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ANATOMICAL INVESTIGATION OF FIVE GENERA THE LEAST-KNOWN TIMBER OF APOCYNACEAE AND THEIR POTENTIAL UTILIZATION

Sari D. Marbun[1*], Vidya F. Astutiputri[2], Ratih Damayanti[1*], Hadisunarso[2], Deazy R. Trisatya[1], Djarwanto[1], Listya M. Dewi[1], R.G.H Rahmanto[1], Dyah A. Agustiningrum[1], Rohmah Pari[1], Imran A. Sofianto[1], Yunita Lisnawati[3], Titi Kalima[3], Sona Suhartana[1], Setiowati[1], Krisdianto[4], Marfuah Wardhani[5], Agus Ismanto[6], Yuniawati[1], Agung W. Nugroho[5], Sri Utami[6], Wahyu Dwianto[1], Widya Fatriasari[1], Adik Bahanawan[1], Danang S. Adi[1], Sarah Augustina[1], Hengki Siahaan[3]

[1]Research Center for Biomass and Bioproducts, National Research and Innovation Agency (BRIN), Cibinong, Bogor 16911, Indonesia
[2]Department of Biology, Faculty of Mathematics and Natural Sciences, IPB University, Bogor, 16680, Indonesia
[3]Research Center for Ecology and Ethnobiology, National Research and Innovation Agency (BRIN), Cibinong, Bogor 16911, Indonesia
[4]Directorate of Processing and Marketing of Forest Product, Ministry of Environment and Forestry, The Republic of Indonesia
[5]Plant Conservation, Botanic Gardens, and Forestry Research Center of National Research and Innovation Agency (BRIN), Cibinong, Bogor 16911, Indonesia
[6]Applied Zoology Research Center of National Research and Innovation Agency (BRIN), Cibinong, Bogor 16911, Indonesia

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ANATOMICAL INVESTIGATION OF FIVE GENERA THE LEAST-KNOWN TIMBER OF APOCYNACEAE AND THEIR POTENTIAL UTILIZATION. Doubtlessly, wood identification is critically important for a number of sectors, including government organizations, the wooden-based industry, museums, law enforcement, and scientists working in botany, ecology, forestry, and wood technology. Unfortunately, most wood species listed as "the least-known species" lack essential knowledge or their anatomical features and basic properties to promote their usage. This research aimed to investigate the anatomical characteristics and fiber quality of the least-known timber species of Apocynaceae family, which are authentic wood collection from Xylarium Bogoriense, namely, *Ervatamia sphaerocarpa*, *E. aurantiaca*, *Kopsia flavida*, *Lepiniopsis ternatensis*, *Plumeria acuminata*, *P. rubra*, and *Voacanga foetida*. Wood samples have indistinct growth ring boundaries, diffuse-porous vessels in diagonal and/or radial pattern, vessels in radial multiples of 4 or more cells, simple perforation plate, alternate intervessel pits; distinct borders of vessel-ray pits, similar with those of intervessel pits in size and shape throughout the ray cell, and septate fibers with simple pits to minutely bordered pits which are common in radial and tangential walls. Based on the fiber length and the derived values of fiber dimension, some species are classified into Quality Class II and III, and the rest of them are classified into Quality Class II or III for pulp and paper manufacturing. Based on general characteristics, commonly Apocynaceae can be used as handicrafts raw material. Based on the fiber quality, some species which are classified into Quality Class II, are predicted to have potential as pulp and paper material with medium quality.

Keywords: Anatomical properties, Apocynaceae, fiber dimensions, least-known species, pulp and paper, Xylarium Bogoriense

INVESTIGASI ANATOMI LIMA GENERA THE LEAST-KNOWN SPECIES DARI FAMILI APOCYNACEAE DAN POTENSI PEMANFAATANNYA. Tidak diragukan lagi, identifikasi kayu merupakan hal yang sangat penting dalam berbagai sektor, termasuk organisasi pemerintah, industri kayu, museum, penegak hukum, dan para ilmuwan yang bekerja di bidang botani, ekologi, kehutanan, dan teknologi kayu. Akan tetapi sungguh

* Corresponding author: sari.delvianamarbun@gmail.com, ratih.damayanti@brin.go.id

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sangat disayangkan, minimnya informasi terkait karakteristik anatomi dan sifat-sifat dasar dari sebagian besar kayu yang terdaftar dalam kelompok the least-known species membatasi penggunaan kayu-kayu tersebut. Penelitian ini bertujuan untuk menginvestigasi karakteristik anatomi dan kualitas serat dari the least-known species dari famili Apocynaceae, yang merupakan koleksi dari Xylarium Bogoriensis, yaitu Ervatamia sphaerocarpa, E. aurantiaca, Kopsia flavida, Lepiniopsis ternatensis, Plumeria acuminata, P. rubra, *dan* Voacanga foetida. *Hasil penelitian memperlihatkan bahwa 5 genera dari Apocynaceae yang diteliti memiliki lingkar tumbuh yang tidak jelas, berpembuluh tata baur dalam pola diagonal dan/ atau radial, pembuluh berganda radial 4 atau lebih biasa dijumpai, bidang perforasi sederhana, ceruk antar pembuluh selang seling, ceruk pembuluh-jejari dengan halaman yang jelas, sama dalam ukuran dan bentuk dengan ceruk antar pembuluh pada seluruh sel jejari, memiliki serat bersekat dengan ceruk sederhana sampai berhalaman sangat kecil yang umum pada bidang radial dan tangensial, Berdasarkan panjang serat dan nilai turunan dimensi serat, beberapa species diklasifikasikan ke dalam kelas Mutu II dan III, dan sisanya ke dalam kelas mutu II atau III sebagai bahan baku pulp dan kertas. Berdasarkan karakteristik umum, Apocynaceae dapat digunakan sebagai bahan baku kerajinan tangan. Berdasarkan kualitas seratnya, beberapa species yang tergolong kelas mutu II diperkirakan berpotensi sebagai bahan baku pulp dan kertas dengan kualitas sedang.*

Kata kunci: *karakteristik anatomi, Apocynaceae, dimensi serat, least-known species, pulp dan kertas, Xylarium Bogoriensis*

I. INTRODUCTION

According to their trades, timber species grown in South East Asian were categorized into four categories in 1998 by Plant Resources of South-East Asia: major, minor, lesser-known, and the least-known timber species. The new classification of the least-known timber was introduced firstly in 2008 as information on wood properties at least for the anatomical structure have not available (Damayanti and Rulliaty, 2011). Major and minor wood species (commercial timber) are becoming scarcer due to intensive exploitation, which affects their supply. Because of the scarcity of commercial wood, there has been an increase in the usage of lesser-known and least-known species. As a result, many researchers from South-East Asian and other countries have worked to examine their lesser-known or least-known species resources in an effort to find substitute wood species that could possibly replace commercial timber species. Some of them came from India (Hedge, 2019), Malaysia (Hamdan et al., 2020; Siam et al., 2022), Mozambique (Ali, Uetimane, Lhate, & Terziev, 2008; Uetimane & Ali, 2011), Bangladesh (Chowdhury, Sarker, Deb, & Sonet, 2013; Chowdhury, Hossain, Hossain, Dutta, & Ray, 2017), Ghana (Brunner, Appiah-Kubi, Zurcher, Reinhard, & Kankam, 2008), Peru (Haag, Koch, Melcher, & Welling, 2020), Turkey (Korkut, 2011), Nigeria (Areo, 2021), as well as Indonesia (Damayanti & Rulliaty, 2010; Damayanti & Dewi, 2019; Marbun, Wahyudi, Suryana, & Nawawi, 2019). Observation of the wood's properties is unavoidable if it is to be utilized appropriately. Presently, data and information from the major, minor, and the lesser-known group have been compiled for various timber applications. However, fewer studies have been conducted on the wood characteristics of the least-known timber species.

