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ORIGINAL

Some Indonesian mangrove wood species: wood anatomy and their potential for paper pulp raw material

Algunas especies de madera de manglar de indonesia: anatomía de la madera y su potencial como materia prima de pasta de papel

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ABSTRACT

Introduction: many mangrove wood species exhibit similar physical appearances. Identifying wood based on anatomical characteristics can help to sort, select, and differentiate among various mangrove wood species, with the result that the purpose of their utilization aligns with the characteristics inherent to that species.
Objective: this study aims to analyze the anatomical characteristics of several selected mangrove wood species both macro- and microscopic.
Method: the macroscopic and microscopic features of wood anatomy were observed. The observations were to obtain the differences and similarities of anatomical structures of seven mangrove wood species. The macroscopic features were observed using a 15x magnifying glass and microscope stereo loupe axiovision (1-4 times magnification) directly on wood samples, whereas the microscopic features were observed using a light microscope through microtome slices on three sections of observation.
Results: anatomy features in one genus were no different. The distinct differences of anatomy features were found on intergenus. The fiber of mangrove wood species is grouped in the quality class II to III.
Conclusions: mangrove wood species can be distinguished from each other by differentiation of wood anatomy structures.

Keywords: Identification; Macroscopic; Mangrove; Microscopic; Anatomy Structure; Fiber.

RESUMEN

Introducción: muchas especies de madera de manglar presentan características físicas similares. La identificación de la madera según sus características anatómicas permite clasificar, seleccionar y diferenciar entre las diversas especies, de modo que su aprovechamiento se ajuste a las características propias de cada especie.
Objetivo: este estudio analiza las características anatómicas, tanto macroscópicas como microscópicas, de varias especies de madera de manglar seleccionadas.
Método: se observaron las características macroscópicas y microscópicas de la anatomía de la madera. Las observaciones se realizaron para determinar las diferencias y similitudes en las estructuras anatómicas de siete especies de madera de manglar. Las características macroscópicas se observaron directamente en muestras de madera utilizando una lupa de 15x y un microscopio estereoscópico Axiovision (aumentos de 1

a 4x), mientras que las características microscópicas se observaron mediante un microscopio óptico a través de cortes realizados con un micrótomo en tres secciones de observación.
Resultados: las características anatómicas dentro de un mismo género no mostraron diferencias. Se encontraron diferencias significativas en las características anatómicas entre géneros. La fibra de las especies de madera de manglar se clasifica en las clases de calidad II a III.
Conclusiones: las especies de madera de manglar se pueden distinguir entre sí por la diferenciación de las estructuras anatómicas de la madera.

Palabras clave: Identificación; Macroscópico; Manglar; Microscópico; Estructura Anatómica; Fibra.

INTRODUCTION

The mangrove wood can be used as building and bridge components, pulp and paper, charcoal, firewood, plywood, and so on.[1] The salinity and root system are characteristics that distinguish mangrove forest vegetation from other forest vegetation. According to Idrus et al.[2] in addition to fruit, the existing root system—be it the tunjang root, pencil root, plank root, or knee root—can all be used to identify species. These are no longer useful, unfortunately, if the object is no longer a tree. It is difficult to identify different species if the tree has been felled and become a log or sawn timber product that has no leaves or other phenotypic parts. So, the wood anatomical structure acts as a distinguishing feature between each wood species.

On the other hand, the law process in order to prevent and overcome the recurrence of illegal logging cases requires evidence. The evidence will certainly begin with determining the wood species, so we need a correct understanding of the wood anatomical structures in wood identification. For these reasons, the anatomical structures of wood species, especially from Indonesian mangrove forests, need to be investigated.

Many mangrove forest woods—mainly in lumber—have a similar physical appearance in color and hardness. The lack of information or skill about each wood species' characteristics affected faults in sorting, selecting, and determining the wood species. It will have an impact on the inefficiency and wastefulness of raw materials, because the purpose of using a wood species must be appropriate to the characteristics possessed by the wood species.[3] The inappropriate wood characteristics information will also cause problems in the wood processing, and they can reduce the quality of the product and also can obscure evidence in court if there is an illegal logging case. To prevent all that and conserve the remaining forest resources, the study of wood anatomy characteristics must be continuously encouraged, as it is a key factor for identification of wood species in relation to their most appropriate use. It impacts the prevention of wood waste.

METHOD

Tool and Material

This study is observational. Wood samples were obtained from the mangrove forest area in Indramayu Regency, West Java Province, Indonesia, and Cilacap Regency, Central Java-Indonesia. The main materials were shaped disks with a thickness of 6–10 cm representing the base, middle, and top of the trunk of seven healthy and dominant mature trees. The chemicals used included glacial acetic acid, glycerin, safranin, alcohol, carboxylol, xylene, toluene, 50 % HNO_3, and $KClO_3$. The main equipment used included a loop, cutter, camera, sliding microtome, and light microscope.

Identification of tree species

Confirmation of tree names (species) based on the identification of leaves, flowers, fruit, and bark was carried out at the LIPI Herbarium in Cibinong.

