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Original article

Characterization of bast fibers in selected dicotyledonous plants: *Hibiscus rosa-sinensis*, *Ficus septica*, and *Phaleria macrocarpa*

Masfufah Qurrota A'yun[1], Ratnawati[1]*, Budiwati[1], Sudarsono[1], Annisa Latifa[1]

[1] Biology Study Program, Faculty of Mathematics and Natural Sciences, Yogyakarta State University, Indonesia

Abstract

At present, a wide range of commercial natural fibers is utilized in various products. However, further investigation is required to expand the applications of natural fiber. This study examined the anatomical characteristics and mechanical properties of bast fibers from *Hibiscus rosa-sinensis*, *Ficus septica*, and *Phaleria macrocarpa*, and explored their potential applications. Anatomical characteristics, including fiber diameter, lumen diameter, and fiber wall thickness, were assessed through the observation of cross-sectional slides of the stem bark. Fiber length was measured using maceration specimens. Tensile strength and elongation data were obtained through tensile strength and elongation tests conducted with a Tenso Lab machine. The results indicated that the diameters of *H. rosa-sinensis* and *Ficus septica* fibers were classified as medium, while the diameter of *Phaleria macrocarpa* fiber was relatively small. All three fibers were characterized by very thick fiber walls and small lumens and were classified as long fibers. Regarding mechanical properties, these fibers exhibited relatively high tensile strength but low elongation values. Based on these findings, the three fibers demonstrate significant potential as raw materials for use in the paper and composite industries.

Keywords: Bast Fiber, *Hibiscus rosa-sinensis*, *Ficus septica*, *Phaleria macrocarpa*
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Introduction

The use of natural fiber has been widely studied, showing rapid development in the field. Numerous studies have explored the potential of natural fiber as a substitute for synthetic fiber. The growing demand for products across various industries is not matched by the availability of synthetic fiber, which is derived from limited resources. Despite its favorable properties in terms of strength and durability, synthetic fiber contributes to environmental harm due to its resistance to natural decomposition. In contrast, natural fiber provides a sustainable solution, offering not only biodegradability but also a reduced ecological footprint. As industries move toward more sustainable practices, natural fiber is increasingly recognized for its role in reducing reliance on synthetic materials and minimizing environmental damage.

According to Habibie et al. (2021), natural fiber plays a crucial role in environmental protection by enabling the production of products that do not have a detrimental impact on the environment. Natural fiber is biodegradable, ensuring that its waste does not adversely affect the environment. Additionally, the processing of natural fiber does not produce harmful gases during production. In comparison to synthetic fiber, natural fiber is more abundant and sustainable in nature.

Although a variety of commercial natural fibers, such as hemp, kenaf, and jute, have been utilized to date, further exploration of natural fibers is still necessary. Given their environmentally friendly nature, natural fibers may be used and processed in a wider range of products in the future. Many non-commercial plants, which are infrequently used, remain underexplored, and information regarding their fiber properties and quality is yet to be fully understood.

Hibiscus and *Ficus* are genera that have been widely studied for their potential as natural fiber sources; however, many species within these groups remain underexplored. Among these, *Hibiscus rosa-sinensis* and *Ficus septica* are particularly abundant and easily found in local environments. *Phaleria macrocarpa*, on the other hand, was chosen due to its unique origin in Papua, Indonesia, and its existing but limited practical applications.

H. rosa-sinensis, commonly known as hibiscus or kembang sepatu, is a member of the Malvaceae family, originating from China and widely distributed across Asia. The leave, flower, and root are typically the plant parts most frequently utilized for medicinal purposes. In contrast, the medicinal uses of the stem are less documented (Amtaghri et al., 2024). Furthermore, the practical applications of the stem bark remain underexplored, highlighting the need for further research into the potential of its bast fiber to improve productivity and expand its utility.