Anatomical investigation is a very crucial in wood identification process. It could be important for the wood-based industry, government organizations, museums, law enforcement, and scientists working in the fields of botany, ecology, forestry, and wood technology (Wiedenhoeft, 2010). The differences on the types, sizes, proportions, pits, and arrangements of different cells that comprise wood become fundamental differences between wood species and could affect the use of wood. Wood from different species will have different properties and perform differently under various conditions. Inaccurate wood species identification would pose serious problem in wooden product's manufacture (Pandit & Ramdan, 2002). Moreover, Wahyudi (2013) mentioned that the correlation between the characteristic, utility, and manufacture with the anatomical structure of wood is very inherent. Therefore, wood processing requires wood species identification includes scientific name, general characteristics, and anatomical features (microscopic). Additionally, since Indonesia's pulp and paper industries are expanding rapidly, it is necessary to examine the fiber quality of the lesser-known and least-known timbers to decide if they are suitable for making pulp and paper products.

Xylarium Bogoriense 1915 is a collection of 232,020 wood samples from 167 families, 1,105 genera, and 6,679 species. It is managed by the Center for Standardization of Sustainable Forest Management Instruments (previously known as the Forest Products Research and Development Center) in Bogor, West Java. The group of the least-known species comprises about 800 species of wood from 251 genera and 77 families. Apocynaceae is among them. Some species in the Apocynaceae includes *E. aurantiaca*, *E. macrocarpa*, *E. sphaerocarpa*, *K. flavida*, *L. ternatensis*, *P. acuminata*, *P. rubra*, and *V. foetida*. There is a severe lack of published scientific data on the anatomy and characteristics of these species. Heyne et al. (1987), Ingle and Dadswell (1953), and InsideWood are a few places to look. Some described the general characteristic, while others described specific anatomical features of particular genera or species of Apocynaceae. Recently, Tripathi et al. (2023) elucidated the root anatomical structure of *Kopsia fruticose* to understand its physiological functions. However, the targeted wood species in this study have not been examined for their anatomical properties. So, the aim of this research is to investigate the anatomical structure and quality of wood fibers to explore the potential utilization as raw material of pulp and paper of five genera of the Apocynaceae least-known timber, namely: *E. macrocarpa*, *E. sphaerocarpa*, *E. aurantiaca*, *K.* flavida, *L. ternatensis*, *P. acuminata*, *P. rubra*, and *V. foetida*.

II. MATERIALS AND METHOD

Authentic woods collection of the Xylarium Bogoriense, were used i.e., *E. aurantiaca* Gaud. (No. 14905 and 16352), *E. macrocarpa* Merr. (No. 17196, 19188, and 21682), *E. sphaerocarpa* Burkill. (No. 2081), *K. flavida* Bl. (No. 3337), *L. ternatensis* Val. (No. 6340, 23238, 16577, and 24042), *P. acuminata* Ait. (No. 16347 and 16348), *P. rubra* L. (No. 16349), and *V. foetida Rolfe.* (No. 4576 and 2584).

The general characteristics, namely color, figure, texture, fiber orientation, burnish, surface impression, hardness, and odor were observed directly or using a magnifying glass (10x) (Mandang & Pandit, 2002). Thin microtome sectioned samples prepared using the Sass technique were used for microscopic observation (1958). A small cube (1x1x1 cm^3) was cut, softened by soaking it in a solution of glycerine and alcohol (1:1), and then sliced at three sections (transversal, radial, and tangential) using a microtome. The thin slices were cleaned with distilled water, stained with safranin, dehydrated with ethanol solutions of 30%, 50%, 70%, 80%, 96%, and 100%, separately soaked in xylol and toluene, and then mounted on the object glass using Entellan. The anatomical feature was observed using Axio Optilab and AxioVision Rail software 4.8. The IAWA List of Microscopic Features for Hardwood Identification was used as the terminology for anatomical features (Wheeler, Baas, & Gasson, 1989). For each sample, quantitative characteristics were observed 30 times.

Franklin method modified by Rulliaty (1994) was used on maceration process. Matchsticks wood samples were placed into a test tube containing solution of 30% hydrogen peroxide and 60% glacial acetic acid (1:1), then it is heated in a water bath. The separated fibers were washed several times to remove the acid content, stained with safranin, stored in an object-glass, then fiber length, fiber diameter, and lumen diameter were measured. In order to categorize the quality class of wood fiber as outlined in Table 1, the Runkle ratio (RR), felting power (FP), flexibility ratio (FR), coefficient of rigidity (CR), and Muhlstep ratio (MR), which are derived values of fiber dimension, are determined (Abdurachman et al., 2020). The equations of derived values of fiber dimension as follow:

$$RR = {}^{2w}/_{l} \quad FP = {}^{L}/_{d} \quad FR = {}^{l}/_{d}$$

$$CR = {}^{w}/_{d} \quad MR\ (\%) = \frac{(d^2 - l^2)}{d^2}\ x\ 100$$

Remarks:

W = Wall Thickness l = Lumen Diameter

d = Fiber Diameter L = Fiber Length

III. RESULT AND DISCUSSION

A. General Characteristics

Table 2 lists the general characteristics of eight wood species from the least-known Apocynaceae family. According to the findings of general characteristic observation, the samples share a number of characteristics, including odor, fiber orientation, and wood hardness. All samples do not have a special odor. Heyne (1987) reported that *L. ternatensis* has a pulasari odor at its roots and it can affect the odor on the stems. If the pulasari is not preserved with saltwater, its odor rapidly dissipates, making it difficult to detect the odor of *L. ternatensis* wood. If preserved with saltwater, this odor is often used as a fragrance for clothing. The pulasari fragrance will be stronger and more last after preservation.

Most species have rather hard for hardness, except *L. ternatensis* with moderately soft and *V. foetida* with slightly soft. Heyne (1987) mentioned that *E. macrocarpa* possesses very soft wood, which might be observed in green condition, whereas these wood samples were observed in dry conditions. The sample also has a slippery to rough surface impression. Plumeria, *K. flavida*, and *E. aurantiaca* give of slippery impression; *E. sphaerocarpa*, *L. ternatensis* are rough; *E. macrocarpa* is rather rough, and *V. foetida* is slightly slippery. The impression usually correlates with burnishing. Burnish in all areas was seen in *E. aurantiaca* and Plumeria. Burnish of *E. macrocarpa* was mainly in the radial and tangential section; burnish in cross-section is only owned by *E. sphaerocarpa*. The other species, namely *V. foetida* is not glossy, *K. flavida* is rather dull, and *L. ternatensis* is very dull. Although *P. acuminata* typically has a beautiful burnish and pattern, it is difficult to process and intact wood is hard to come by. As a result, it is employed as the raw material for household utensils and sculptures (Heyne, 1987). Result showed that there is a correlation between burnish and surface impression. Shiny wood tends to have a slippery surface impression, while the dull wood tends to have rough impression when touched. Moreover, generally, wood with bigger diameter of lumina and/or higher frequency of vessel tends to have a rough surface impression when touched.

