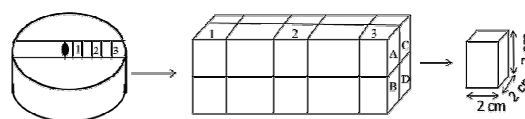### 2.1.3. Pisang Merah (*H. hellwigii*, Myristicaceae)

According to Krisdianto *et al*. (2013), and ITTO's site, the trees are small to medium-large, 30 m tall, and about 60 cm in diameter. The trunk is straight, cylindrical, and occasionally has small buttress. The bark is smooth and greyish white. The natural distribution of this species is from the Malay Peninsula, Kalimantan, Sumatera, and Java to New Guinea. According to Ogata *et al*. (2008), the trees growing scattered in lowlands, lower montane, or rarely montane rain forests up to 1200 m asl.

2.1.4. Terap (*A. odoratissimus*, Moraceae)

The trees are medium to large and 35−43 m tall. The trunk is straight, cylindrical, without buttress, and often about 65 cm in diameter. The bark is brown to greyish brown and dense woolly. The natural distribution of this species ranges from India to Southeast Asia and Western Pacific. In Indonesia the tree growing on lowland evergreen forest to 750 m asl. (Abdurrohim *et al*., 2004; ITTO's site; Ogata *et al*., 2008).

2.2. Sample preparation

The main materials were 5 cm thick wood discs of Benuang, Duabanga, Pisang Merah, and Terap from tropical rainforest in Kalimantan, Indonesia. Infor-

A = Macroscopic sample
B = Microscopic sample
C = Specific gravity
D = Fiber quality

Fig. 1. Schematic of sample preparation.

mation on the experimental materials is presented in Table 1.

A small block of 2 cm (width) by 5 cm (thick) by 5 cm (length) was prepared from wood disc representing three locations, i.e. near the pith (1st segment), middle (2nd segment), and near the bark (3rd segment). Wood blocks were then divided again into four parts of 2 cm by 2 cm by 2 cm for each parameter studied (Fig. 1).

2.3. Macro− and microscopic observations

Macroscopic characteristics, namely wood color, odor, texture, grain, luster, and heartwood percentage, were directly observed using loupe of 15 times magnification. Microscopic characteristics observation was carried out through the thin microtome specimens by light microscope (Zeiss Axio Imager. A1m). The specimen of 25 μm was produced by sliding microtome using safranin as a dying agent. The IAWA Hardwood

Table 1. Information on the experimental materials

Species	Diameter (cm)	MC (%)	SG	Distance from the Pith (cm)		
				Near the Pith (1st Segment)	Middle (2nd Segment)	Near the Bark (3rd Segment)
O. sumatrana	50−70	23.07	0.33	3	11	20
D. moluccana	50−60	35.65	0.35	3	11	20
H. hellwigii	50−60	22.09	0.45	3	11	20
A. odoratissimus	50−70	32.34	0.41	3	7*	20

* Transition zone from sapwood to heartwood

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List of IAWA Committee (Wheeler *et al.*, 1989) was used as a reference for anatomical characteristics observation.

2.4. Fiber dimension and its derived value measurement

Fiber dimensions, namely fiber length, fiber diameter, and lumen diameter, were measured through macerated specimens using the same light microscope equipped with a camera. Cell wall thickness was half of the difference between fiber diameter and lumen diameter. Maceration process was based on the modification of Franklin's method (Rulliaty, 1994). A total of 50 individual fibers were measured for each segment. The derived values of fiber dimension namely Runkel ratio (RR), felting power (FP), Muhlsteph ratio (MR), flexibility ratio (FR), and coefficient of rigidity (CR) were calculated following the equations:

$$RR = \frac{2w}{l} \quad \text{.......................... (1)}$$

$$FP = \frac{L}{d} \quad \text{.......................... (2)}$$

$$\% MR = \frac{(d^2 - l^2)}{d^2} \times 100 \quad \text{.................. (3)}$$

$$FR = \frac{l}{d} \quad \text{.............................. (4)}$$

$$CR = \frac{w}{d} \quad \text{.............................. (5)}$$

Where,
w = fiber wall thickness
L = fiber length
l = diameter lumen
d = diameter fiber

The derived values were then used to determine fiber quality class following Rachman and Siagian (1976), as described in Table 2.

3. RESULTS and DISCUSSION

3.1. Anatomical structure

3.1.1. Benuang (*O. sumatrana*)

Results showed that heartwood is yellowish-brown but quite easy to be differentiated from sapwood (Fig. 2A). Wood texture is medium and even, wood grain is straight to interlocked (Fig. 2A&B) while growth ring indistinct (Fig. 2C). The wood surface is dull and has no specific odor. From the measurement, it was found that the heartwood portion is 63.38%.

