

# Anatomical Characteristics and Fiber Morphology of Palmyra Wood (*Borassus Flabellifer* L.) Originating from Timor Island, East Nusa Tenggara Province

Rynaldo Davinsy\*, Adrin, Lora Septrianda Putri, Melkianus Pobas, Luisa Moi Manek, Ni Kade Ayu Dewi Aryani, Mahardika Putra Purba, Emi Renoat, Yudhistira Ardhyana Nugraha Rua Ora, Ika Kristinawanti, Kristianto Wibison So, Yakub Benu

Forestry Department, State Agricultural Polytechnic of Kupang,  
Jl. Prof. Dr. Herman Johanes, Kupang City, Nusa Tenggara Timur, Indonesia.

## Corresponding author\*

davinsyr@gmail.com/ryaldo024@gmail.com

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## Abstract

Palmyra wood (*Borassus flabellifer* L.) is a widely distributed palm species in tropical Asia, including East Nusa Tenggara (NTT). Its wood has potential applications in construction, handicrafts, and bioenergy, making anatomical and fiber morphology studies essential for understanding its value and utilization. This research used palmyra wood samples from Timor Island, Kupang, in the form of discs with a diameter of approximately 30 cm, taken from the base, middle, and upper parts of the stem. Test specimens were prepared in  $2 \times 2 \times 5$  cm dimensions, and analyses were conducted following standard procedures. The results revealed that palmyra wood possesses anatomical characteristics typical of palms, namely collateral closed-type vascular bundles irregularly scattered within parenchymatous ground tissue, with phloem located outside the xylem. Fiber morphology exhibited a gradual reduction in dimensions from the base to the tip of the stem, with fiber diameters ranging from 38.48 to 15.64  $\mu\text{m}$ , wall thickness from 17.09 to 6.92  $\mu\text{m}$ , and lumen diameters from 13.02 to 5.42  $\mu\text{m}$ . The number of vascular bundles also decreased from 3.0 at the base to 1.21 at the tip, with bundle density ranging from 0.49 to 0.20/mm<sup>2</sup>. Overall, palmyra wood exhibits stronger mechanical properties at the base of the trunk, as demonstrated by the anatomy and morphology of its fibers, thus increasing its biological durability. These findings highlight its potential as a structural material, craft resource, and bioenergy feedstock in dryland regions such as NTT.

**Keywords:** anatomical characteristics; fiber morphology; palmyra wood; timor island.

## INTRODUCTION

The wood demonstrates intricate and unique anatomical characteristics as well as distinctive fiber morphology, a natural material, dictate its mechanical and physical characteristics as well as its application in a variety of industries. Understanding the anatomical structure of wood is critical because it helps determine its worth and potential for industrial and conservation applications. The lontar tree (*Borassus flabellifer* L.) is one type of plant that has considerable potential due to wood diversification but has not been thoroughly investigated in terms of wood anatomy (Lempang et al., 2009; Davinsy et al., 2024). Lontar is a species of palm that grows throughout tropical Asia, including islands in eastern Indonesia such as East Nusa Tenggara (NTT), Maluku, and Papua. It has immense biological potential but has not been fully explored Davinsy et al. 2024; Sari & Prasetyo, 2016; Yusof et al. 2016). So far, on Timor Island, the palm tree has been used mostly for its sap, leaves, and fruit, with the wood not being fully utilized.

Palm tree trunks have the potential to be used as raw materials in construction, crafts, and bioenergy. Palm wood has attractive grain, texture, and color, as well as good physical features, so it may be utilized to make a variety of products, from household furniture to building materials (Davinsy & Pobas, 2024; Davinsy et al., 2024). However, the utilization of palm wood remains limited, largely due to a lack of understanding of its anatomical structure.