F. septica, commonly known as awar-awar or fig among local people, belongs to the Moraceae family. The plants are relatively easy to find due to their adaptability to various environmental conditions and soil types, in addition to their resistance to drought (Mariwy et al., 2020). The widespread presence of these plants in natural environments offers opportunities for research into their potential to produce fiber. To date, *F. septica* has been

* Corresponding Author:
Ratnawati
Biology Study Program, Faculty of Mathematics and Natural Sciences, Yogyakarta State University, Indonesia
Phone: +6281227656348
E-mail: ratnawati_bio@uny.ac.id

primarily recognized as a medicinal plant, and the potential of its bast fiber remains unexplored.

P. macrocarpa, or God's crown, is a plant native to Indonesia and belongs to the Thymelaeaceae family. Traditionally, the Papuan people have utilized *P. macrocarpa* bast fiber for an extended period as a raw material for crafting noken, a type of bag created by intertwining plant fiber into rope (Maryone, 2021). Despite its significant potential as a source of fiber, the anatomical properties and quality of *P. macrocarpa* bast fiber remain unexplored.

Anatomical and mechanical properties of fiber are foundational data for assessing its quality. Fiber length, fiber diameter, fiber wall thickness, and lumen diameter are used to determine the derived values, which influence its grade in paper production. Data on mechanical properties, such as tensile strength and elongation, are also required to evaluate its potential applications, including composite production and other products. Therefore, the purpose of this study was to investigate the potential applications of bast fibers from three Dicotyledonous species—*H. rosa-sinensis*, *F. septica*, and *P. macrocarpa*—for natural fiber-based products by examining their anatomical and mechanical properties.

Methods

This study was a descriptive observational investigation aimed at examining and analyzing the anatomical characteristics and mechanical properties of bast fibers in several Dicotyledonous plants. The research was conducted at the Research and Development Laboratory, Department of Biology Education, Faculty of Mathematics and Natural Sciences, Yogyakarta State University, and the Textile Manufacturing and Testing Laboratory, Faculty of Industrial Technology, Islamic University of Indonesia. The study was carried out from March to September 2023.

Sample collection

The stem barks of *Hibiscus rosa-sinensis*, *Ficus septica*, and *Phaleria macrocarpa* were collected from trees growing in Pajangan district, Bantul regency, Indonesia. The samples were taken approximately 30 cm above the soil surface.

Preparation of stem bark cross section

Cross-sectional slides of the stem barks from *H. rosa-sinensis*, *F. septica*, and *P. macrocarpa* were prepared using the paraffin embedding method, and staining was performed with safranin. The preparation process involved several stages, including fixation, dehydration, dealcoholization, paraffin infiltration, mounting, sectioning, and staining (Ruzin, 1999).

Maceration

The maceration process was conducted following a modified Gifford method (Ruzin, 1999). Stem bark samples were cut to the size of matchsticks and placed in a solution consisting of 30% H_2O_2, distilled water, and AAG in a ratio of 1:4:5. The samples were then incubated in an oven at 56°C until they turned whitish to transparent. After maceration, the samples were thoroughly washed with distilled water. The final step involved staining with safranin.

Water retting

The stem bark samples were soaked in water in a plastic container and left to soften and become mushy, during which an unpleasant odor developed. The stem barks of *P. macrocarpa* and *H. rosa-sinensis* were soaked for 20 days, while the *F. septica* stem bark was soaked for 10 days. The fibers were then washed to remove any residual mucus and subsequently dried in the sun for several days. Finally, the fibers were separated into strands.

Tensile strength and elongation test

The extracted bast fibers were tested for their tensile strength and elongation. Tensile strength and elongation tests were conducted using a Tenso Lab machine (MESDAN LAB specifications: Spa. 25087 SALO-ITALY, model tenso.300, type 168 E, serial number 397, built in 1997).

Data collection

Observations of the anatomical characteristics of bast fibers, including fiber diameter, lumen diameter, and fiber wall thickness, were conducted on cross-sectional specimens of stem bark. Fiber length data were obtained by observing maceration specimens. Measurements of fiber diameter, lumen diameter, fiber wall thickness, and fiber length were repeated 100 times. Tensile strength and elongation data were collected through repeated tensile tests, which were conducted 10 times.