Macroscopic and microscopic feature observation

The directly observation of macroscopic features was carried out using a loupe with a magnification of 15 times and a digital loupe connected to a computer (microscope stereo loupe) with axiovision 1–4 times. The microscopic features were observed using an Olympus microscope CX 23LED. The macroscopic characteristics observed consisted of the presence of growth ring, porosity, wood color, pattern, texture, fiber direction, gloss, touch impression and relative hardness level following standard procedures as Mandang et al.[4].

Microscopic features were observed through microtome preparations on the three sections (cross, radial, and tangential) using a light microscope. The making of microtome preparations followed Gasson et al.[5] The wood sample was softened in a pressure cooker for ± 4 hours and then immersed in a glycerol solution (alcohol, glycerin = 1:1) and then sliced using a microtome to a thickness of 20-25 µm. The best slice was then washed with distilled water, then stained with safranin by sinking it in it for 1-3 minutes, and washed again until free of safranin. The selected slices were dehydrated in stages using alcohol 30, 50, 70, and 96 % (absolute) for 5 minutes, then placed on an object glass, dripped with xylene or toluene, then glued with enthelen, and then covered with a cover glass until ready to be observed. The microscopic features observed consisted of the arrangement as well as the shape and special marks on the cell walls of wood constituents, especially vessels (pores), axial parenchyma, rays, and fibers, as well as intercellular canals as listed according to the IAWA (International Association of Wood Anatomists) identification list of microscopic features for hardwood identification.[6]

The sample preparation

The three discs were obtained from each tree species for analysis (figure 1). The surface of the disc was sanded finely until the heartwood and sapwood boundaries were clear, then two samples sized 3 cm × 3 cm × 6 cm were taken, which represented the heartwood: one for observation of anatomical structures (microtome preparations) and the other for measuring vessel and fiber cell dimensions (maceration preparations) and determining fiber quality classes. The remaining disk portion was used for macroscopic feature observations.

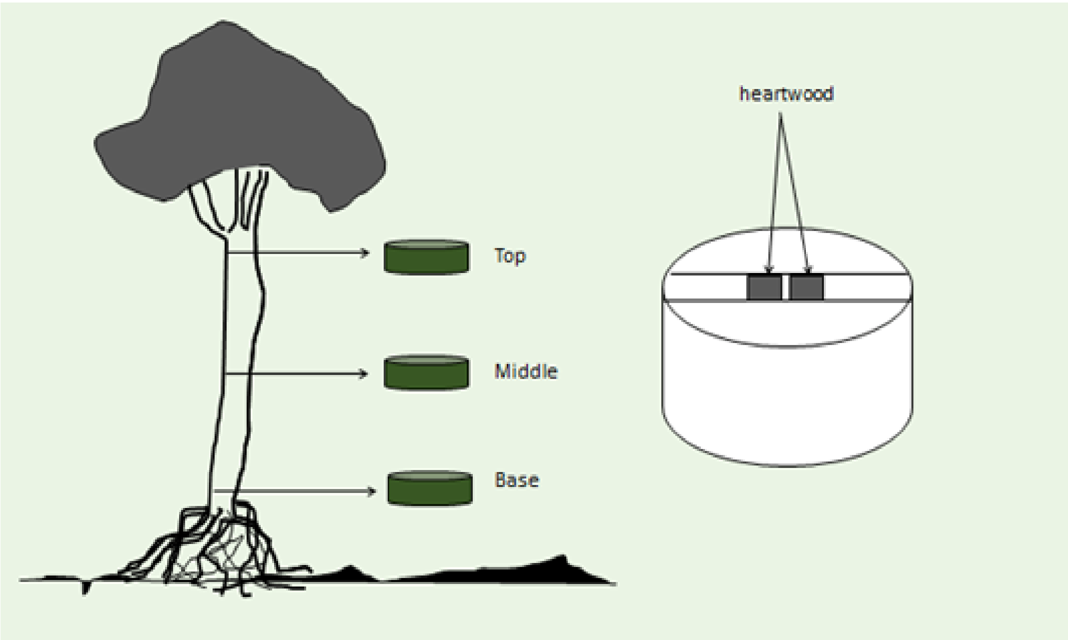

Figure 1. Illustration of wood samples

Fiber dimension measurement

The dimensions of the vessel and wood fibers were measured by maceration preparations which made using the modified Schultze method. The stages of its measuring follow Sass[7] and Tesoro[8]. Wood samples, cut to matchstick size, were placed into a reaction tube. Next, 50 % HNO_3 and $KClO_3$ were added. The tube was then placed in an 80°C water bath until the fibers were separated. Afterward, the reaction tube was shaken to ensure the complete separation of the fibers. The reaction tube is then taken and then shaken in order to separate fibers completely. The separated fibers were filtered and washed with distilled water until free of acid, then it stained with 2 % safranin for 8 hours and washed again until free of safranin. The fibers were then dehydrated, graded with alcohol and then mounted until they were ready to be observed under a microscope for measuring and data collection. A total of 50 fibers and vessels from each wood sample were measured for length and diameter as well as fiber lumen diameter at a magnification of 2,5 times and 20 times using an AxioVision software. The fiber wall thickness was defined as half of the difference between the fiber diameter and the fiber lumen diameter.