Table 1. Criteria of fiber class quality for pulp and paper

Criteria	Class I		Class II		Class III	
	Requirement	Value	Requirement	Value	Requirement	Value
Fiber length (μm)	>2000	100	1000-2000	50	<1000	25
Felting power (FP)	>90	100	50-90	50	<50	25
Muhlsteph ratio (MR)	<30	100	30-60	50	60-80	25
Flexibility ratio (FR)	>0.80	100	0.50-0.80	50	<0.50	25
Runkle ratio (RR)	<0.25	100	0.25-0.50	50	0.50-1.0	25
Coef. of rigidity (CR)	<0.10	100	0.10-0.15	50	>0.15	25
Scoring	450-600		225-449		<225	

Table 2. General characteristic of eight wood species of the least-known timber from Apocynaceae

Species	General Characteristics							
	Color	Figure	Texture	Fiber Orientation	Burnish	Surface Impression	Hardness	Odor
E. aurantiaca	Light brown	Plain	Smooth	Straight	Shiny in all areas	Slippery	Rather hard	No special odor
E. macrocarpa	Brown	Bands are indistinct in longitudinal section due to color differences	Rather coarse	Straight	Shiny mainly in longitudinal section	Rather rough	Rather hard	No special odor
E. sphaerocarpa	Yellowish-brown	Bands are indistinct in radial and tangential sections due to color differences	Smooth	Straight	Shiny in axial section	Rough, slippery in axial section	Rather hard	No special odor
K. flavida	Light brown	Bands are indistinct in longitudinal	Very smooth	Straight	Rather dull	Slippery	Rather hard	No special odor
L. ternatensis	Gray-brown	Bands are indistinct in all section	Very smooth	Straight	Very dull	Rough	Moderately soft	No special odor
P. acuminata	Reddish-brown	Bands are indistinct in all section	Rather coarse	Straight	Shiny in all areas	Slippery	Rather hard	No special odor
P. rubra	Dark brown	Bands are indistinct in all section	Smooth	Straight, semi interlocked	Shiny in all areas	Slippery	Rather hard	No special odor
V. foetida	Yellow-brown	Likely plain	Rather coarse	Straight	Not glossy	Rather slippery	Slightly soft	No special odor

Brown in color, each sample has a distinct tendency. On *E. aurantiaca* and *K. flavida*, it appeared as light brown; on *E. macrocarpa*, brown; on *P. rubra*, dark brown; on *E. sphaerocarpa* and *V. foetida*, yellowish brown; on *L. ternatensis*, gray; and on *P. acuminata*, reddish brown. According to Heyne (1987), *E. macrocarpa* has a white and beautiful color that is used for keris sheaths, which need a beautiful appearance. According to Heyne's report, the lengthy storage period may be the cause of the changing color. The colors, patterns, and burnish of all the samples were not prominent. For some species, general characteristics—such as color, pattern, and burnish—are crucial to identification process, and finishing process will emphasizes this appearance (Wahyudi, 2013). Yet, wood strength and durability are more crucial for wood processing.

Seng (1964) reported *E. macrocarpa*, *E. spaherocarpa*, *L. ternatensis*, and *V. foetida* are in the durability class V; Kopsia is in the durability class IV; *P. acuminata* and *P. rubra* are in the durability class IV/V. Due to their poor durability class, these wood species are easily destroyed by wood-destroying organisms, necessitating preservation measures like painting or varnishing. *E. macrocarpa*, *E. sphaerocarpa*, Kopsia, *L. ternatensis*, and *V. foetida* are in the strength class III, while *P. acuminata* and *P. rubra* are in the strength class II (Seng, 1964). Jelutung (*Dyera* spp.) and pulai, (*Alstonia* spp.) which belong to Apocynaceae, have the same strength class (III – V) with observed species. Jelutung (strength class III-IV) has a high potential for drawing tables, moulds, clogs and carvings, battery separators, pencils, and plywood, while pulai (strength class IV-V) can be used as crates, matches, concrete moulds, and handicraft items such as clogs, wayang golek, masks, and others (Idris et al., 2008).

B. Anatomical Structures

Anatomical features of eight wood species from five genera of the least-known timber from Apocynaceae are represented in Table

3. The IAWA List of Microscopic Features for Hardwood Identification was shown by numerical symbols in Table 3 (Wheeler et al., 1989). All studied samples of Apocynaceae have indistinct or absent growth ring (Fig. 1). This anatomical feature matches with database from http://insidewood.lib.ncsu.edu, which reported that *Ervatamia* spp., *L. ternatensis*, *V. grandifolia*, *V. thouarsii* have the same tendency of absent growth ring. The seasonality of provenance is related to this growth ring boundary. But, this type of boundary is also one of the considerations that can be used to diagnose or identify wood within Apocynaceae.

All studied Apocynaceae showed wood diffuse-porous feature (Figure 1). For the vessel grouping, these studied samples showed that all features of vessel grouping listed on IAWA list of microscopies features for hardwood identification are identified. Solitary vessel,

Table 3. Anatomical features of eight wood species of the least-known timber from Apocynaceae

Species	No. Collection	Growth Rings	Vessels	Fibers	Parenchyma	Rays	Mineral Inclusions
E. aurantiaca	14905	2	5,7, 9, 10v, 40, 48, 49, 52, 13, 22, 24, 30	65, 72, 61, 63, 69	75	116, 97, 96, 107,108, 109	159, 160
	16352	2	5,7, 10, 11, 40, 49, 53, 13, 22, 24, 30	65, 72, 61, 63, 69	75	116, 97, 96, 108, 105, 109	136, 137, 154
E. macrocarpa	19188	2	5, 7, 10, 11, 41, 48, 53, 54, 13, 58v, 22, 24, 30	65, 73, 61, 63, 69	75	115, 97,98, 96, 107, 108,109	136, 137, 154, 155, 159, 160
	17196	2	5, 7, 10, 11, 41, 49, 53, 54, 13, 22, 24, 30	65, 73, 61, 63, 69	75	115, 97,98, 96, 107, 108, 109, 112v	136, 137, 154, 155
	21682	2	5, 7, 10v, 11v, 41, 48, 54, 13, 22, 24, 30	65, 73, 61, 63, 68	75	102v, 115, 97,98, 96, 107, 109, 112v	136, 137, 154
E. sphaerocarpa	2081	2	5, 7, 10, 11, 40, 41, 48, 53, 13, 58v, 22, 24, 30	65, 73, 61, 63, 69	75	115, 98, 96, 107, 108, 109, 112v	136, 137, 138, 155, 156
K. flavida	3337	2	5,7, 10v, 11v, 41, 47,48, 53, 54, 13, 58v, 22, 24, 30	65, 66, 73, 61, 63, 69	75	116, 97, 96, 100, 107, 108, 105, 109	140, 152, 153
L. ternatensis	6340	2	5, 7, 10, 11, 41, 49, 54, 13, 58v, 22, 24, 30	65, 73, 61, 63, 70	76, 93, 94	102, 116, 97, 100, 108, 109	
	16577	2	5, 7, 10, 11, 41, 49, 54, 13, 22, 24, 30	65, 73, 61, 63, 70	76, 93, 94	102, 115, 116, 97, 100, 108, 109, 112v	
	23238	2	5, 7, 10, 11, 41, 49, 54, 13, 22, 24, 30	65, 73, 61, 63, 70	76, 93, 94	102, 116, 97, 100, 108, 109, 112v	
	24042	2	5, 7, 10, 11, 41, 49, 54, 13, 22, 24, 30	65, 73, 61, 63, 70	76, 93, 94	102, 116, 97, 100, 108, 109, 112v	
P. acuminata	16347	2	5, 7, 10, 11, 41, 48, 53, 13, 22, 25, 30	65, 73, 61, 63, 70	76, 77, 92, 93	114, 115, 97, 106, 109	136, 142, 159, 160
	16348	2	5, 7, 10, 11, 41, 47, 53, 13, 22, 25, 30	65, 73, 61, 63, 70	76, 77, 92, 93	115, 97, 98, 106, 107, 109	136, 142, 159, 160