Data analysis

The data obtained from testing and measuring the anatomical characteristics and mechanical properties of the bast fibers from *H. rosa-sinensis, F. septica,* and *P. macrocarpa* were analyzed descriptively for each variable to describe the fiber characteristics. Subsequently, the potential applications of the three fibers were analyzed based on their anatomical and mechanical properties.

Results

Anatomical characteristics of bast fibers in several Dicotyledoneae

In this study, the observed fibers were extraxylary fibers, specifically phloem fibers. The staining process resulted in fiber cells appearing redder than other cells, which facilitated the measurement of their anatomical characteristics. Cross-sections of the stem bark from several Dicotyledonous plants are presented in Figure 1.

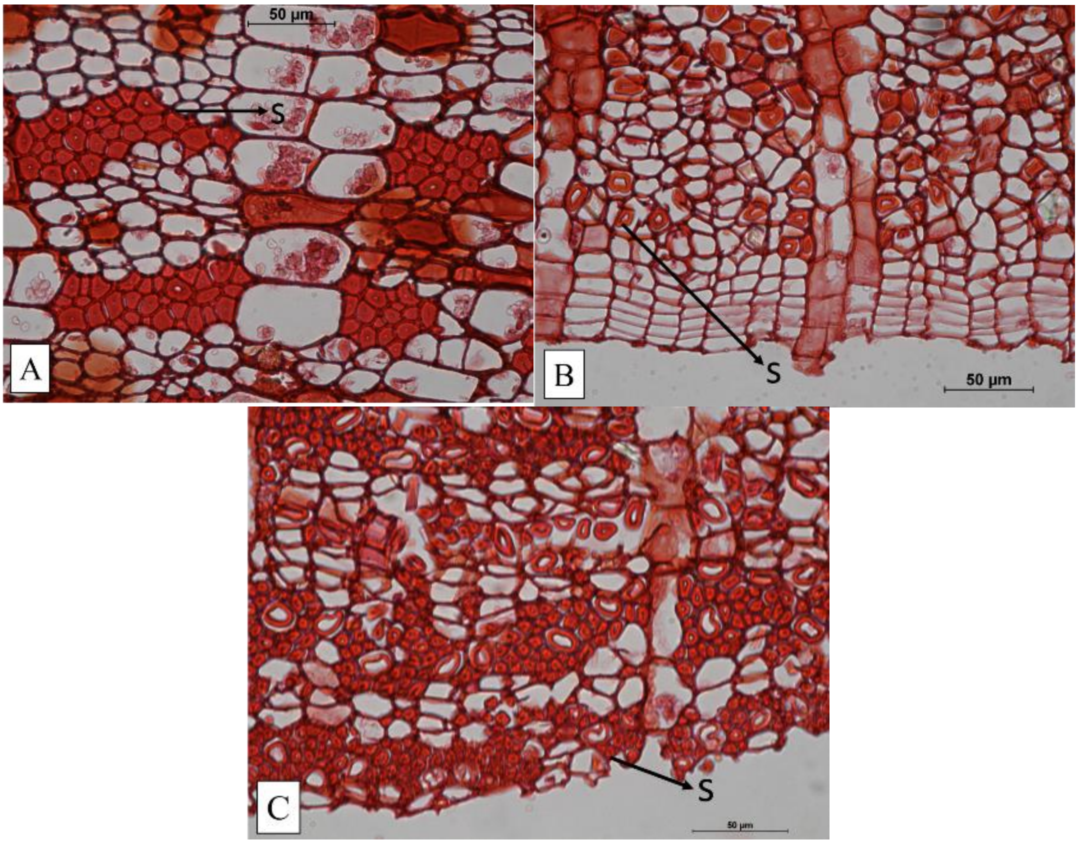

Figure 1. Cross Section of Stem Bark in Several Dicotyledoneae. Keys=A: *Hibiscus rosa-sinensis*, B: *Ficus septica*, C: *Phaleria macrocarpa*, S: Fiber.

The anatomical characteristics of the fibers, as determined from cross-sectional observations of the stem bark of *Hibiscus rosa-sinensis*, *Ficus septica*, and *Phaleria macrocarpa*, included fiber diameter, lumen diameter, and fiber wall thickness. Fiber length, on the other hand, was obtained from observations of the maceration preparations. The measurement data on the anatomical characteristics of the fibers are presented in Table 1.