Wood has a different anatomical structure than dicots, especially in monocots like lontar palms. Monocot wood lacks cambium and secondary growth and is made up of features including vascular bundles, ground parenchyma, and fibers organized in a complicated manner. Research such as that conducted by Dwianto et al. (2020) and Fengel & Wegener (1989), shows that understanding the tissue structure, both anatomical and fiber morphology, of monocot wood is crucial in determining the strength and processing characteristics of the material. In addition, studies by Fajriani et al., 2019; Davinsy et al.,

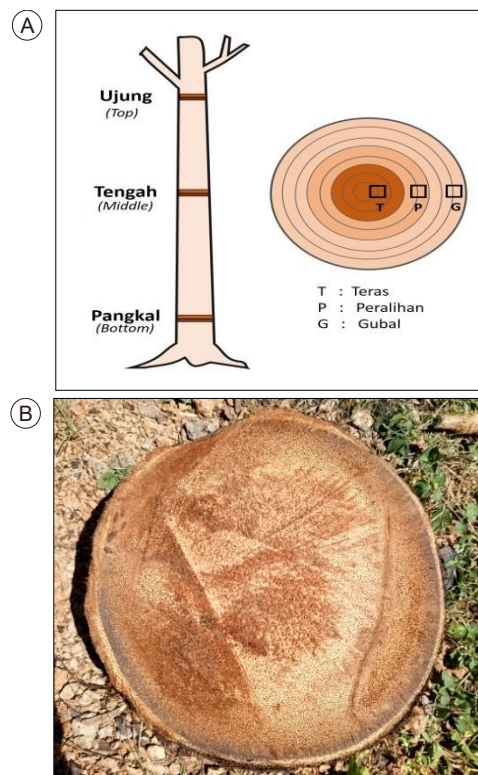
2024; Lempang et al., 2009 also emphasized the importance of using a microscopic technique to discover features of palm wood tissue structure as a first step toward conservation and sustainable use. Lontar wood is classified as palmae, which has a different anatomical structure than hardwood or softwood in general, but has a complex chemical content (Davinsky et al., 2025). This difficulty has caused misunderstanding among wood users, technologists, and policymakers due to a dearth of scientific evidence clarifying the functional qualities of palmyra wood from the east. Given Palmyra wood's enormous potential and the scarcity of relevant studies, determining its anatomical structure (characteristics and fiber morphology) is critical.

Given the importance of precise and relevant scientific data, the goal of this study is to quantitatively identify, describe, and evaluate the anatomical structure of palm trees from Timor Island in depth, as well as to investigate their possible industrial applications. This study's theoretical merits include advances to palm tree anatomical taxonomy and the use of quantitative approaches in wood science. A greater understanding of palm tree features is predicted to boost the economic value and sustainability of forest resource management. Furthermore, palm trees have a significant cultural value in many areas, with local communities using various sections of the plant for daily requirements. This study will fill this scientific gap by utilizing a quantitative approach through anatomical analysis, tissue parameter measurements, and descriptive and inferential statistical tests on palm tree samples from Timor Island.

## MATERIALS AND METHODS

### Research Materials and Equipment

The primary material used in this study was palm wood. Disc samples approximately 30 cm in thickness and 30 cm in diameter were collected from three longitudinal positions along the trunk, namely the base, middle, and tip (**Figure 1**). Each disc represented a specific stem position. The sample tree originated from Timor Island, Kupang, East Nusa Tenggara, Indonesia. The disc was converted and modified into a test sample per segment with a size of 2 x 2 x 5 cm (Augustina et al. 2020; BSI 373:1957; Davinsky et al. 2024; Muthmainnah et al. 2024). The samples consisted of sound wood free from visible defects. The equipment used in this study included a circular saw, drying oven, electronic balance, calipers, desiccators, hand lens, sliding microtome, cutting tools, microscope slides and cover slips, beakers, water bath, digital microscope with image-capture system, film vials, pipettes, light microscope, Petri dishes, test tubes, and a digital camera.



**Figure 1.** (A) Sample distribution chart (Muthmainnah *et al.* 2020), (B) Palmyra wood samples

### Procedures

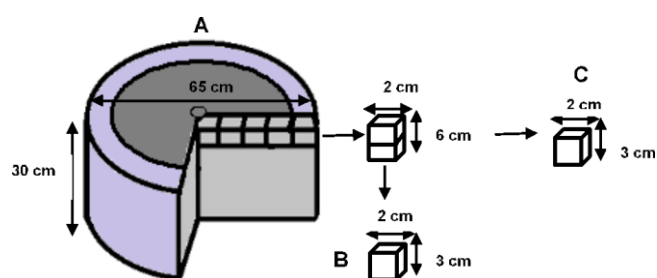
#### *Observation of the Anatomical Characteristics of Palmyra Wood.*