The calculation of the derived value of fiber dimensions was carried out based on Silitonga et al.[9].The calculation of fiber quality class as paper raw material is based on Rachman & Siagian.[10] The derivatives of fiber dimensions consist of the Runkel Ratio (RR), Felting Power (FP), Muhlsteph Ratio (MR), Coefficient Rigidity (CR), and Flexibility Ratio (FR). The calculations were as follows:

$$RR = \frac{2w}{l} \qquad FP = \frac{L}{d} \qquad MR = \frac{(d^2 - l^2)}{d^2} \times 100\% \qquad CR = \frac{w}{d} \qquad FR = \frac{l}{d}$$

1 = Fiber lumen diameter (µm); L = Fiber length (µm); d = Fiber diameter (µm); w = Fiber wall thickness (µm)

Data analysis

The quantitative data was calculated based on the average value and standard deviation using Microsoft Excel 2013 and presented in the form of tables or graphs. The qualitative data was presented in the form of photographs and described in a narrative manner. The influence of the wood sample location in the stem (base-middle-top) on the anatomical structure and fiber as well as vessel dimension was statistically analyzed using a significant difference test (t-student) at a 95 % confidence level by the MINITAB program(11) and continued by Duncan's test. The differences and similarities in wood anatomical properties among wood species were based on the observation results approach.

RESULTS

Tree species identification

The tree species identification results are seven tree species, which can be grouped into five genera, namely Bruguiera, Rhizophora, Avicennia, Camptostemon, and Sonneratia. The genus of Bruguiera, Rhizophora, and Camptostemon each consists of one species, namely *B. gymnorhiza*, *R. apiculata,* and *C. philippinensis*, whereas Avicennia and Sonneratia each consist of two species, namely *A. marina*, *A. officinalis*, *S. alba* and *S. caseolaris*.

Macro- and Microscopic Features

B. gymnorhiza

The macroscopic features: growth ring boundaries indistinct; wood diffuse porous; the wood is dark brown to purple-grey, slightly patterned, slightly fine to fine texture; the fiber direction is straight to slightly coalesced and smooth, and the surface is less shiny; it does not have a specific odor; this wood species is classified as hard to very hard.

The microscopic features: vessel grouping is solitary and in radial multiples of 2 to 3; 21-35 vessels per square millimeter, average vessel diameter is 92-115 μm; scalariform perforation plates; intervessel pits scalariform; vessel-ray pits distinct borders, similar to intervessel pits in size and shape throughout the ray cell; sometimes vessel contains tyloses; diffuse (apotracheal) and scanty parenchyma (paratracheal); 2-7 cells per parenchyma strand; ray width 3-7 cells; ray cellular composition: heterocellular, 8 cells procumbent with one row square that contains prismatic crystals; silica in ray; septate fiber present; fiber with bordered pits; average fiber length is 880-1600 μm, and average fiber wall thickness is 6-8 μm.

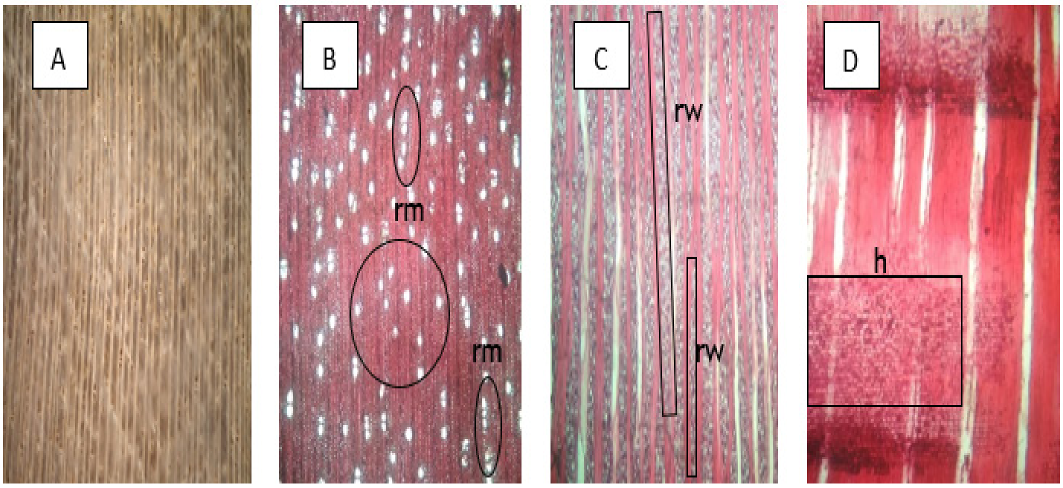

Figure 2. Macro- and microscopic sections of *B. gymnorhiza*. (A) Transverse section-macroscopic; (B) Transverse section-microscopic showing vessel grouping: solitary (s) and radial multiples of 2 to 3 (rm); (C) Tangential section-microscopic showing ray width of 3-7 cells (rw); (D) Radial section-microscopic showing ray cellular composition: heterocellular, 8 cells procumbent with one row square (h). Scale bars: 500 μm (A); 200 μm (B); 100 μm (C, D)

R. apiculata

The macroscopic features: growth ring boundaries indistinct; wood diffuse porous; the wood is red-yellowish-brown, no pattern, fine texture; the fiber direction is straight and smooth; the surface is shiny and odorless; this wood species is classified as hard to slightly hard.