Table 3. Continued

Species	No. Collection	Growth Rings	Vessels	Fibers	Parenchyma	Rays	Mineral Inclusions
P. rubra	16349	2	5, 7, 10, 11, 41, 47, 53, 54, 13, 58, 22, 24, 30	65, 72, 73, 61, 63, 70	76, 77, 92, 93, 94	115, 97, 106, 107, 109, 112v	159, 160
V. foetida	2584	2	5, 7, 9, 10v, 11v, 41, 48, 54, 13, 22, 24, 30	65, 72, 73, 61, 63, 69	75	115, 116, 98, 96, 107, 108, 105, 109, 112v, 100	
	4576	2	5, 7, 9, 10v, 11v, 6v, 41, 48, 49, 53, 13, 22, 24, 30	65, 72, 61, 63, 69	75	115, 98, 96, 107, 108, 105, 109, 112v, 100	

Note: The numerical symbols stand for IAWA List of Microscopic Features for Hardwood Identification (Wheeler et al., 1989).

vessel in radial multiples of 4 or more, and vessel clusters are found in this Apocynaceae. Most of Ervatamia showed vessel in radial multiples and cluster. Vessels partly solitary, partly in radial multiples of 4 or more, or very small cluster are shown in *E. aurantiaca* (No. 14905) (Figure 1A and B); vessels cluster common, partly in radial multiples, or very small solitary are shown in *E. macrocarpa* (No. 21682) (Figure 1C - E); while vessels in radial multiples of 4 or more and vessels cluster are predominantly in *E. sphaerocarpa*. Insidewood and Ingle and Dadswell (1953) reported that vessels of *Ervatamia* spp. are predominantly in radial multiples of 4 or more. Kopsia flavida showed that vessels are mostly radial multiples with wide range of length (Figure 1G). All of the samples of *L. ternatensis* showed that vessels in radial multiples of 4 or more are dominant (Figure 1H - K), which match with the database from Insidewood. Meanwhile, Plumeria showed vessel in radial multiples with wide range of length and in clusters (Figure 1L - N). Partly solitary vessel and vessel in radial multiples of 2 are predominantly shown in *V. foetida* (No. 2584) (Figure 1O), while vessel in radial multiples of 4 or more and very small solitary are predominantly found in *V. foetida* (No.4576) (Figure 1P). Almost all of the studied samples showed vessels in diagonal and/ or radial pattern, with exception for *V. foetida* which showed a tangential bands of vessels arrangement (Figure 1P).

The studied Apocynaceae have vessel frequencies range from 12.78 – 94.47 per sq.mm, with Ervatamia having a vessel frequency of 23.94 – 94.47 per sq.mm, *K. flavida* having a vessel frequency of 19.68 – 21.58 per sq.mm, *L. ternatensis* having a vessel frequency of 58.29 – 92.37 per sq.mm, Plumeria having a vessel frequency of 12.78 – 24.63 per sq.mm, and *V. foetida* having a vessel frequency of 29.09 – 43.77 per sq.mm. These findings demonstrated that the quantitative vessel frequency from Apocynaceae varied widely in this investigation. However, it can be noted that each of the genera analyzed has a distinct pattern; for example, Ervatamia and *L. ternatensis* have a wide range of up to 90 per sq. mm, whereas *V. foetida* is about 30 to 40 per sq. mm and Plumeria and *K. flavida* are about 20 per sq. mm. The mean vessel element length ranges from 550.7 – 1272.6 μm, which mean vessel element length of Ervatamia ranges 677.3 – 1272.6 μm, *K. flavida* 729.3 – 945.3 μm, *L. ternatensis* 802.9 – 1193.5 μm, Plumeria 550.7 – 818.1 μm, and *V. foetida* 632.7 – 998.6 μm. All studied Apocynaceae also showed a large range variation mean vessel element length.

All studied Apocynaceae showed a simple perforation plate. Insidewood and Ingle and Dadswell (1953) also reported this simple perforation plate feature for several species of Apocynaceae. Furthermore, Insidewood reported that *L. ternatensis* has scalariform perforation plates, however our investigation was unable to detect it in any samples (No. 6340, 16577, 23238, and 24042) (Table 3). Intervessel pits are generally arranged in an alternate pattern for all examined Apocynaceae. Insidewood and Ingle and Dadswell (1953) reported that some species of Ervatamia and Voacanga, as well as *L. ternatensis* has alternate intervessel pits. Intervessel pit sizes ranges from 2.04 – 5.25 μm, with Ervatamia's pit sizes ranging between 2.04 μm and 5.21 μm, *K. flavida*'s between 2.76 μm and 3.00 μm, *L. ternatensis*'s between 2.18 μm and 3.01 μm, Plumeria's between 3.61 μm and 5.25 μm, and *V. foetida*'s between 2.69 μm and 3.61 μm. All ranges of pit size in these studied samples are categorized in minute and small pit size, and considerable as diagnostic value. Vessel - ray pits of all studied Apocynaceae samples are similar to intervessel pits in size and shape with distinct border.

Examined Apocynaceae have both septate and non-septate fibers (Figure 2). The examined Apocynaceae have a fiber length range of 1267.4 – 2815.2 μm, of which Ervatamia's range is 1267.4 – 2658.5 μm, *K. flavida*'s range is 1617.8 – 1780.5 μm, *L. ternatensis*'s range is 2028.3 – 2815.2 μm, Plumeria's range is 1581.1 – 1964.0 μm, *V. foetida*'s range is 1427.7 – 1759.4 μm. Based on IAWA List of microscopic features for hardwood identification, it can be concluded that fiber length from these studied Apocynaceae categorized into two, i.e., 900 – 1600 μm and ≥1600 μm. Simple to minutely bordered pits of fiber are found on all studied Apocynaceae, which are common in both radial and tangential walls. Fiber wall thickness are varied from thin- to thick-walled and very thick-walled. All studied species from Ervatamia, *K. flavida*, and *V. foetida* have thin- to thick-walled, while all studied species from Plumeria and *L. terratensis* have very thick-walled. It is suspected that *E. sphaerocarpa* (No. 2081) has helical thickening, but it is still doubtful because it is a tropical plant. Damayanti (2010) stated that tropical plants typically exhibit helical thickening. Thus, the presence of this helical thickening is expected due to the rapid wood growth of this E. sphaerocarpa.

All examined species from Ervatamia, *K. flavida*, and *V. foetida* had axial parenchyma that was absent or extremely rare; however, *L. ternatensis* had diffuse apotracheal axial parenchyma and all examined species from Plumeria had diffuse apotracheal axial parenchyma along with diffuse-in-aggregates apotracheal parenchyma (Figure 1). The apotracheal axial parenchyma of *L. ternatensis* has a length of 5–8 or more cells per parenchyma strand, while the axial parenchyma of Plumeria has a length of 3–4 cells, 5–8, or more cells per parenchyma strand. Rays show the whole range of IAWA list of ray cells composition except the composition of all ray cells procumbent (Figure 3). All studied species from Ervatamia, *K. flavida*, and *V. foetida* show composition of all ray cells upright and/ or square, body ray cells procumbent with one row, 2 – 4 rows, or more than 4 rows of upright and/ or square marginal cells, and rays with procumbent, square and upright cells mixed throughout the ray. All studied species of Plumeria only show composition of body ray cells procumbent with one row or 2 – 4 rows of upright and/ or square marginal cells and rays with procumbent, square, and upright cells mixed throughout the ray, while *L. terratensis* shows compositions of body ray cells procumbent with more than 4 rows of upright and/ or square marginal cells, and rays with procumbent, square, and upright cells mixed throughout the ray. Each species has combination of rays' composition, which Ervatamia, *K. flavida*, and *V. foetida* show a large range and *L. ternatensis* has the shortest range in all studied species. Due to the wide range of rays' composition, its diagnostic and taxonomic value are limited (Baas, Esser, van der Westen, & Zandee, 1988). Ray height vary from 216.5 to more than 1000 μm, with *L. ternatensis* having the longest ray at >1000 μm, followed by Ervatamia, *V. foetida*, *K. flavida*, Plumeria, which have height of 444.5 to 1048.7 μm, 552.2 to