The test specimens represented the three radial positions within each disc. Prior to sectioning, the specimens were softened by boiling in distilled water for 2–3 days. Transverse sections were then prepared using a sliding microtome at a target thickness of 20–30  $\mu\text{m}$ . Selected sections were stained with 2% safranin for 1–6 h, rinsed thoroughly with distilled water, and subsequently dehydrated through a graded ethanol series (30, 50, 70, 90, and 96% [absolute]) for 3–10 min at each concentration. The sections were mounted on glass slides, cleared with xylene, and sealed using Entellana mounting medium following standard histological procedures (Augustina *et al.* 2020; Muthmainnah *et al.* 2024; Maulana 2019a). The mounted sections were covered with cover slips and subsequently examined under a light microscope, with representative images captured for documentation. Anatomical characteristics were identified and described in accordance with the guidelines of the International Association of Wood Anatomists (IAWA 2008).

#### *Observation of the Fiber Morphology of Palmyra Wood*

Lontar palmyra wood was prepared as slivers, defined as nearly rectangular specimens with a length at least four times their thickness. Maceration was conducted using a modified Franklin method (Rulliaty 1994; Augustina et al. 2020). The test specimens represented three

longitudinal positions of the stem (base, middle, and tip), with three replicates for each position. Fibers obtained from the maceration process were stained with 1–2% safranin for 30 min to 8 h, followed by stepwise dehydration in an ethanol series (50, 70, 90, and 96%) for 5 min at each concentration. The stained fibers were mounted on glass slides and directly observed under a light microscope. Fiber length, fiber diameter, and lumen diameter were calculated as the mean of 50 measurements of intact individual cells per test specimen. Fiber wall thickness was determined as half of the difference between the fiber diameter and the corresponding lumen diameter.



**Figure 2.** Sample division and preparation pattern. (A) 30 cm thick Disk and 65 cm diameter, (B) Test sample for anatomical feature analysis and, (C) Fiber morphology (Augustina et al. 2020)

### Data analysis

Qualitative data were presented as microphotographs and described descriptively based on the observed anatomical features. Quantitative data were analyzed by calculating the mean values and standard deviations. Differences among stem positions (base, middle, and tip) were evaluated using one-way analysis of variance (ANOVA) at a 95% confidence level. All statistical analyses were performed using Microsoft Excel (Microsoft Corp., USA).

## RESULTS AND DISCUSSION

Palmyra wood (*Borassus flabellifer* L.) exhibits distinctive anatomical characteristics because it belongs to the Palmae (Arecaceae) group, which lacks a vascular cambium. Consequently, its wood structure differs fundamentally from that of typical hardwoods and softwoods (Lempang et al. 2009; Davinsky et al. 2024). In palms, the stem tissue is anatomically characterized by the presence of vascular bundles embedded and irregularly distributed within the ground tissue matrix. Variations in the density, size, and spatial distribution of these vascular bundles strongly influence the physical and mechanical properties of the wood. A comprehensive understanding of the anatomical characteristics of palmyra palm wood is therefore essential, not only for accurate identification and classification, but also as a scientific basis for evaluating its durability, processing behavior, and potential for optimal and sustainable

utilization in various biological, medical, and natural product applications.

Palmyra wood (*Borassus flabellifer* L.) differs markedly from dicotyledonous wood because palm stems lack secondary vascular cambium and, consequently, do not form annual growth rings. Instead, the stem tissue is composed of a heterogeneous cellular system consisting of fibers and vascular bundles embedded within a parenchymatous ground tissue matrix (Tomlinson 1990). This unique tissue organization leads to pronounced spatial variation in fiber cell morphology and vascular bundle distribution along the longitudinal axis of the stem. Previous studies have indicated that, in palm species, variations in fiber cell dimensions and tissue density are key determinants of the biological and mechanical performance of the stem as a natural lignocellulosic material. The base region of the stem generally exhibits higher tissue density and greater structural integrity than the middle and tip (Grosser and Liese 1971; Rüggeberg et al. 2008). Accordingly, detailed analyses of fiber morphology in palmyra palm wood are crucial for understanding the relationship between cellular structure and material properties, as well as for evaluating its potential applications in construction and non-construction sectors based on a bio-based material perspective.