The microscopic features: vessel grouping is solitary to radial multiples of 2 to 3, 15-20 vessels per square millimeter, average vessel diameter is 80-100 μm; scalariform perforation plates, intervessel pits scalariform; vessel-ray pits distinct borders, similar to intervessel pits in size and shape throughout the ray cell; no tyloses

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but containing white deposit; diffuse (apotracheal), scanty, and vasicentric parenchyma (paratracheal); 5-7 cells per parenchyma strand; ray width 2-5 cells; ray cellular composition: heterocellular, more than 10 cells procumbent with 2-4 rows upright or square and contains prismatic crystals; silica in ray; septate fiber present; fiber with simple to bordered pits; average fiber length is 1800-2100 μm, and average fiber wall thickness is 6-8 μm.

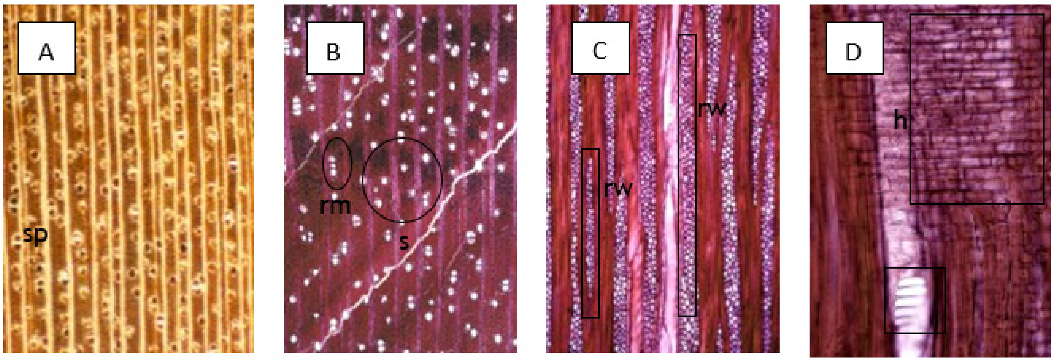

Figure 3. Macro- and microscopic sections of *R. apiculata*. (A) Transverse section-macroscopic; (B) Transverse section-microscopic showing vessel grouping: solitary (s) and radial multiples of 2 to 3 (rm); (C) Tangential section-microscopic showing ray width of 3-7 cells (rw); (D) Radial section-microscopic showing ray cellular composition: heterocellular, more tan 10 cells procumbent with 2-4 rows square (h); scalariform perforation plates (sp). Scale bars: 500 μm (A); 200 μm (B); 100 μm (C, D)

A. marina

The macroscopic features: growth ring boundaries indistinct; wood diffuse porous; the wood is gray-brown, coalesced, and decoratively patterned; the texture is slightly rough; the fiber direction is coalesced; the touch impression is slightly rough until smooth; the surface is shiny and odorless; there is included phloem; this wood species is classified as hard to slightly hard.

The microscopic features: vessel grouping is mostly radial multiples of 2 to 4, 6-8 vessels per square millimeter, there is also solitarry vessels. average vessel diameter is 125-140 μm; simple perforation plates; intervessel pits alternate; vessel-ray pits distinct borders, similar to intervessel pits in size and shape throughout the ray cell; no tyloses but containes white deposit; vasicentric, scanty, and unilateral parenchyma (paratracheal); 4-7 cells per parenchyma strand; ray width 1-5 cells; ray cellular composition: heterocellular, 2-4 cells procumbent with 1-2 rows upright or square and contains prismatic crystals; septate fiber absent; fibers with simple to bordered pits; average fiber length is 1170-1260 μm, and average fiber wall thickness is 2,9-5 μm.

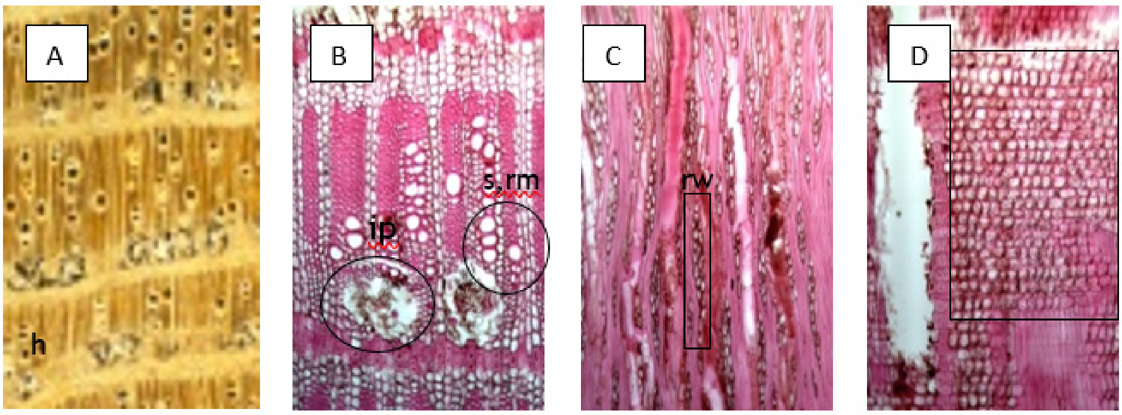

Figure 4. Macro- and microscopic sections of *A. marina*. (A) Transverse section-macroscopic; (B) Transverse section-microscopic showing vessel grouping: solitary (s) and radial multiples of 2 to 4 (rm), included phloem (ip); (C) Tangential section-microscopic showing ray width of 1-5 cells (rw); (D) Radial section-microscopic Radial section-microscopic showing ray cellular composition: heterocellular, 2-4 cells procumbent with 1-2 rows upright or square (h). Scale bars: 500 μm (A); 200 μm (B); 100 μm (C, D)