Results also showed, that wood is diffuse-porous and there is no distinct difference in pore size between earlywood and the latewood (Fig. 3A). Most vessels are solitary and in radial arrangement, partly multiple 2 cells (Fig 3A: arrows). Average lumen diameter is 182.29 (141.90–231.89) µm and vessel frequency is 5 (4–6) cells per mm². The solitary vessel is rounded

Table 2. Criteria of fiber quality for pulp and paper manufacturing

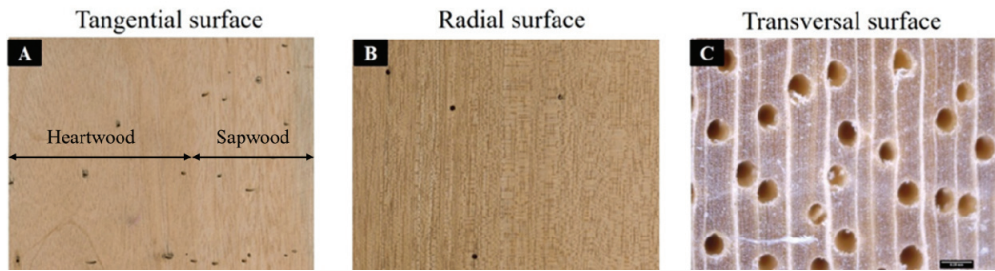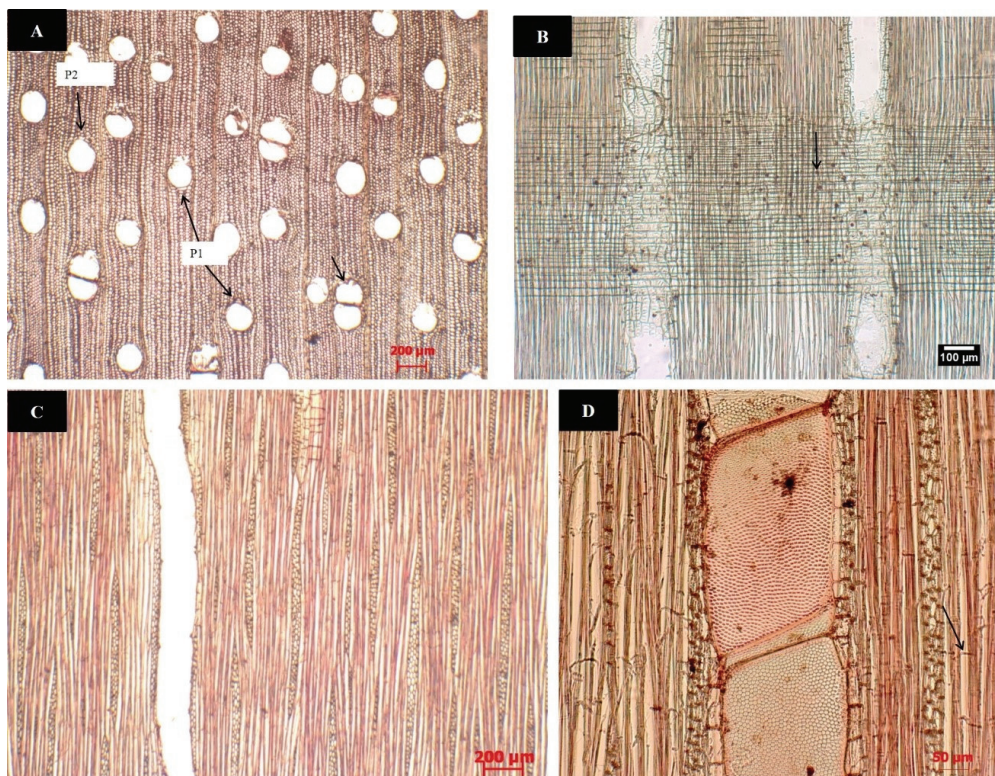| Criteria	Class I		Class II		Class III	
	Requirement	Value	Requirement	Value	Requirement	Value
Fiber length (µm)	>2000	100	1000-2000	50	<1000	25
Runkle ratio (RR)	<0.25	100	0.25-0.50	50	>0.50	25
Felting power (FP)	>90	100	50-90	50	<50	25
Muhlsteph ratio (MR)	<30	100	30-60	50	>60	25
Flexibility ratio (FR)	>0.80	100	0.50-0.80	50	<0.50	25
Coef. of rigidity (CR)	<0.10	100	0.10-0.15	50	>0.15	25
SCORING	450-600		225-449		<225	

Fig. 2. Macroscopic features of Benuang (*O. sumatrana*).

P1 = scanty parenchyma
P2 = sheath narrow parenchyma

Fig. 3. Microscopic features of Benuang (*O. sumatrana*).

in transversal section. Perforation plate is simple, while inter-vessel pitting is alternate with a polygonal shape (Fig. 3D). Gum, tyloses, and other deposits are not present.