### Anatomical Characteristics of Palmyra Wood (*Borassus flabellifer* L.)

Microscopic observations of transverse sections of palmyra palm wood revealed several distinct anatomical components, which were identified and labeled as vascular bundles (bp), parenchyma (pr), fibers (sr), phloem (fl), and metaxylem (mt). The vascular bundles exhibited a closed collateral type and were irregularly dispersed throughout the ground tissue, with the phloem located external to the xylem. This anatomical arrangement is consistent with previous descriptions of palm vascular bundle organization, which classify palmyra palm vascular bundles as closed collateral bundles (Tomlinson 1990; Rich et al. 1986). Overall, the anatomical micrographs confirm that palmyra palm wood possesses a distinctive structural organization characterized by a ground tissue matrix dominated by parenchymatous cells. These parenchyma cells are generally round to oval in shape, have thin cell walls, and function primarily as filler tissue and as reservoirs for water and carbohydrate storage. Embedded within this parenchymatous matrix are vascular bundles that are randomly distributed and do not form annual growth rings, a defining feature of monocotyledonous stems. Although detailed quantitative data on the functional interactions between parenchyma tissue and vascular bundle architecture in palmyra palm wood remain limited, existing studies suggest that this tissue organization contributes to structural flexibility and facilitates the storage of water and essential metabolites

(Karyanto and Nugroho 2023; Lestari and Widodo 2023) (Figure 3).

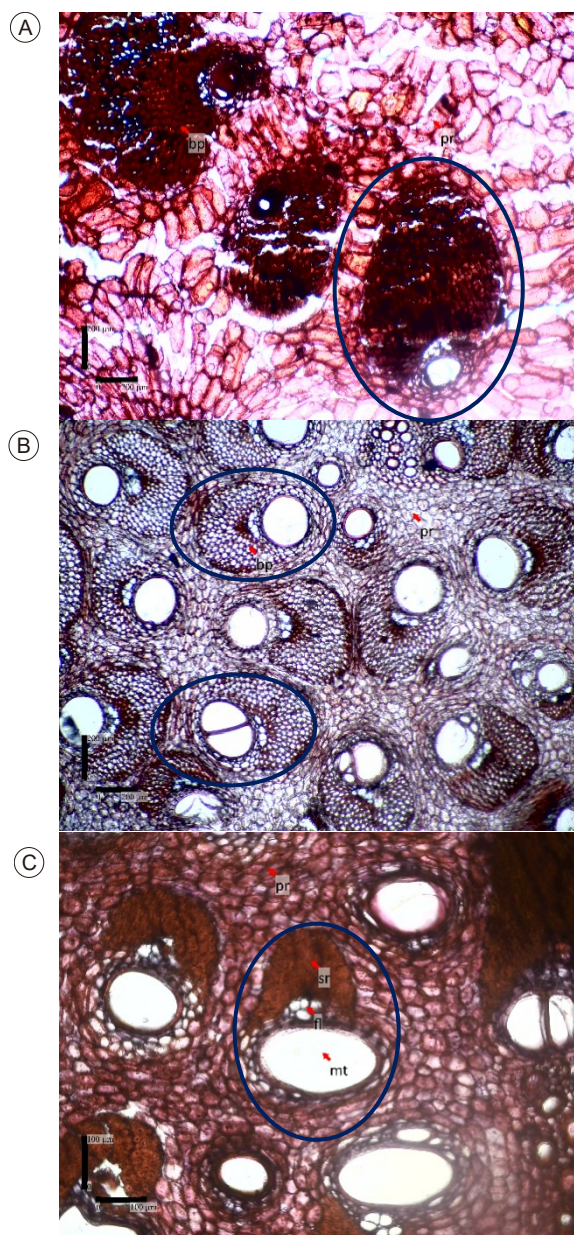


Figure 3. Anatomical structure of palm wood, (A) base, (B) middle, (C) tip

### Fiber Morphology of Palmyra Wood

Based on the data presented in Table 1, fiber diameter exhibited a decreasing trend from the base to the apical portion of the palmyra palm stem, with values ranging

from 38.48 to 15.64  $\mu\text{m}$ . This pattern indicates pronounced longitudinal variation in fiber morphology, in which the base region represents a more mature tissue characterized by larger fiber cells. Similar longitudinal variation in fiber diameter has been reported for other palm species, such as coconut (*Cocos nucifera*), where fibers in the base stem region are generally larger in diameter compared to those in the middle and tip (Tomlinson 1990; Grosser and Liese 1971). Fibers with larger diameters are commonly associated with thicker cell walls and relatively smaller lumina, resulting in higher tissue density and enhanced mechanical performance. Consequently, the base region of the stem demonstrates considerable potential for use in load-bearing applications, including heavy construction materials that require high strength and stiffness. This interpretation is supported by findings of Rana *et al.* (2015), who reported that the base portion of coconut palm stems exhibits higher modulus of elasticity and bending strength, making it suitable as a substitute for conventional hardwoods.