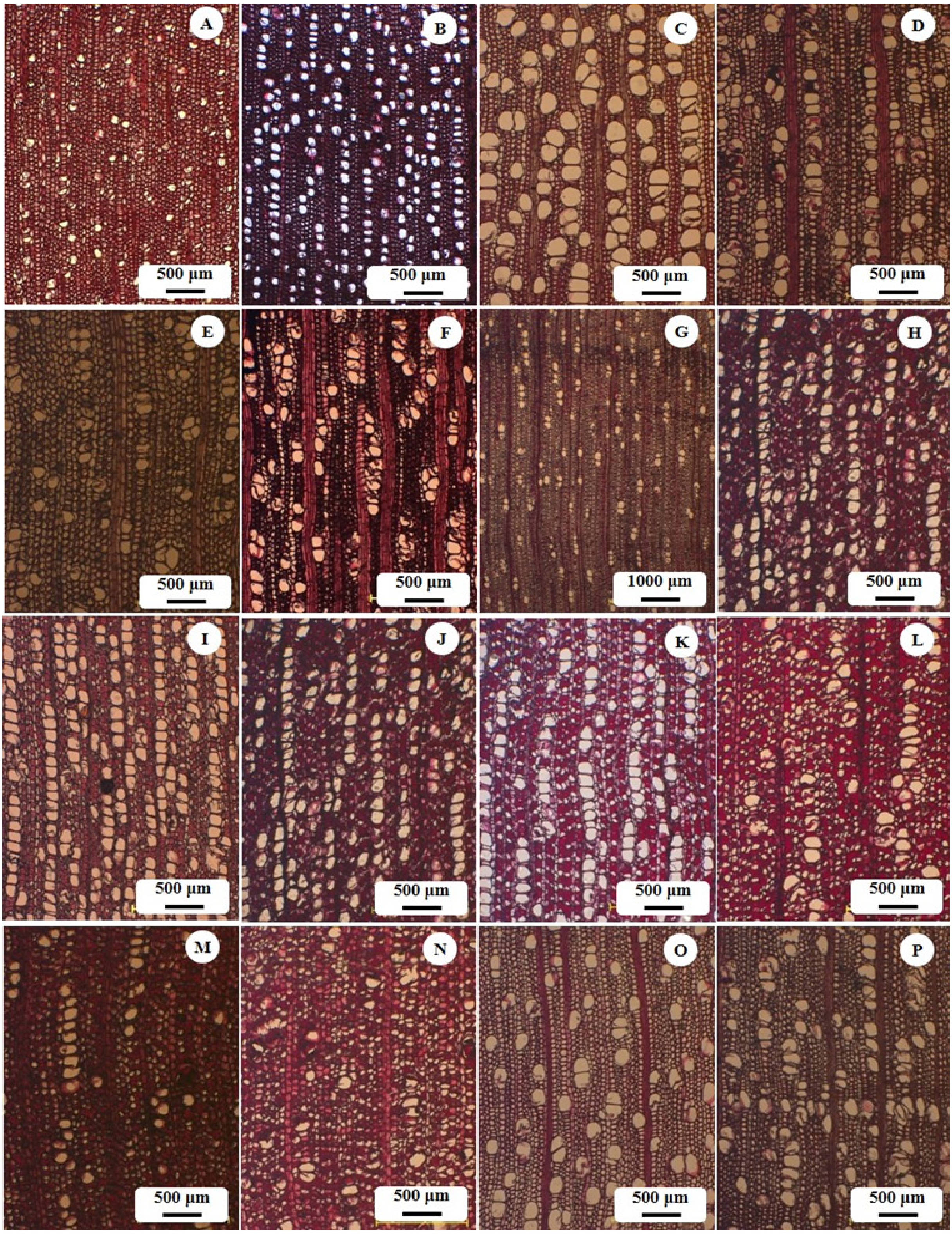

Figure 1. Light microscope images of transverse sections. (A) *E. aurantiaca* No. 14905. (B) *E. aurantiaca* No. 16352. (C) *E. macrocarpa* No. 17196. (D) *E. macrocarpa* No. 19188. (E) *E. macrocarpa* No. 21682. (F) *E. sphaeroarpa* No. 2081. (G) *K. flavida* No. 3337. (H) *L. ternatensis* No. 16577. (I) *L. ternatensis* No. 6340. (J) *L. ternatensis* No. 23238. (K) *L. ternatensis* No. 24042. (L) *P. acuminata* No. 16347. (M) *P. acuminata* No. 16348. (N) *P. rubra* No. 16349. (O) *V. foetida* No. 2584. (P) *V. foetida* No. 4576