Measurement data on the anatomical characteristics of bast fibers were subsequently processed to calculate derived values for fiber dimensions. These parameters include the Runkel ratio, felting power, Muhlsteph ratio, flexibility ratio, and coefficient of rigidity. The derived values for the fiber dimensions of *H. rosa-sinensis*, *F. septica*, and *P. macrocarpa* are summarized in Table 2.

Table 1. Anatomical Characteristics of Bast Fibers in Several Dicotyledoneae

Plant Type	**Anatomical Characteristics (Fiber Dimension)**			
	Fiber Diameter (µm)	Lumen Diameter (µm)	Cell Wall Thickness (µm)	Fiber Length (µm)
Hibiscus rosa-sinensis	11,459 ±1,385	1,850 ±0,493	4,804 ±0,636	3820,578 ±614,794
Ficus septica	10,876 ±1,527	2,243 ±0,596	4,317 ±0,718	4617,989 ±690,504
Phaleria macrocarpa	7,050 ±0,692	1,935 ±0,449	2,558 ±0,324	3950,373 ±746,184

Table 2. Derivative Values of Bast Fiber Dimensions in Several Dicotyledoneae

	Hibiscus rosa-sinensis			***Ficus septica***			***Phaleria macrocarpa***		
	Measure-ments	Value*	Class	Measurements	Value*	Class	Measurements	Value*	Class
Fiber Length (µm)	3820,578	100	1	4617,989	100	1	3950,373	100	1
Runkel Ratio	5,194	25	4	3,849	25	4	2,644	25	4
Felting Power	333,412	100	1	424,603	100	1	560,337	100	1
Muhlsteph Ratio	97,4%	25	4	95,8%	25	4	92,5%	25	4
Flexibility Ratio	0,162	25	4	0,206	25	4	0,275	25	4
Coefficient of Rigidity	0,419	25	4	0,397	25	4	0,363	25	4
Total of Values*		300			300			300	
Fiber Quality Class*	III			III			III		

Note: *Assessment based on Department of Agriculture (1976)

Tensile strength and elongation of bast fiber bundles of several Dicotyledoneae

Tensile strength and elongation tests were conducted using a Tenso Lab machine with a tensile speed of 296.15 mm/min and a gauge length of 100 mm. Each test was repeated 10 times, and the average values for tensile strength and elongation were calculated. The results are presented in Table 3.

Table 3. Tensile Strength and Elongation of Bast Fibers in Several Dicotyledoneae

	Hibiscus rosa-sinensis	***Ficus septica***	***Phaleria macrocarpa***
Tensile Strength (N)	8,740 ± 0,719	4,395 ± 0,650	5,228 ± 0,821
Elongation (%)	1,820 ± 0,686	0,979 ± 0,297	1,330 ± 0,340

Discussion

Anatomical characteristics of bast fibers in several Dicotyledoneae

Phloem fibers are present in both the primary and secondary phloem. In many Angiosperms, fiber bands are formed in the secondary phloem (Evert, 2006). Among the three plants tested, the arrangement of fibers exhibited distinct patterns. In *Hibiscus rosa-sinensis*, the fibers were densely grouped. In contrast, the fibers in *Ficus septica* were dispersed and not closely positioned. In *Phaleria macrocarpa*, the fibers were grouped but not as densely packed as those in *H. rosa-sinensis*.

Based on measurements of fiber diameter, *H. rosa-sinensis* exhibited the largest diameter, while *P. macrocarpa* fibers had the smallest among the three types of fibers tested. Casey (1980) categorized fiber diameter into three groups: 25-40 µm as large, 10-25 µm as medium, and 2-10 µm as small. According to this classification, the fiber diameters of *H. rosa-sinensis* and *F. septica* fall within the medium category, whereas the fiber diameter of *P. macrocarpa* is relatively small.