Fibers are septate and non-septate (Fig. 3D: arrows), the average length of 1565.61 (844.75–2561.5) μm, very thin-walled (2.93 μm), with simple to minutely bordered pits.

Axial parenchyma is rare, narrow to slightly wide and short; 1–4 cells width; and have >8 cells per strand. (Fig. 3A&B). Apotracheal axial parenchyma is diffuse, while paratracheal axial parenchyma is scanty (Fig. 3A: P1), and the sheath is narrow (Fig. 3A: P2).

Rays' width is 1 to 3 cells (Fig. 3C), average height is 738.10 (309.91–1414.47) µm, and have 5 (4–6) cells per mm. The Body ray consists of procumbent cells with 2-4 rows of the square marginal cells (Fig. 3B).

These findings, especially the vessel diameter and vessel frequency, are following Ogata *et al.* (2008), but not for fiber length, cell wall thickness, type of parenchyma, type of fiber, the existence of crystal and silica. The fiber in our study is shorter, thicker, and septated; the axial parenchyma is scanty and sheath narrow (theirs are vasicentric and aliform). Furthermore, silica was observed in our study, but not the crystal.

Compared to Martawijaya *et al.* (2005), the similarity is found in vessel distribution, vessel diameter, vessel frequency, fiber length, cell wall thickness, type of parenchyma, and ray width, while un-similarity is found in tyloses, ray height, and ray frequency. Tyloses were absent in our study, but the ray cell is taller and has a higher frequency.

3.1.2. Duabanga (*D. moluccana*)

The results showed that heartwood is pale yellowish-brown and challenging to differentiate from sapwood (Fig. 4A). Wood texture is moderate to coarse, wood grain is interlocked (Fig. 4A&B), while growth ring boundaries are indistinct (Fig. 4C). The wood surface is dull and have no specific odor.

The result showed that wood is diffuse-porous, and there is no clear distinction in pore size between earlywood to latewood (Fig. 5A). Most of the vessels are solitary, but sometimes the radial multiple 2 cells and clustering up to 3 cells (Fig. 5A: CL). The average diameter of the lumen was 279.51 (196.55–383.51) µm and 3 (2–4) cells per mm^2. The solitary vessel is rounded in transversal section. Perforation plate is simple, while inter-vessel pitting is alternate with a polygonal shape (Fig. 5C: arrows). Gum, tyloses, and other deposits are not present.
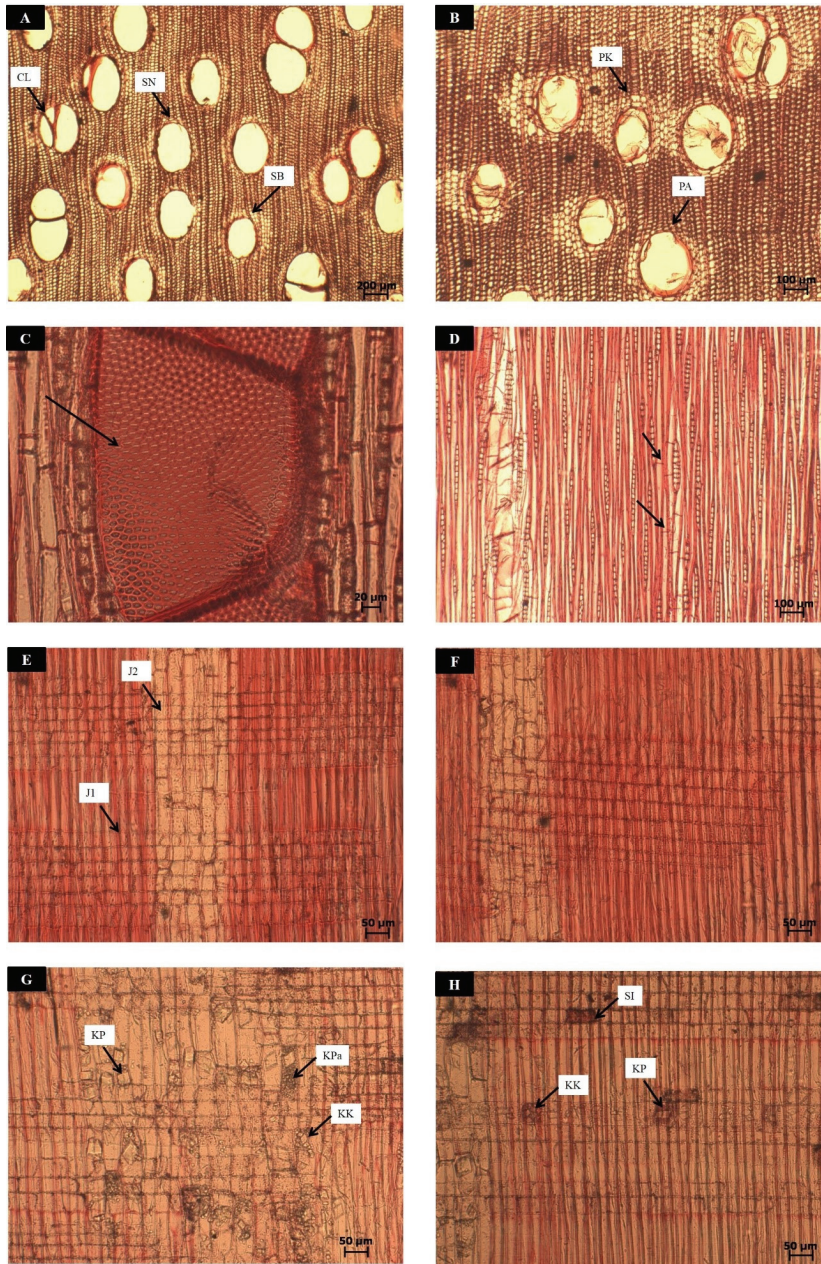
Fibers are septate and non-septate (Fig. 5D: arrows), the average length of 1599.39 (763.00−2670.50) µm, very thin-walled (3.47 µm) with simple to minutely bordered pits.