A. officinalis

The macroscopic features: growth ring boundaries indistinct; wood diffuse porous; the wood is gray-brown,

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decoratively patterned, and slightly rough texture; the fiber direction is coalesced; the touch impression is slightly rough until smooth; the surface is shiny and odorless; there is included phloem; this wood species is classified as hard to slightly hard.

The microscopic features: vessel grouping is mostly radial multiples of 2 to 4 (there is also solitary), 7-8 vessels per square millimeter, average vessel diameter is 120-148 µm; simple perforation plates; intervessel pits alternate; vessel-ray pits distinct borders, similar to intervessel pits in size and shape throughout the ray cell; no tyloses but containes white deposit; vasicentric, scanty, and unilateral parenchyma (paratracheal); 4-7 cells per parenchyma strand; ray width 1-5 cells; ray cellular composition: heterocellular, 2-4 cells procumbent with 1-2 rows upright or square and contains prismatic crystals; septate fiber absent; fiber with simple to bordered pits; average fiber length is 1183-1256 µm, and average fiber wall thickness is 2,9-5 µm.

C. philippinensis

The macroscopic features: growth ring boundaries indistinct; wood diffuse porous; the wood is gray-yellow-brown, no pattern, slightly rough textura; the fiber direction is straight to slightly coalesced, the touch impression is slightly rough until smooth; the surface is shiny and odorless; this wood species is classified as soft to slightly hard.

The microscopic features: vessel grouping is mostly solitary but it is also found radial multiples of 2 to 3, 1-2 vessels per square millimeter, average vessel diameter is 240-415 µm; simple perforation plates; intervessel pits alternate; vessel-ray pits distinct borders, similar to intervessel pits in size and shape throughout the ray cell; vessel contains white deposit and sometime slight tyloses; unilateral, scanty, and vasicentric parenchyma (paratracheal), short bands parenchyma; 3-5 cells per parenchyma strand; ray width 1-2 cells; ray cellular composition: heterocellular, 4-7 cells procumbent with 1 rows upright or square and contains prismatic crystals; septate fiber absent; fiber with simple to bordered pits; average fiber length is 1600-1855 µm, and average fiber wall thickness of 2,4 µm.

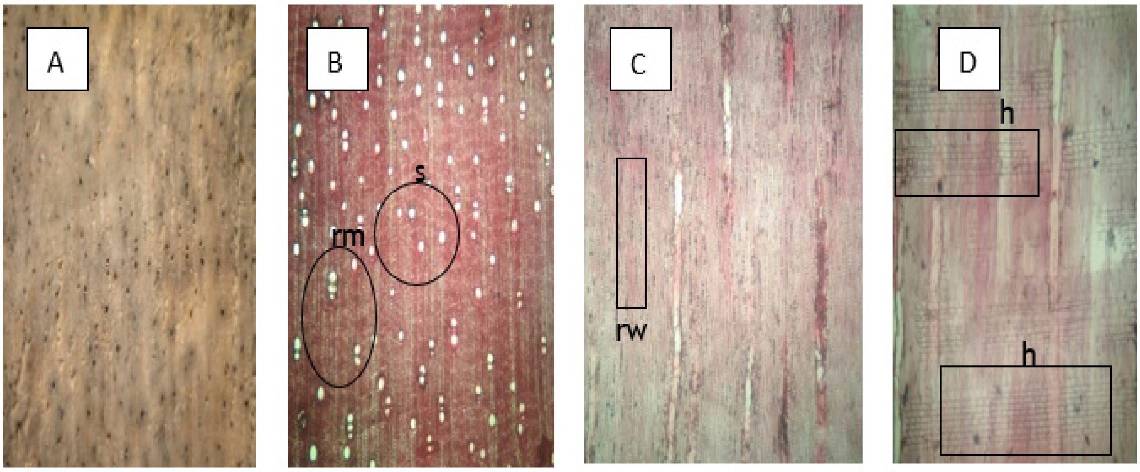

Figure 5. Macro- and microscopic sections of *C. philippinensis*. (A) Transverse section-macroscopic; (B) Transverse section-microscopic vessel grouping: mostly solitary (s) and radial multiples of 2 to 3 (rm); (C) Tangential section-microscopic showing ray width of 1-2 cells (rw); (D) Radial section-microscopic Radial section-microscopic showing ray cellular composition: heterocellular, 4-7 cells procumbent with 1 rows upright or square (h). Scale bars: 500 µm (A); 200 µm (B); 100 µm (C, D)

S. alba

The macroscopic features: growth ring boundaries indistinct; wood diffuse porous; the wood is brown-red-yellowish, not patterned, and slightly fine-textured; the fiber direction is coalesced, the touch impression is smooth, the surface is dull and odorless; this wood species is classified as hard to slightly hard.