Based on the measurements of lumen diameter and fiber wall thickness conducted in the three plant species studied, all three fiber types exhibited a lumen diameter less than twice the fiber wall thickness. According to Wheeler et al.'s (1989) lumen diameter classification, such fibers are categorized as having very thick walls. Furthermore, the lumens of the tested fibers were observed to be very narrow and nearly closed.

The fiber length was determined by measuring from one end of the fiber to the other. Wheeler et al. (1989) categorized fiber length into three groups: <900 µm (short), 900-1600 µm (medium), and >1600 µm (long). Based on this classification, the fibers of *H. rosa-sinensis*, *F. septica*, and *P. macrocarpa* fall into the long fiber category, as their lengths exceed 1600 µm.

Based on the obtained fiber dimension data, derived values can be calculated by comparing the measured fiber dimensional parameters. These derived values, along with fiber length, serve as criteria for determining the quality class of the fiber as a raw material for pulp and paper. The classification of fiber quality was conducted according to the Department of Agriculture (1976).

Based on the analysis of all parameters, including fiber length, Runkel ratio, felting power, Muhlsteph ratio, flexibility ratio, and coefficient of rigidity, the bast fibers of *H. rosa-sinensis*, *F. septica*, and *P. macrocarpa* are classified as Grade III in terms of fiber quality. In general, fibers in Grade III do not fully flatten during the milling process; however, the bond between the fibers remains relatively strong. Consequently, the resulting pulp sheets exhibit moderate tear strength, crack strength, and tensile strength (Department of Agriculture, 1976).

Tensile strength and elongation of bast fiber bundles in several Dicotyledoneae

Fiber properties, such as tensile strength, are critical parameters that influence both the quality of the fiber and the products derived from it (Kessegn et al., 2024). Tensile strength refers to the fiber's ability to withstand the maximum load before breaking (Hinchliffe et al., 2023). Numerous studies have examined the tensile strength of bast fibers. For example, the tensile strength of kereteng (*Triumfetta pilosa*) bast fiber was 1.226 N (Zuhra et al., 2023). The tensile strength of agave leaf fiber was 4.903 N, coconut coir fiber was 4.315 N, and nipa palm frond stalk fiber was 5.492 N (Isnaini et al., 2022).

The three bast fiber samples tested were able to withstand a greater maximum load than hemp fiber, kereteng bast fiber, agave leaf fiber, nipa palm frond stalk fiber, and coconut coir fiber. With higher tensile strength, the bast fibers of *H. rosa-sinensis*, *F. septica*, and *P. macrocarpa* demonstrated equal, if not greater, potential for use in comparison those fibers. Based on their tensile strength, the tested fibers showed potential as raw material for products such as rigging, jute sacks, and bag crafts.

In addition to tensile strength, tests were conducted to measure the elongation values. Elongation refers to the fiber's capacity to extend its length under tensile stress before breaking. A higher elongation value indicates greater suitability for use as a raw material in textile production. Improving the elongation properties of fibers can significantly enhance yarn quality (Delhom et al., 2024).

The elongation values of the three fibers tested were relatively low compared to other fibers, such as hemp fiber at 3% (Ahmed et al., 2022), cotton fiber at 7-8% (Vandepitte et al., 2020), and kapok fiber at 2-4% (Sangalang, 2021). However, the elongation values of the three bast fibers tested were higher than that of kereteng bast fiber at 0.22% (Zuhra et al., 2023). Additionally, the elongation values of *H. rosa-sinensis* and *P. macrocarpa* fibers were nearly equivalent to that of flax fiber (1.2%) (Ahmed et al., 2022), roselle bast fiber (1.6%) (Tamta & Kalita, 2020), and jute fiber (1.16-1.7%) (Sangalang, 2021; Suparno, 2020).

Potential utilizations of bast fibers in several Dicotyledoneae

The three plant fibers tested exhibited potential as raw materials for producing paper with low tear strength, owing to their relatively high Muhlsteph ratios. The Muhlsteph ratio is inversely proportional to tear strength. One type of paper that does not require high tear strength is newsprint (Plazonić et al., 2020). Therefore, it can be suggested that bast fibers from *H. rosa-sinensis*, *F. septica*, and *P. macrocarpa* have potential as raw materials for newsprint production.