Axial parenchyma is wide and long (Fig. 5B&F) and mostly more than three cells in width and eight cells per strand. The apotracheal axial parenchyma is diffuse, while paratracheal axial parenchyma is vasicentric either sheath broad (Fig. 5A: SB), sheath narrow (Fig. 5A: SN), complete circular to oval sheath (Fig. 5B: PK) or incomplete (Fig. 5B: PA), as well as confluent (Fig. 5B: PK).

Rays exclusively uniseriate (Fig. 5D), the average length of 210.81 (79.03−336.29) µm, and 5 (4−6) cells per mm. Rays composition varies, square cells with 1−2 rows of upright marginal cells (Fig. 5E: J1); procumbent cells with 1−2 rows of upright marginal

Tangential surface   Radial surface   Transversal surface

Fig. 4. Macroscopic features of Duabanga (*D. moluccana*).

CL = clustered vessels
J1 = square cells with 1−2 rows upright cells
J2 = procumbent cells with 1−2 rows upright cells
KK = cubic crystals
KP = prismatic crystals
Kpa = crystal sand

PA = incomplete vasicentric parenchyma
PK = complete circular to oval sheath vasicentric parenchyma
SB = sheath broad parenchyma
SI = silica
SN = sheath narrow parenchyma.

Fig. 5. Microscopic features of Duabanga (*D. moluccana*).

cells (Fig. 5E: J2); and procumbent, square, and upright cells mixed throughout the ray (Fig. 5F).

Furthermore, Duabanga wood, especially xylem area near to the bark, has loads of crystals in ray and axial parenchyma. In one chamber, there is one or more crystal. Prismatic crystals (Fig. 5G: KP), small cubic crystals (Fig. 5G: KK), and crystal sand (Fig. 5G: KPa) are found in axial parenchyma; while prismatic crystals (Fig. 5H: KP) and small cubic crystals (Fig. 5H: KK) are found in ray parenchyma. Silica was also found in ray parenchyma (Fig. 5H: SI).

These findings especially vessel distribution, vessel frequency, vessel diameter, ray wide, fiber length, type of axial parenchyma, and the existence of crystal are in accordance with Ogata *et al*. (2008), but not for the cell wall thickness, ray height, type of fiber, and existence of tyloses and silica. When compare to Ogata *et al*. (2008), the cell wall of Duabanga wood is thicker, but the ray is shorter. Furthermore, septate fiber and silica exist, but tyloses absent.

3.1.3. Pisang Merah (*H. hellwigii*)

The results showed that heartwood is reddish-brown but slightly challenging to distinguish from the sapwood (Fig. 6A). The wood texture is medium and even, wood grain is straight (Fig. 6B), while growth ring boundaries slightly distinct to indistinct (Fig. 6C). The wood surface is slightly luster and without specific odor.

Results showed that wood is diffuse-porous and there is no significant difference in pore size between earlywood to the latewood (Fig. 7A). Most vessels are radial multiples of 2–4 cells, partly solitary and clustering up to 3 cells (Fig. 7A: CL). The average lumen diameter is 152.80 (72–219.60) µm, and 5 (4–7) cells per mm^2. The solitary vessel is round in the transverse section. Perforation plate is simple, while inter-vessel pitting is alternate with a polygonal shape (Fig. 7C: arrows). Gum, tyloses, and other deposits are not present.