The microscopic features: vessel grouping is mostly radial multiples of 2 to 3 (there is also solitary), 20-38 vessels per square millimeter, average vessel diameter is 86-120 µm; simple perforation plates; intervessel pits alternate; vessel-ray pits distinct borders, similar to intervessel pits in size and shape throughout the ray cell; vessel contains tyloses; very scanty parenchyma (apotracheal); 3-7 cells per parenchyma strand; ray width 1-2 cells; ray cellular composition: heterocellular, rays with procumbent, square and upright cells mixed throughout the ray and contains prismatic crystals; all fiber are septate (exclusive); fiber with simple to bordered pits; average fiber length is 1155-1435 µm, and average fiber wall thickness is 3-4,8 µm.

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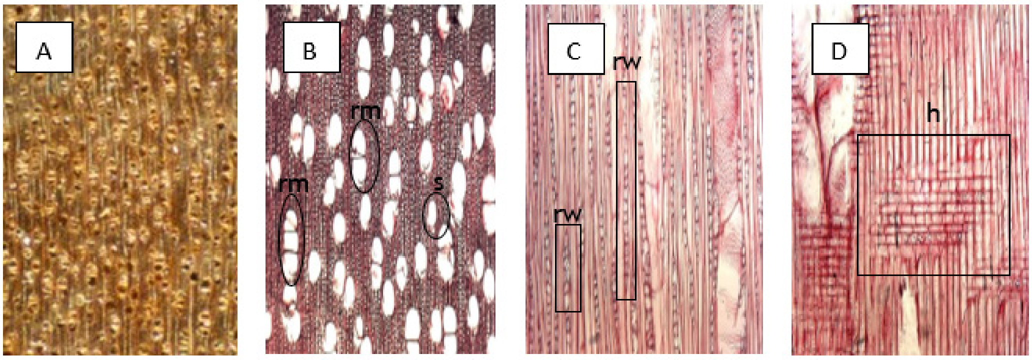

Figure 6. Macro- and microscopic sections of *S. alba*. (A) Transverse section-macroscopic; (B) Transverse section-microscopic vessel grouping: solitary (s) and radial multiples of 2 to 3 (rm); (C) Tangential section-microscopic showing ray width of 1-2 cells (rw); (D) Radial section-microscopic showing ray cellular composition: heterocellular, rays with procumbent, square and upright cells mixed throughout the ray (h). Scale bars: 500 µm (A); 200 µm (B); 100 µm (C, D).

S. caseolaris

The macroscopic features: growth ring boundaries indistinct; wood diffuse porous; the wood is brown-red-yellowish, no patterned, slightly fine texture; the fiber direction is coalesced; the touch impression is smooth; the surface is dull and odorless; this wood species is classified as hard to slightly hard.

The microscopic features: vessel grouping is mostly radial multiples of 2 to 3 (there is also solitary), 22-40 vessels per square millimeter, average vessel diameter is 88-119 *µ*m; simple perforation plates; intervessel pits alternate; vessel-ray pits distinct borders, similar to intervessel pits in size and shape throughout the ray cell; vessel contains tyloses; very scanty parenchyma (apotracheal); 4-8 cells per parenchyma strand; ray width 1-2 cells; ray cellular composition: heterocellular, rays with procumbent, square and upright cells mixed throughout the ray and contains prismatic crystals; fiber with simple to bordered pits; all fiber are septate (exsclusive); average fiber length is 1165-1413 *µ*m, and average fiber wall thickness is 3-5 *µ*m.

The observation results showed that the anatomy features in one genus are no different. The distinct differences of anatomy features are found on intergenus. Figures 2-6 represent the cross/transversal section of wood (macro- and microscopic) as well as radial and tangential microscopic sections of mangrove wood species. Wood species of *A. marina* represented the genus of Avicennia, *B. gymnorhiza* represented the genus Gymnorhiza, *R. apiculata* represented the genus Rhizophora, and *C. philippinensis* represented the genus Camptostemon, while the genus of Sonneratia was represented by *S. alba*. Every figure of the cross section showed a specific appearance for every wood species, with the results that will be used as the basis for wood species identification.

Fiber dimension

The results showed that microscopic features that are influenced by location in the stem length are vessel diameter as well as length and thickness of fiber wall. The length and thickness of the fiber wall tend to increase from the base to the middle of the stem and then decrease towards the top, while the vessel diameter keeps decreasing from the base to the top of the stem. Based on the value of the length and dimension of the derivative fiber (Table 1) and the assessment criteria of Indonesian timber for pulp and paper (table 2), the fiber of some mangrove wood species was grouped in the quality class II to III. The The comparison of wood fibers of some mangrove wood is available in figure 7.