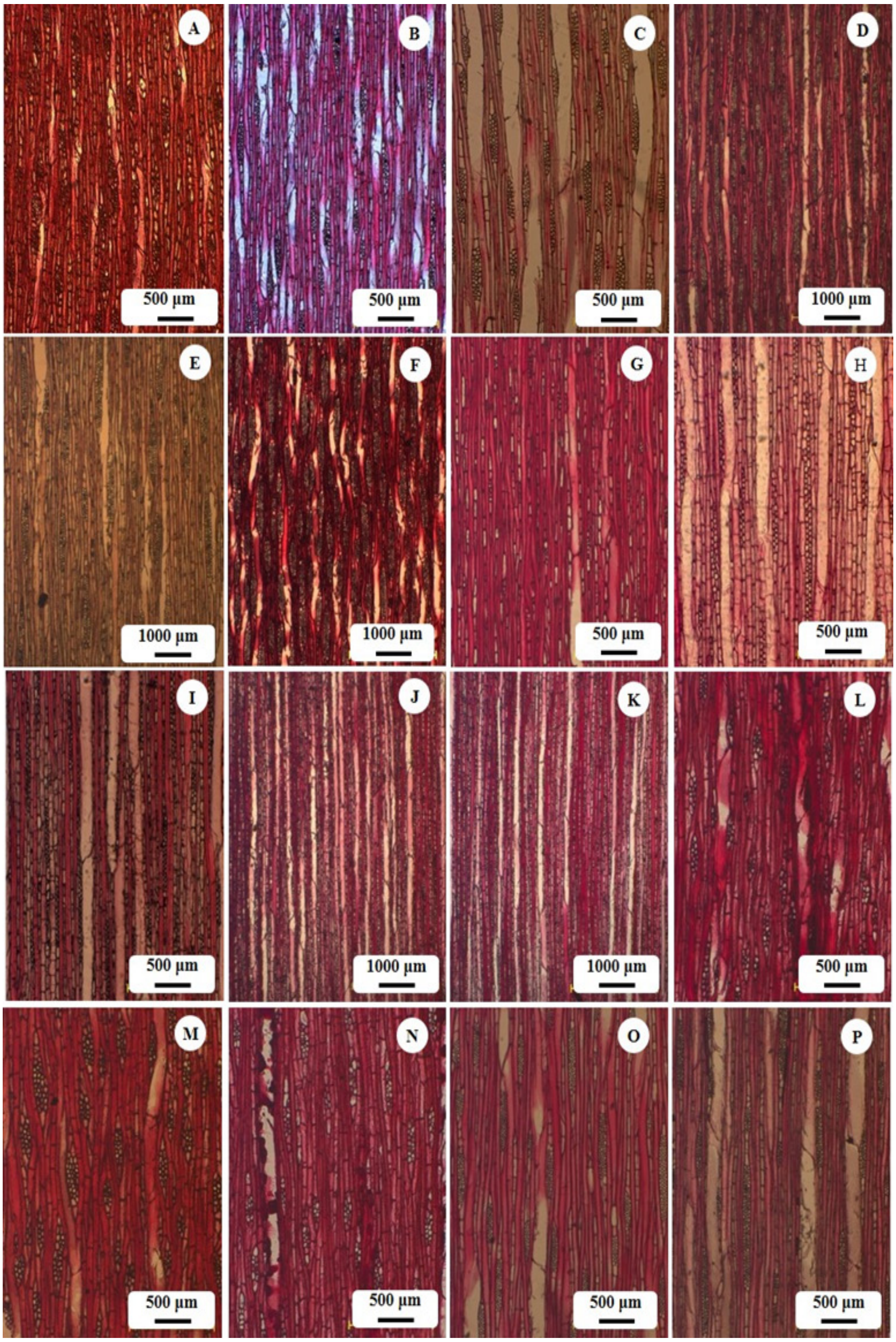

Figure 2. Light microscope images of tangential longitudinal sections. (A) *E. aurantiaca* No. 14905. (B) *E. aurantiaca* No. 16352. (C) *E. macrocarp*a No. 17196. (D) *E. macrocarpa* No. 19188. (E) *E. macrocarpa* No. 21682. (F) *E. sphaeroarpa* No. 2081. (G) *K. flavida* No. 3337. (H) *L. ternatensis* No. 16577. (I) *L. ternatensis* No. 6340. (J) *L. ternatensis* No. 23238. (K) *L. ternatensis* No. 24042. (L) *P. acuminata* No. 16347. (M) *P. acuminata* No. 16348. (N) *P. rubra* No. 16349. (O) *V. foetida* No. 2584. (P) *V. foetida* No. 4576

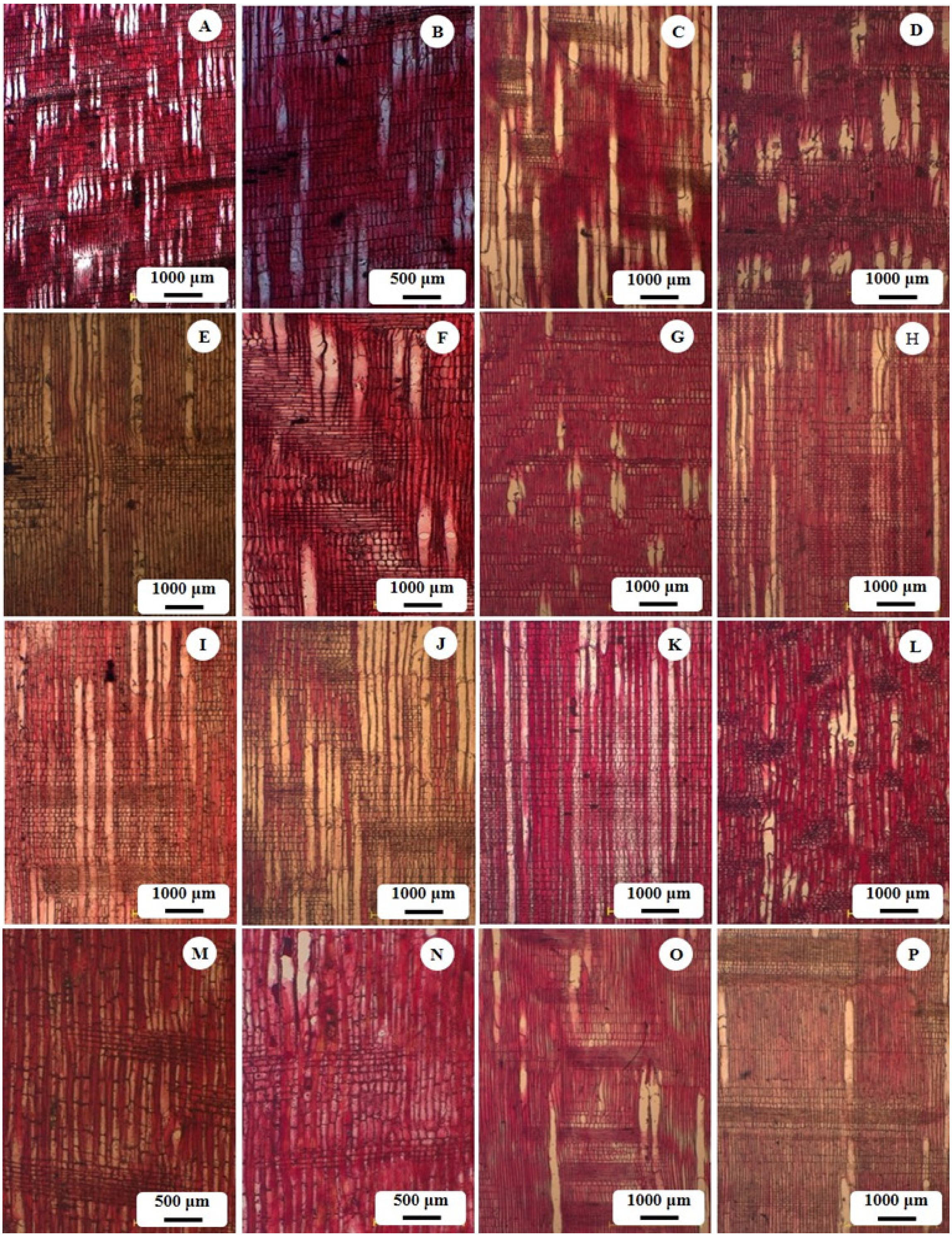

Figure 3. Light microscope images of radial longitudinal sections. (A) *E. aurantiaca* No. 14905. (B) *E. aurantiaca* No. 16352. (C) *E. macrocarpa* No. 17196. (D) *E. macrocarpa* No. 19188. (E) *E. macrocarpa* No. 21682. (F) *E. sphaeroarpa* No. 2081. (G) *K. flavida* No. 3337. (H) *L. ternatensis* No. 16577. (I) *L. ternatensis* No. 6340. (J) *L. ternatensis* No. 23238. (K) *L. ternatensis* No. 24042. (L) *P. acuminata* No. 16347. (M) P. acuminata No. 16348. (N) *P. rubra* No. 16349. (O) *V. foetida* No. 2584. (P) *V. foetida* No. 4576

816.1 µm, 451.2 to 659.6 µm, 216.5 to 471.4 µm, respectively.

Ray width may be between 1 and 10 cells; however, 1 to 3 cells is the most typical range. Rays with multiseriate portion(s) as wide as uniseriate portions are found in *L. ternatensis* and *V. foetida*, and it is also presumed to be found in *E. macrocarpa*. Ervatamia has ray cell frequency ranging from 7.14 to 16.38 ray cells per mm, *K. flavida* has ray cell frequency ranging from 17.65 to 19.02 ray cells per mm, *L. ternatensis* has ray cell frequency ranging from 11.27 to 17.65 ray cells per mm, Plumeria has ray cell frequency ranging from 3.48 to 4.98 ray cells per mm, *V. foetida* has ray cell frequency ranging from 10.79 to 12.37 ray cells per mm are found in. Perforated ray cells are sometimes found in some studied species of Ervatamia, *L. ternatensis*, *P. rubra*, and *V. foetida*, but it is rarely found.

The most common shape of mineral inclusion in all samples is the prismatic crystal, which consists of two or more crystals of the same size or different sizes in each cell or chamber in procumbent or upright ray cells. Additionally, *P. acuminata*'s axial parenchyma cells contain this prismatic crystal. Some species of Ervatamia and Plumeria that have been observed have silica bodies in their ray cells. *K. flavida* contains crystal sand or other shapes of crystal in chambered upright ray cells. It is assumed that *E. macrocarpa* and *V. foetida* contain oil and/ or mucilage cells associated with ray parenchyma. Although Insidewood reports that *L. ternatensis* has prismatic crystal in both axial parenchyma cells and upright and/or procumbent ray cells, no crystal has been observed in *L. ternatensis* in this study. According to Fromm (2013), differences in a plant's age led to variations in cell size, shape, and crystallization. Less crystallization occurs when a plant is younger. Plant metabolism, which is influenced by the environment, has an impact on the presence of mineral inclusions (Metcalfe & Chalk, 1983). It is assumed that the presence of crystals represents a metabolic waste product, a structural reinforcement of plants, protection against herbivores, or a mechanism of drought self-protection. The existence of crystals in a plant species is thus yet uncertain, despite the fact that it is generally stable.