Fibers are non-septate, the average length of 1691.86 (1062.75–2507) µm, very thin-walled (3.46 µm) with simple to minutely bordered pits.
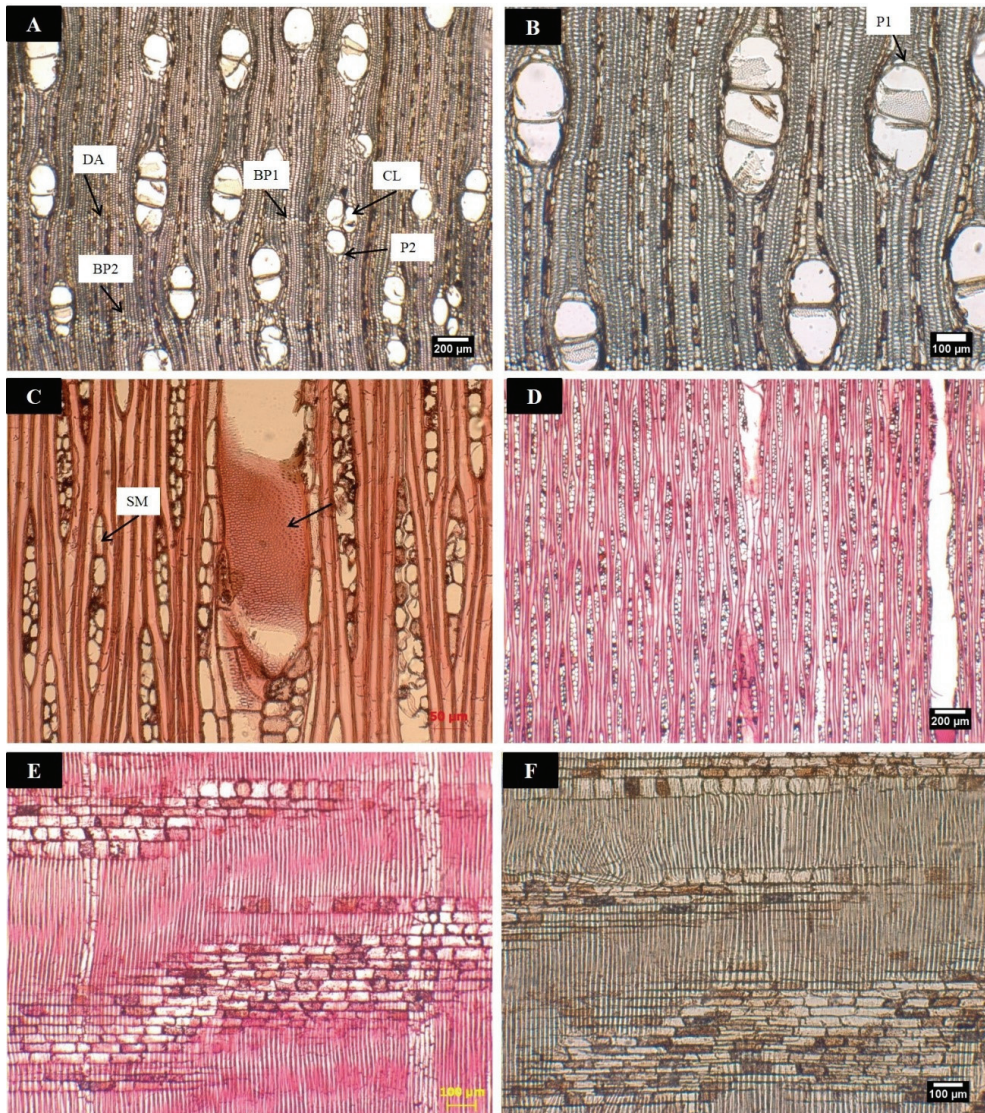
Axial parenchyma is narrow to slightly wide and long (Fig. 7A&E), consisted of 2–5 cells width and more than eight cells per strand. Apotracheal axial parenchyma is diffuse-in-aggregates, which is grouped into short discontinuous tangential line (Fig. 7A: DA). Paratracheal axial parenchyma is scanty (Fig. 7B: P1) and sheath narrow (Fig. 7A: P2). Banded marginal parenchyma (Fig. 7A: DA) was also detected both in narrow (1–3 cells) (Fig. 7A: BP1) and wide bands (>3 cells) (Fig. 7A: BP2).

Rays wide is 1 to 3 cells (Fig. 7D), the average height of 449.89 (140.63–862.12) µm, and have 9 (6–12) cells per mm. Body ray consists of procumbent cells with 1 to 2 rows of square marginal cells (Fig. 7E&F). The diffuse silica bodies present in ray cells (Fig. 7B&F), while oil and/or mucilage cells associated with ray parenchyma (Fig. 7C, SM).