Table 1. Fiber quality of some mangrove wood species

No.	Wood species	Fiber length, µm	Value of fiber derivative dimensión					Total score	Fiber quality (Class)
			Runkle ratio	Felting power	Muhlsteph ratio, %	Flexibility ratio	Coeffisient of rigidity		
1.	Avicennia marina	1066,84	1,02	53,97	75,36	0,49	0,25		
	Score	50	0	50	25	25	25	175	III
2.	Bruguiera gymnorhiza	1405,51	1,03	50,79	75,75	0,49	0,25		
	Score	50	0	50	25	25	25	175	III
3.	Rhizophora apiculata	1608,66	1,13	51,38	78,13	0,46	0,26		
	Score	50	0	50	25	25	25	175	III

4.	Avicennia alba	1357,12	0,76	53,4	68,56	0,56	0,21		
	Score	50	25	50	25	50	25	225	II
5.	Bruguiera cylindrica	1353,4	1,19	51,18	79,29	0,45	0,27		
	Score	50	0	50	25	25	25	175	III
6.	Sonneratia ovata	927,82	0,65	34,86	63,58	0,6	0,19		
	Score	25	25	25	25	50	25	175	III
7.	Sonneratia caseolaris	1004	0,47	34,2	53,81	0,67	0,16		
	Score	50	50	25	50	50	25	250	II

Table 2. The assessment criteria of Indonesian timber for pulp and paper[10]

Criteria	Class I		Class II		Class III	
	Condition	Value	Condition	Value	Condition	Value
Fiber length	>2000	100	1000-2000	50	<1000	25
Runkle ratio	<0,25	100	0,25-0,50	50	0,50-1,00	25
Felting power	>90	100	50-90	50	<50	25
Flexibility ratio	>0,80	100	0,50-0,80	50	<0,50	25
Coeffisient of rigidity	<0,10	100	0,10-0,15	50	>0,15	25
Muhlsteph ratio, %	<30	100	30-60	50	60-80	25
Interval	450-600		225-449		<225	

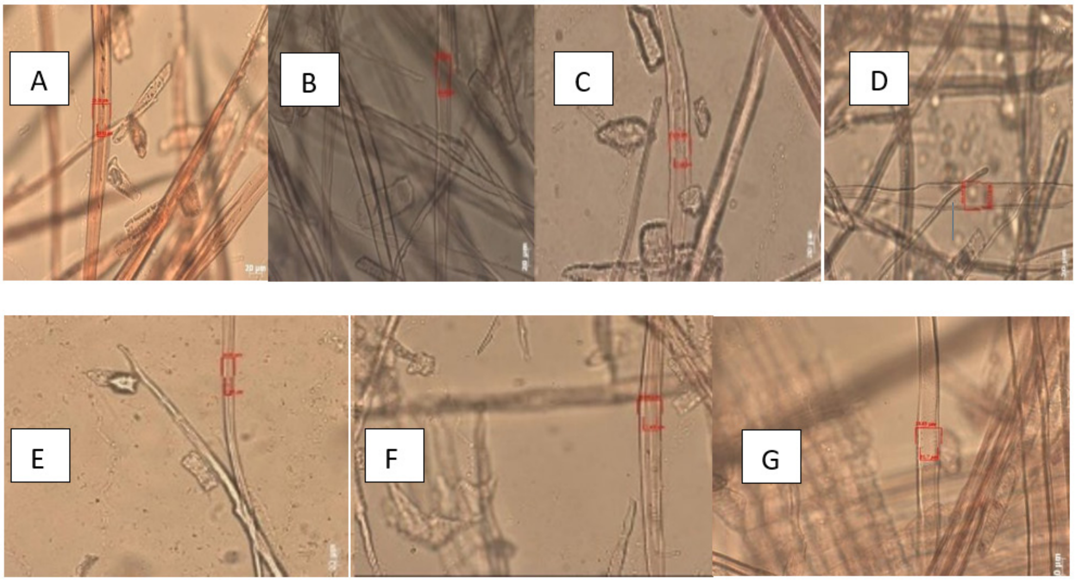

Figure 7. The comparison of wood fibers of some mangrove species. (A) *R. apiculata;* (B) *T. catappa;* (C) *B. gymnorhiza;* (D) *H. tyliaceus;* (E) *A. marina;* (F) *S. caseolaris;* (G) *E. agallocha*

DISCUSSION

There are similarities and differences in wood features among mangrove species. Every genus (genera) of wood can be distinguished from each other in terms of color, pattern, texture, fiber direction, impression of touch, gloss, presence of included phloem, and hardness. The similarities of wood features among mangrove species were the presence of growth rings, which were difficult to see, porosity in diffuse porous, and distinctive odor.

The anatomical structural characteristics of wood within a genus are relatively similar, except for cell size and the unique structural conditions of the cell walls. This is in accordance with the opinion of Wahyudi[3] and Vidyasagaran et al.[12], who stated that the anatomical characteristics of wood species within the same genera do not differ. The distinct differences of anatomy features were found on intergenus. The same anatomical characteristics of A. marina were also mentioned by Vidyasagaran et al.[12] and Detienne[13], who conducted research using similar wood species originating from Kerala (India) and Madagascar. The overall characteristics of A. alba wood are relatively similar to A. marina wood. The difference between the two lies only in the length and thickness of the fiber walls.