Longitudinal differences in fiber morphology in palmyra palm stems further reveal a close relationship between fiber wall thickness and lumen dimensions. In the present study, fiber wall thickness and lumen diameter from the base to tip ranged from 17.09 to 6.92  $\mu\text{m}$  and from 13.02 to 5.42  $\mu\text{m}$ , respectively. In the base region, fibers tend to possess substantially thicker walls, which significantly contribute to mechanical properties such as compressive, tensile, and bending strength. Although the lumina in this region are relatively larger, the potential structural weakness associated with void spaces is effectively compensated by the thick fiber walls, resulting in a robust tissue capable of supporting substantial mechanical loads. This anatomical configuration is consistent with the observations of Liese (2004), who identified the presence of a peripheral “hard zone” in palm stems characterized by thick-walled fibers as a mechanical adaptation to maintain stem rigidity. In contrast, fibers in the tip display thinner walls and smaller lumina. As noted by Fathi and Frühwald (2014), lumen size influences wood density and water absorption capacity in palm species; however, increases in density do not necessarily translate into improved mechanical strength when fiber wall thickness is relatively low.

Table 1. Morphological distribution of palm wood fiber (base, middle, tip)

Sample	Fiber diameter ( $\mu\text{m}$ )	Fiber wall thickness ( $\mu\text{m}$ )	Fiber lumen diameter ( $\mu\text{m}$ )	Number of vascular bundles per field of view	Vascular bundle density (/mm <sup>2</sup> )
Base	38,48	17,09	13,02	3,00	0,49
<i>St.Dev</i>	0,58	0,17	0,70	0,00	0,00
Middle	19,53	8,63	6,86	1,50	0,24
<i>St.Dev</i>	26,79	11,96	8,71	2,12	0,34
Tip	15,64	6,92	5,42	1,21	0,20
<i>St.Dev</i>	13,53	6,08	4,20	1,09	0,18

Note: Direct Research Data, 2025

## Discussion

### *Anatomical Characteristics of Palmyra Wood.*

Each vascular bundle in the palmyra palm wood is composed of several distinct structural elements. The outermost region is predominantly occupied by fiber tissue (sr), which is densely arranged and encases the vascular bundle, providing mechanical reinforcement that enables the palm stem to maintain structural stability and support vertical growth. These fibers appear as elongated cells with thickened cell walls and exhibit darker staining compared to the surrounding parenchyma. Studies on densification and structural reinforcement of palmyra palm wood have demonstrated that the inner softwood region responds favorably to compressive treatment, supporting the assumption that fiber tissue plays a critical role in enhancing the mechanical performance of the stem as a bio-based material (Rahman and Hossain 2021). Internal to the fiber sheath, the phloem tissue (fl) functions in the translocation of photosynthates throughout the plant. In palm species, the phloem is positioned adjacent to the xylem and is composed of relatively small, thin-walled cells, generally less developed than phloem tissues in cambium-bearing woody plants. The metaxylem (mt), characterized by larger lumen diameters, serves as the principal pathway for efficient water transport. This anatomical feature reflects physiological adaptation to water demand in stems growing under relatively dry environmental conditions (Sharma and Patel 2021; Lestari and Widodo 2023).

At the central region of each vascular bundle, the metaxylem (mt) is clearly observed as a large, unstained cavity corresponding to an empty lumen, which functions as the primary conduit for the upward transport of water and mineral nutrients from the roots to the leaves. The presence of large-diameter metaxylem vessels is a characteristic anatomical feature of palmyra palm wood; however, this structural trait also has implications for material durability, as the enlarged lumina may serve as preferential pathways for the ingress of wood-decaying fungi and wood-boring insects. The integrated organization of parenchyma as the ground tissue matrix, fibers as the main mechanical support, phloem as the photosynthate transport system, and metaxylem as the principal water-conducting element reflects the structural and functional adaptation of palmyra palm wood as a member of the Palmae group (Farhana *et al.* 2024). This adaptive tissue arrangement provides an optimal balance between efficient transport of water and solutes, adequate mechanical reinforcement, and internal storage capacity, thereby supporting sustained growth and survival under semi-arid environmental conditions (Ingle and Venkaiah 2019; Sharma and Patel 2021).