C. Fiber Quality

Table 4 lists the fiber length of eight wood species along with its derived values. It was confirmed that *E. sphaerocarpa* and *K. flavida* belong in to quality class of II, *E. aurantiaca*, *L. ternatensis*, *P. acuminata*, and *P. rubra* belong in to quality class of III, and *E. macrocarpa* and V. foetida belong in to quality classes of II and III. The differences quality class of each species are caused by the differences of fiber length, cell wall thickness, and lumen diameter. *E. sphaerocarpa* and *K. flavida* have thin cell wall and wide diameter lumen, while *E. aurantiaca*, *L. ternatensis*, *P. acuminata*, and *P. rubra* have thick cell walls and narrow lumen diameter. These species are consequently classified into various quality classes. The *L. ternatensis* fiber was shown to be the longest among the species, although it was given a quality class of III. It seems that *L. ternatensis* fiber quality is more closely connected to the derived fiber values rather than simply the fiber length.

Table 4 showed that *E. macrocarpa* (No. 21682) has the lowest value of RR (0.31), *L. ternatensis* (No. 6340) has the highest value of FP (68.17), *E. macrocarpa* (No. 21682) has the highest value of FR (0.77), *E. macrocarpa* (No. 21682) has the lowest value of CR (0.12), and *V. foetida* (No. 2584) has the lowest value of MR (47.24). The RR value indicates the tensile strength of pulp and paper manufactured from that species, with the lowest RR value indicating greater tensile strength (Supartini, Dewi, Kholik, & Muslich, 2013). As a result, *E. macrocarpa* (No. 21682) pulp and paper will have the greatest tensile strength among other species. The FP value or slenderness ratio could be used to predict the tear strength of pulp and paper (Ververis, Georghiou, Christodoulakis, Santas, & Santas 2004). As a result, among other species, *L. ternatensis* (No. 6340) will produce

Table 4. Fiber Dimension and its derived values of 8 the least-known timber species of Apocynaceae

Species	No. Collection	L (μm)	RR	FP	FR	CR	MR	Class
E. aurantiaca	14905	1352.85	0.67	41.98	0.61	0.20	62.35	III
	16352	1465.08	0.89	46.54	0.54	0.23	70.20	III
E. macrocarpa	19188	1769.28	0.89	50.82	0.54	0.23	70.78	II
	17196	1809.15	0.70	45.84	0.60	0.20	63.41	III
	21682	2210.53	0.31	39.67	0.77	0.12	41.26	II
E. sphaerocarpa	2081	2472.74	1.29	66.72	0.46	0.27	78.28	II
K. flavida	3337	1699.18	0.80	50.85	0.56	0.22	68.25	II
L. ternatensis	6340	2562.45	2.39	68.17	0.33	0.33	87.44	III
	16577	2566.17	1.46	64.68	0.43	0.28	80.61	III
	23238	2142.45	4.78	54.56	0.19	0.41	96.15	III
	24042	2661.33	3.54	59.72	0.24	0.38	93.87	III
P. acuminata	16347	1850.03	2.97	51.70	0.30	0.35	89.24	III
	16348	1829.32	5.58	55.52	0.19	0.40	95.62	III
P. rubra	16349	1662.81	1.86	47.57	0.38	0.31	84.25	III
V. foetida	2584	1659.19	0.39	40.06	0.72	0.14	47.24	II
	4576	1512.15	0.65	41.38	0.61	0.19	62.42	III
Remarks:	L = fbre length			RR = Runkel Ratio			FP = felting point	
	FR = flexibility			CR = coefficient of rigidity			MR = Muhlstep Ratio	

pulp and paper with the highest tear strength.

The tensile strength, folding resistance, and density of pulp and paper may be predicted using the value of FR (Supartini et al., 2013). The results showed that *E. macrocarpa* (No. 21682), which has the greatest value of FR, would produce pulp and paper with the best tensile strength, folding resistance, and density compared to other species. *E. macrocarpa* (No. 21682), among other species, is expected to produce the highest pulp yield and density based on CR value (Supartini et. al., 2013). Additionally, it is possible to determine from the MR value that *V. foetida* (No. 2584) would produce pulp and paper with a high tear resistance.

As a result of its strong fiber bonding and ease of beating, fiber with quality class II will produce sheets with a moderate tear, rupture, and tensile strength. In contrast, class III fiber is tough to beat and produces sheets with poor tensile, rupture, and tear strengths (Abdurachman et al., 2020. Due to this, *E. macrocarpa* (No. 19188 and 21682), *E. sphaerocarpa*, *K. flavida*, and *V. foetida* (No. 2584) are predicted to have the potential to be utilized as pulp and paper material. It is recommended to utilize *E. aurantiaca*, *E. macrocarpa* (No. 17196), *L. ternatensis*, *P. acuminata*, *P. rubra*, and *V. foetida* (No. 4576) for other uses than being used as pulp and paper's raw material. While for *E. aurantiaca*, *E. macrocarpa* (No. 17196), *L. ternatensis*, *P. acuminata*, *P. rubra*, and *V. foetida* (No. 4576) can be potentially considered for other uses such as engineered wood products, veneer, and furniture component. As it mentioned by Oey (1990) that *E. macrocarpa* had specific gravity 0.55, durability class V and strength class III; *L. ternatensis* had specific gravity 0.52, durability class V and strength class III; both *P. acuminata* and *P. rubra* had specific gravity 0.62-0.63, durability class IV/V and strength class II.; and *V. foetida* had specific gravity 0.44, durability class V and strength class III.

IV. CONCLUSION

In conclusion, wood from the Apocynaceae family in this research had brown, light brown, dark brown, yellow-brown, gray brown, and reddish-brown colors; plain or with patterns in the form of indistinct bands in the longitudinal, tangential, or all section; very fine to slightly coarse texture; the direction of the fibers is straight or semi interlocked; very dull to shiny; the surface impression of rough to smooth in one or all section; soft to rather hard; does not have a special odor; wood diffuse-porous arranged in diagonal or radial pattern; growth ring boundaries indistinct; the vessel in radial multiples of 4 or more is common; simple perforation plate, intervessel pits alternate; vessel ray pits with distinct border; similar to intervessel pits in size and shape; fibers with simple to minutely bordered are common in both radial and tangential section. Based on general characteristics, commonly Apocynaceae can be used as raw material for handicrafts. Some species, such as *E. macrocarpa*, *E. sphaerocarpa*, *K. flavida*, and *V. foetida* are potential as pulp and paper materials with medium quality (Quality Class II). Further research is needed to fully understand the properties of these "the least-known species", such as mechanical properties, durability, etc.

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REFERENCES

Abdurachman, Akbar A, …., Yuniawati. (2020). Vademecum Kehutanan Indonesia. Kementerian Lingkungan Hidup dan Kehutanan.

Ali, A. C., Uetimane Jr, E., Lhate, I. A., & Terziev, N. (2008). Anatomical characteristics, properties, and use of traditionally used and lesser-known wood species from Mozambique: a literature review. *Wood Science and Technology*, *42*, 453-472.

Areo, O. S. (2021). *Wood properties and natural durability of Artocarpus altilis (Parkinson Ex F.A. Zorn) Fosberg* (Unpublished doctoral dissertation). University of Ibadan, Ibadan.