Vidyasagaran et al.[12] stated that Bruguiera sp. has scanty and vasicentric parenchyma, while Sonneratia has none. This phenomenon differs from the results of research that showed that B. gymnorhiza has scanty and diffuse parenchyma, while S. caseolaris has scanty parenchyma. Differences in species, collection location, and tree age may cause differences in observation results.

Anatomical characteristics such as intervessel pits scalariform, unclear growth rings, diffuse porosity, scalariform perforation plates, the presence of septate fibers, very thick fiber walls, and rays containing prismatic crystals found in R. mucronata[13] are also found in R. apiculata, but the parenchyma shape is different in these two species. Axial parenchyma is absent or very rare in R. mucronata, but in R. apiculata there are diffuse, scanty, and vasicentric parenchyma. Ladder-shaped perforation planes (scalariform) are only found in R. apiculata (less than 10 bars) and B. gymnorhiza (up to more than 10 bars), while other species have simple perforation planes. Another same characteristic in these two species is the presence of scalariform intervessel pits, while other species have alternate intervessel pits. The difference between these two species is in the number of bars of scalariform perforation plates. The scalariform perforation plates consisting of up to 10 bars is only found in B. gymnorhiza.

From a microscopic point of view, the similarity of the anatomical features of all seven mangrove wood species is only in the presence of prismatic crystals in ray cells and no intercellular canal. Specifically for wood species of the genera Bruguiera and Rhizophora have many similarities that are relatively different from the other wood species. The similarities in microscopic features of Bruguiera and Rhizophora wood are not only in terms of wall thickness but also in terms of vessel grouping, type of perforation plates, pits on vessel walls, vessel content, and ray composition. The method of identification of wood species needs to be improved, especially to distinguish between Rhizophora and Bruguiera. Another technique that can be tried involves testing the color reaction of extractive substances in each wood species using a drop of a specific solvent. The main difference between Bruguiera and Rhizophora is in terms of fiber length, where fibers of Rhizophora wood tend to be longer. That is why in the timber trade, both Bruguiera and Rhizophora are grouped together and known as mangrove wood. Bruguiera and Rhizophora wood are classified as strong wood, and they are widely used as raw materials for structural purposes and the high-quality charcoal in particular for export purposes.[14]

The results also showed that Avicennia, Camptostemon, and Sonneratia have similarities in type of perforation plates (simple perforation). The differences between them are the content of the pores, the type of parenchyma, and the presence of septate fibers. The vessels of Avicennia contain white deposits, Sonneratia contains tylosis, while Camptostemon contains both. The parenchyma cells of Avicennia are varied but only parenchyma scanty in Sonneratia, while Camptostemon has two types of parenchyma that are parenchyma vasicentric and parenchyma short tangential line. According to Vidyasagaran et al.[12] and Emerhi[15], Sonneratia spp. is characterized by the absence of parenchyma cells, but according to Rao et al.[16] axial parenchyma is absent or rare in Sonneratia spp. The wood species that has sparse, vasicentric, and unilateral parenchyma is A. marina, while another species that also has sparse and vasicentric parenchyma is R. apiculata.

Broadleaf wood species generally have a fiber length range between 800 and 1500 µm[17], while the fiber length of mangrove wood species in this study ranged from 927,82 µm (S. ovata) to 1608,66 µm (R. apiculata), which is included in the medium/intermediate group.[6,18] Bruguiera sp. has the thickest fiber walls compared to other wood species. The difference between B. gymnorhiza and B. cylindrica can be seen from the fiber dimensions. The fiber length of B. cylindrica from Cilacap is 1256 µm, and the fiber wall thickness is 7,26 µm, while the fiber length of B. gymnorhiza from the same origin is 1242 µm with a fiber wall thickness of 6,78 µm.

In terms of fiber length, these wood species in this study can be grouped into three classes. Rhizophora and Camptestemon wood have long fibers, Avicennia and Sonneratia wood are moderate, while Bruguiera wood is classified as short to moderate. The vertical variation in each species of wood is low and could be ignored. The variations are mainly found in terms of wood hardness, vessel diameter, and fiber wall thickness. The existing variation pattern follows the general pattern.[1]Hardness tends to decrease from the base to the tip of the stem, while the vessel diameter is the opposite. The thickness of the wall increases from the base to the middle but then decreases towards the tip of the stem.

Fiber with class quality III is not suitable for pulp and paper raw materials, while fiber with quality class II (medium) can be recommended as a raw material for pulp and paper.[19] The classification of quality class III for other Rhizophora species was also conveyed by Sushardi et al.[20] where R. mucronata is included in pulp quality class III. The results of research by Sulastri et al.[21] stated that A. marina can be used as raw material for paper, while A. alba can be used as low-quality building material. This finding is not the same with the results of this study, which instead indicates that A. alba wood falls into quality class II, which is suitable for paper production. This discrepancy is thought to be due to the fact that Sulastri et al.'s study was based solely on fiber cell wall thickness and did not include calculations of the fiber's derived dimensions.

CONCLUSIONS

Some mangrove wood species can be differentiated by wood anatomy characteristics, and they are grouped in the quality class II to III for pulp and paper raw material. The method of identification of wood species needs to be improved, especially to distinguish between Rhizophora and Bruguiera. Another technique that can be tried involves testing the color reaction of extractive substances in each wood species using a drop of a specific solvent.

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