Compared to Ogata *et al*. (2008), the similarity was

Fig. 6. Macroscopic features of Pisang Merah (*H. hellwigii).*

BP1 = narrow bands parenchyma
BP2 = wide bands parenchyma
CL = clustered vessels
DA = discontinuous tangential line parenchyma

P1 = scanty parenchyma
P2 = sheath narrow parenchyma
SM = oil and/or mucilage cells

Fig. 7. Microscopic features of Pisang Merah (*H. hellwigii).*

found on the fiber type (septate), axial parenchyma type, without crystal, and the occurrence of oil cell. Un-similarities are found in vessel distribution (clustering is observed in our study), fiber length (ours is shorter), and the existence of silica (was not observed by them). Compared to Abdurrohim *et al.* (2004), the similarity was found in vessel distribution, vessel frequency, type of axial parenchyma, cell wall thickness,

without crystal, and also tyloses. The unsimilarity was found in vessel diameter (our vessel is bigger), fiber length (ours is longer), ray width (theirs is wider), ray height (theirs is taller), ray frequency (ours is greater), and the occurrence of oil cell and silica (were not observed in their study).

3.1.4. Terap (*A. odoratissimus*)

The result showed that heartwood is brown to reddish-brown and easy to differentiate from the sapwood (Fig. 8A). Wood texture is medium and even, the wood grain is interlocked (Fig. 8B), while the growth of ring boundaries are indistinct (Fig. 8C). The wood surface is slightly luster and has a distinctive odor. The measurement showed that the heartwood portion is 46.29%.

Results also showed, that wood is diffuse-porous and there is no distinct difference in pore size between earlywood and the latewood. Vessels are mostly solitary but radial multiples of 2–4 cells are sometimes present (Fig. 9A). Average lumen diameter is 156.22 (61.06–261.78) µm and 4 (2–8) cells per mm^2. The solitary vessel is rounded in transversal section. Perforation plate is simple, while inter-vessel pitting is alternate with a polygonal shape (Fig. 9B: arrows). Gum, tyloses, and other deposits are present in the heartwood vessels (Fig. 9C: arrows).

Fibers are septate and non-septate (Fig. 9D: arrows), average length of 1709.66 (1199–2452.5) µm, very thin-walled (3.55 µm), and with simple to minutely bordered pits.
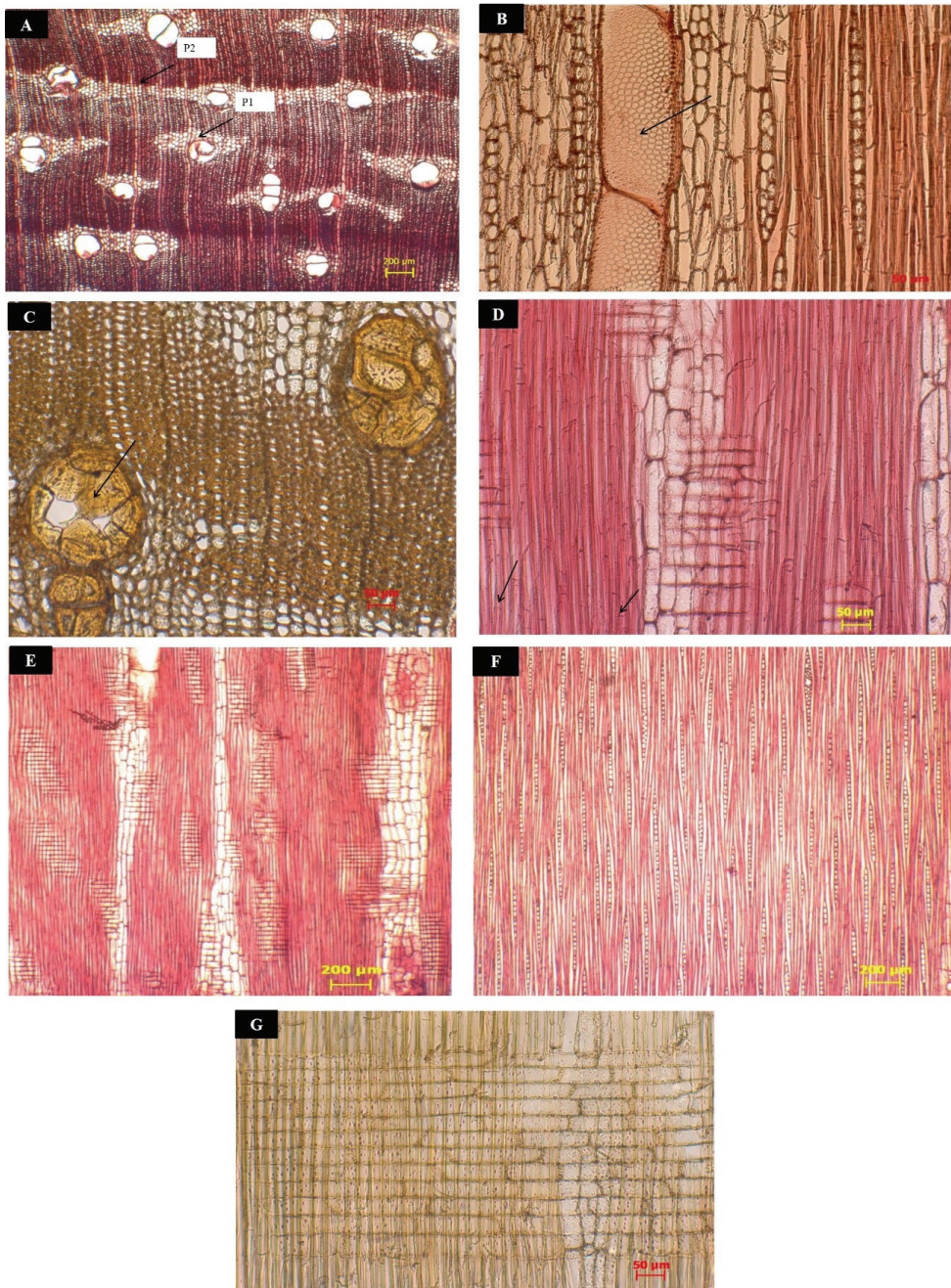
Axial parenchyma is wide and long (Fig. 9A&E), mostly more than three cells in width and eight cells per strand. Apotracheal axial parenchyma is diffuse, while paratracheal axial parenchyma is aliform (Fig. 9A: P1), and confluent (Fig. 9A: P2).