Baas, P., Esser, P. M., van der Westen, M. E. T., & Zandee, M. (1988). Wood anatomy of the Oleaceae. *IAWA Bulletin*, *9*(2), 103-182.

Brunner, M., Appiah-Kubi, E., Zurcher, N., Reinhard, M., & Kankam, C. K. (2008). WAWABIMA: outstanding mechanical properties of some lesser-known timber species in Ghana. *Proceedings of world conference on timber engineering*, *WCTE*, 2-9.

Chowdhury, M. Q., Sarker, S. K., Deb, J. C., & Sonet, S. S. (2013). Timber species grouping in Bangladesh: linking wood properties. *Wood Science and Technology*, *47*, 797-813.

Chowdhury, P., Hossain, M. K., Hossain, M. A., Dutta, S., & Ray, T. K. (2017). Status, wood properties, and probable uses of lesser-used species recorded from Sitapahar Reserve Forest of Bangladesh. *Indian Forester*, *1439*(12), 1241-1248.

Damayanti, R. (2010). Macro, micro, and ultramicroscopic structure of superior Indonesia teak and conventional teak (Master's thesis). Institut Pertanian Bogor, Bogor.

Damayanti, R., & Dewi, L. M. (2019). Wood anatomy and fiber quality of the least-known timbers belong to Actinidiaceae from Indonesia. *Wood Research Journal*, *10*(2), 33-38.

Damayanti, R., & Rulliaty, S. (2010). Anatomical properties and fiber quality of five potential commercial wood species from Cianjur, West Java. *Journal of Forestry Research*, *7*(1), 53-69.

Damayanti, R., & Rulliaty, S. (2011). Anatomical structure and fibre quality of least known wood timbers belongs to bignoniaceae from Indonesia. *Proceeding of International Conference* *of Indonesian Forestry Researchers* (INAFOR).

Fromm, J. (2013). *Cellular aspects of wood formation*. Heidelberg: Springer.

Glass, S. V., & Zelinka, S. L. (2010). Moisture relations and physical properties of wood. In R. J. Ross (Eds.), *Wood handbook: Wood as an engineering material* (pp. 70-88). Madison: USDA Forest Service.

Haag, V., Koch, G., Melcher, E., & Welling, J. (2020). Characterization of the wood properties of Cedrelinga cateniformis as substitute for timbers used for window manufacturing and outdoor applications. *Maderas: Ciencia Y Tecnologia*, *22*(1), 23-36.

Hamdan, H., Nordahlia, A. S., Anwar, U. M. K., Iskandar, M. M., Omar, M. K. M., & Tumirah. (2020). Anatomical, physical, and mechanical properties of four pioneer species in Malaysia. *Journal of Wood Science*, *66*(59), 1-9.

Hedge, N. (2019). *Physical and mechanical properties of lesser-known timber species of Mizoram* (Unpublished doctoral dissertation). Mizoram University, Aizawl.

Heyne, K. (1987). *De Nuttige planten van Indonesië*, *Vol. 3*. In M. S. Hardjodarsono, S. Soerohaldoko, Y. I. Mandang, S. R. Gadas, S. Partosatmoko, B. Moeljosoedirdjo, O. S. Hardjodarsono, & S. W. Sapoetro (translator). Jakarta: Yayasan Sarana Wana Jaya.

Idris, M. M., Rachman, O., Pasaribu, R. A., Roliadi, H., Hadjib, N., Muslich, M., Jasni, Rulliaty, S., & Siagian, R. M. (2008). *A handbook of Selected Indonesian Wood Species*. Jakarta: Indonesian Sawmill and Woodworking Association.

Ingle, H. D., & Dadswell, H. E. (1953). The anatomy of the timbers of the South-West Pacific. II. Apocynaceae and Annonaceae. *Australian Journal of Botany*, *1*, 1-26.

Korkut, S. (2011). Physical and mechanical properties and the use of lesser-known native silver lime (Tilia argentea Desf.) wood from Western Turkey. *African Journal of Biotechnology*, *10*(76), 17458-17465.

Mandang, Y. J., & Pandit, I. K. N. (2002). *Guidelines for wood identification in the field*. In: S. Prawirohatmodjo, & S. Danimihardja (eds). Bogor: PROSEA.

Marbun, S. D., Wahyudi, I., Suryana, J., & Nawawi, D. S. (2019). Anatomical structures and fiber quality of four lesser-used wood species grown in Indonesia. *Journal of The Korean Wood Science and Technology*, *47*(5), 617-632.

Metcalfe, C. R. & Chalk, L. (1983). *Anatomy of the dicotyledons: wood structure and conclusion of the general introduction, Vol. 2*. Oxford: Oxford University Press.

Oey, DS. (1964). Specific gravity of Indonesian woods and its significance for practical use (in Indonesian). Bogor: Pusat Penelitian dan Pengembangan Hasil Hutan.

Pandit, I. K. N., & Ramdan, H. (2002). *Anatomy of wood: An introduction to the properties of wood as a raw material*. Bogor: Yayasan Penerbit Fakultas Kehutanan Institut Pertanian Bogor.

Rulliaty, S. (1994). *Wood quality indicators as estimator of juvenile wood in mahogany (Swietenia macrophylla King) from forest plantation in Sukabumi, West Java, Indonesia* (Master's Thesis). University of Philippines Los Banos, Los Banos.

Sass, J. E. (1958). *Botanical microtechnique*. IOWA: The IOWA State Collage Press.

Seng, O. D. (1990). *Specific gravity of Indonesian woods and its significance for practical use*. In: P. H. Soewarsono (translator). Bogor: Pusat Penelitian dan Pengembangan Hasil Hutan Press.

Siam, N. A., Lipeh, S., Uyup, M. K. A., Juhari, M. A. A. A., Talip, N., Amri, C. N. A. C., & Abdulla, N. A. (2022). Anatomical and physical properties of three lesser-known timber species from Malaysia. *Bioresources*, *17*(1), 1090-1105.

Supartini, Dewi, L. M., Kholik, A., & Muslich, M. (2013). Anatomical structure and fiber quality of Shorea hopeifolia (Heim) Symington from East Kalimantan. *Journal of Tropical Wood Science and Technology*, *11*, 29-37.

Tripathi, S.N.; Sahney, M.; Tripathi, A.; Pandey, P.; Jatav, H.S.; Minkina, T.; Rajput, V.D. (2023). Elucidating the anatomical features, adaptive and ecological significance of Kopsia fruticosa Roxb. (Apocynaceae). *Horticulturae*, *9*(3), 387. doi://10.3390/horticulturae9030387.

Jr Uetimane, E., & Ali, A. C. (2011). Relationship between mechanical properties and selected anatomical features of ntholo (Pseudolachnostylis maprounaefolia). *Journal of Tropical Forest Science*, *23*(2), 166-176.

Ververis, C., Georghiou, K., Christodoulakis, N., Santas, P., & Santas, R. (2004). Fiber dimensions, lignin and cellulose content of various plant materials and their suitability for paper production. *Industrial Crops and Products*, *19*, 245-254.

Wahyudi, I. (2013). *The relationship between the anatomical structure of wood and the properties of wood, its uses, and its processing*. Bogor: Forestry Engineering and Forest Product Processing R&D Center-FORDA-Ministry of Forestry.

Wheeler, E. A., Baas, P., & Gasson, P. E. (1989). IAWA list of microscopic features for hardwood identification. *IAWA Bulletin*, *10*(3), 219 – 332.

Wiedenhoeft, A. (2010). Structure and function of wood. In R. J. ROSS (Eds.), *Wood handbook*: *wood as an engineering material* (pp. 52-69). Madison: USDA Forest Service.