Apart from influencing the tear strength of paper, a high Muhlsteph ratio also negatively impacts the paper's surface quality, compressive strength, and plasticity. Consequently, the resulting paper tends to have a rough surface and low crumple strength. Thus, the three plant fibers tested are not suitable as raw materials for writing paper. However, they still show potential as raw materials for wrapping paper and art paper (Herlina et al., 2018).

Some of the essential criteria for wrapping paper include high values for base weight/grammage, whiteness, opacity, crack resistance, tensile resistance, tear resistance, and sheet thickness, as well as low water absorption (Smook, 2002). Although the Muhlsteph ratios of the three fibers tested were relatively high—leading to low crack resistance and density—these limitations can be mitigated. One potential solution is to blend these fibers with others that have thin cell walls and wide lumens, thereby producing paper with the desired properties.

Herlina et al. (2018) stated that fibers with a high Muhlsteph ratio still hold potential for use in art paper production. The fibers tested in this study exhibited relatively thick cell walls, which may hinder complete flattening during milling. Consequently, the roughness of the fibers increases, resulting in thicker paper. Increased fiber roughness is associated with greater paper porosity. Therefore, when used as raw materials for art paper, these fibers are expected to yield paper with a rough surface, enhanced thickness, and higher porosity. Further research is needed to identify the optimal conditions for producing art paper with the desired properties.

Fahmi & Hermansyah (2011) stated that higher felting power corresponds to greater tensile strength in a composite. Additionally, long fibers are more efficient than short fibers in terms of their placement within the composite. Based on these two characteristics, the three fibers tested exhibit significant potential as composite materials due to their high felting power and classification as long fibers.

From the calculation of the derived fiber dimension values, the Muhlsteph ratios of *H. rosa-sinensis*, *F. septica*, and *P. macrocarpa* fibers were found to be relatively high, while their flexibility values were low. These characteristics contribute to high porosity and low density in fiber-based products. Such properties offer advantages in composite production, as low-density results in lighter composites (Arum & Ismulia, 2022; Sadik et al., 2022).

The strength values of *F. septica*, and *P. macrocarpa* fibers were comparable to that of nipa palm frond stalk fiber and coconut coir fiber, while the strength of *H. rosa-sinensis* fiber is greater. Research on the use of nipa palm frond stalk fibers as reinforcement materials for composites has shown that the resulting composites exhibit tensile strength values comparable to those of ABS High Impact plastic, which is commonly used in car dashboards and ranges from 20 to 40 MPa (Rizki et al., 2023). Furthermore, several studies have investigated the use of coconut coir fibers in producing composites and medium-density fiberboard (Pugazhenthi & Anand, 2020, 2021; Sadik et al., 2022). These findings suggest that *H. rosa-sinensis*, *F. septica*, and *P. macrocarpa* fibers also hold potential as raw materials for composite and fiberboard production.

Fiberboard is a manufactured product in panel form made from wood fibers or other materials containing lignin and cellulose, combined with adhesive to meet specific criteria (National Standardization Agency, 2006). It is typically characterized by its relatively large surface area, thin thickness, and smooth surface (Muhammad et al., 2021). Fiberboard is classified into three groups based on its density: low, medium, and high. Further research is necessary to determine the classification and properties of fiberboard produced from *H. rosa-sinensis*, *F. septica*, and *P. macrocarpa* fibers.

This study demonstrated that the characteristics of the three fibers tested were relatively similar. The fiber diameters of *H. rosa-sinensis* and *F. septica* were classified as medium, whereas the fiber diameter of *P. macrocarpa* was relatively small. All three fibers exhibited very thick cell walls with extremely narrow lumens. Additionally, measurements indicated that the fibers were classified as long. Regarding their mechanical properties, the three fibers tested showed relatively high tensile strength, surpassing several other fibers previously studied. However, their elongation values were comparatively low. These findings suggest that the three fibers exhibit significant potential as raw materials for products such as newsprint, art paper, wrapping paper, fiberboard, and composites.

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