Rays exclusively uniseriate (Fig. 9F), sometimes 1 to 3 cells width, the average height of 423 (210–854.56) µm, and 5 (4–6) cells per mm. Body ray consists of procumbent cells with one row of square marginal cells. Silica bodies present in ray cells (Fig. 9G).

These findings have similarity and un-similarity with the previous study (Abdurrohim *et al.*, 2004; Ogata *et al.*, 2008). Compared to Ogata *et al.* (2008), the similarity was found in fiber length and fiber wall thickness; while the un-similarities are found in pore frequency (our findings is greater), type of axial parenchyma (vasicentric was not observed in our study), and type of fiber (septate fibers were not found by them). Compared to Abdurrohim *et al.* (2004), the similarity was found in vessel distribution, vessel frequency, type of axial parenchyma, cell wall thickness, and the presence of septate fibers; while the un-similarity was found in vessel diameter (ours is smaller), fiber length (ours is longer), type of ray parenchyma (uniseriate in our sample, multi seriates in them), existence of crystal (was not observed in ours), and existence of silica (was observed in our study but was not observed by them).

Fig. 8. Macroscopic features of Terap (*A. odoratissimus*).

P1 = aliform parenchyma
P2 = confluent parenchyma

Fig. 9. Microscopic features of Terap (*A. odoratissimus*).

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Table 3. Fiber quality of each species based on fiber length and its derived values

Criteria	*O. sumatrana*	*D. moluccana*	*H. hellwigii*	*A. odoratissimus*
Fiber length (μm)	1565.60	1599.39	1691.86	1709.67
RR	0.26	0.31	0.35	0.38
FP	53.07	52.04	61.11	64.93
MR	58.58	40.06	85.36	93.02
FR	0.80	0.77	0.75	0.76
CR	0.10	0.12	0.13	0.13
Scoring	300	300	275	275
Class	II	II	II	II

3.2. Fiber quality

The fiber length of the four lesser-used species studied and their derived values, are tabulated in Table 3. It was confirmed that wood fiber of all species was classified into Quality Class of II. It means that the resulting pulp and paper would have good quality, especially in tensile, folding, and tear strengths. According to Rahman and Siagian (1976), the fiber of Quality Class II is easily beaten, and fiber bonding is particularly strong.

Even though in general they were categorized in the same quality class, however, some variation in the strength of pulp and paper and fiber length among the species also exists. In each wood species, fiber length tended to increase from pith (1st segment) to the bark (3rd segment) (Fig. 10). The latter phenomenon is correlated with the presence of juvenile wood (Tsuchiya and Furukawa, 2009; Tanabe *et al.*, 2016).

Variation in the strength of pulp and paper in this study is more correlated to the derived value of the fibers since fiber length of the four wood species is almost similar (1560 to 1700 μm). Table 3 shown that Benuang wood has the lowest Runkel Ratio (RR), Terap wood has the highest Felting Power (FP), while Duabanga wood has the lowest Muhlstep Ratio (MR). All fibers have a similar Coefficient of Rigidity (CR) and Flexibility Ratio (FR). CR has a positive correlation
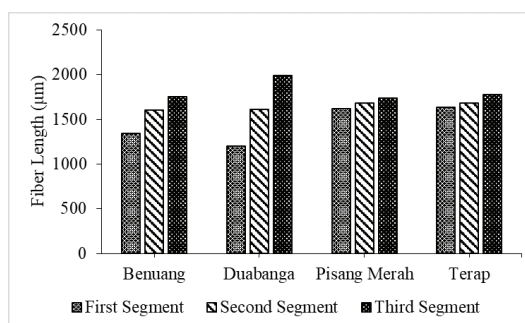

Fig. 10. Radial variation in fiber length of four lesser-used wood species.

with pulp yield and density, while FR has correlations: positive with tensile strength, folding resistance, and density; negative with the porosity of pulp and paper (Adi *et al.*, 2014; Supartini and Dewi, 2010; Supartini *et al.,* 2013).

According to Panshin and de Zeeuw (1980) and Adi *et al*. (2014), the lowest RR resulted in the highest tensile strength. Hence, pulp and paper made from Benuang wood will have the highest tensile strength. Felting power or slenderness ratio has a positive correlation with tear strength (Ververis *et al.*, 2012). Hence, pulp and paper made from Terap wood will have the highest tear strength. A higher value of MR meant lower bonding and contact area between fibers. It means that pulp and paper with higher MR value made from Pisang Merah wood are not resistant to tear.

Table 4. Quantitative characters of four lesser-used wood species

Anatomical characters	Values						
	O. sumatrana	*D. moluccana*	*H. hellwigii*	*A. odoratissimus*	*A. mangium**	*F. moluccana**	*Eucalypth spp.**
a) Vessel:							
− Diameter (μm)	142–232	197–384	72–220	61–262	150–280	250–330	230–310
− Cell per mm²	5	3	5	4	4 – 9	2	6 – 12
b) Rays:							
− Ray height (μm)	738.10	210.81	449.89	423.83	230–450	300–580	430–680
− Cell per mm	5	5	9	5	–	5 – 6	–
c) Fiber:							
− Fiber length (μm)	1565.61	1599.39	1691.86	1709.66	1100	1300	1100
− Fiber diameter (μm)	29.38	35.55	27.46	26.72	15–30	25	4–21
− Lumen diameter (μm)	23.26	29.28	20.70	19.81	12–25	21	11
− Fiber wall thickness (μm)	3.06	3.13	3.38	3.46	1.5–2.5	1.5–2	1–5
d) Cell precentage:							
− Vessel precentage (%)	12.75	19.33	12.77	5.40	–	–	–

*Source: Donaldson (1984); Martawijaya *et al*. (2005); Ogata *et al*. (2008).

With the lowest in MR value, therefore, pulp and paper made by Duabanga wood will have the highest tear and tensile strength.

3.3. Quantitative comparison to Mangium, Sengon, and Eucalyptus woods' characters

Important quantitative of anatomical features and fiber dimensions of these four wood species are tabulated in Table 4. Data is then compared to the conventional woods namely Mangium (*A. mangium*), Sengon (*F. moluccana*), and Eucalyptus (*Eucalyptus* spp.) These are common raw material in pulp and paper manufacturing.

It showed that vessel diameter of Pisang Merah and Terap wood is smaller than the Mangium, Sengon, and Eucalyptus, while Benuang and Duabanga are equal to the three conventional pulpwood. For the vessel frequency, Duabanga wood has similar frequency to Sengon wood, while Benuang, Pisang Merah, and Terap

similar to Mangium and Eucalyptus.

It also showed that Benuang wood has the tallest ray parenchyma compared the others, except for Eucalyptus. Ray parenchyma in Duabanga and Mangium woods is similar and categorized as the shortest.

In contrast to Mangium, Sengon, and Eucalyptus woods, the fiber length of the four wood species studied is longer. However, their cell wall is thicker. The latter phenomenon is a valid judgment to support the idea that pulp and paper from the fiber of Mangium, Sengon, and Eucalyptus woods are better than the four wood species' studied. According to Rachman and Siagian (1976), fibers of Mangium, Sengon, and Eucalyptus woods belong to Quality Class of I.

4. CONCLUSION

Fiber length and fiber quality class of Benuang, Duabanga, Pisang Merah, and Terap wood are similar, but their anatomical structures varied. The similarity

in anatomical structures are found in growth ring, porosity, vessel outline, ray width, and deposits; while un-similarity are seen on vessel diameter size, vessel grouping, vessel frequency, the presence of tyloses, type of axial parenchyma, and ray height.

These lesser-used wood species are potential to be utilized as raw material for pulp and paper manufacturing. Their fibers belong to the Quality Class of II. Tensile, folding, and tear strengths of pulp and paper produced from all species studied are good. To promote their utilization, silviculture aspect of these four wood species has to be well understood and developed.

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