Structurally, the distribution and frequency of vascular bundles in the palmyra palm wood exhibit a characteristic spatial pattern. Toward the peripheral region of the stem, the number and density of vascular bundles tend to increase, corresponding with a gradual

increase in tissue density toward the outer stem region (Ingle and Venkaiah 2019). In line with this pattern, Davinsky and Pobas (2024) reported that the outer wood region (analogous to sapwood) displays favorable physical properties, rendering it suitable for use as a construction material. This organization is consistent with the general anatomical characteristics of monocotyledonous stems, in which vascular bundles are embedded within the ground tissue and collectively contribute to both mechanical support and physiological transport. The dense arrangement of vascular bundles at the stem periphery and their progressively lower frequency toward the central region indicate the presence of a mechanical strength gradient, with the outer stem region exhibiting superior mechanical performance. A near-linear relationship between fiber density, vascular bundle frequency, and cell wall thickness with respect to physical strength underlies the material behavior of palmyra palm wood, conferring a combination of high strength and sufficient flexibility. This structure–property relationship enables the palm stem to support considerable height and to withstand bending loads and wind-induced stresses in its natural habitat.

### *Fiber Morphology of Palmyra Wood*

The base region of the palmyra wood stem exhibited a higher number of vascular bundles per microscopic field of view compared to the tip, with values ranging from 3.00 to 1.21 bundles per field, respectively. This observation indicates a greater vascular bundle density in the basestem, which contributes substantially to the mechanical strength required to support structural loads. Correspondingly, the vascular bundle density decreased from the base to the tip, with values of approximately 0.49 to 0.20 bundles mm<sup>-2</sup>. A higher density of vascular bundles in the base stem region enhances tissue stiffness and load-bearing capacity, whereas the lower bundle density observed in the tip is associated with reduced mechanical strength. This distribution pattern is characteristic of palm stems and has been widely reported as a key biomechanical adaptation. Broschat (2017) emphasized that, in palm species, vascular bundles are more densely distributed in the base and middle portions of the stem as well as in the peripheral zone, functioning as the primary structural support for tall stems subjected to wind loading and canopy weight. The present findings indicate that the spatial distribution of vascular bundles in palmyra palm wood is not random, but rather represents an adaptive mechanical strategy that provides a structurally reinforced base to support the upper portions of the stem. Rüggeberg *et al.* (2008) further demonstrated the presence of a longitudinal gradient in vascular bundle density in palm stems, resulting in a so-called stiffness gradient, where the base region exhibits higher rigidity while the tip remains more flexible. Such a biomechanical gradient enables an optimal combination of strength at the stem base and flexibility toward the upper stem, thereby enhancing the

overall stability and resilience of the palm under natural environmental stresses.

## CONCLUSIONS

Palmyra wood exhibits anatomical features typical of Palmae, characterized by irregularly distributed vascular bundles embedded within a parenchymatous ground tissue matrix composed of parenchyma, fibers, phloem, and metaxylem. This structure clearly differentiates it from cambium-bearing woods that form annual growth rings. The fiber morphology of palmyra palm wood is marked by relatively large fiber diameters, thick cell walls, and small lumina, resulting in higher tissue density and favorable mechanical characteristics. Longitudinal variation in fiber morphology indicates that the base and middle stem regions possess superior structural attributes compared to the tip. Therefore, these stem portions are recommended for use in structural applications requiring high strength and stiffness, highlighting the potential of palmyra palm wood as a sustainable bio-based construction material.

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**Authors' Contributions:** Rynaldo Davinsky designed, coordinated all research activities and ensured the suitability of the methodology, Melkianus Pobas was responsible for the location and sampling, Adrin was responsible for wood sample preparation, Ika Kristinawanti designed the discussion, Ni Kade Ayu D. Aryani assisted in the data discussion, Luisa Moi Manek assisted in analyzing fiber morphology data, Mahardika Putra Purba documented the activities, Emi Renoat edited the manuscript, Lora Septrianda Putri analyzed the distribution of the carrier files, Yudhistira Ardhyana Nugraha Rua Ora was a researcher in data analysis and statistics, Kristianto Wibison So assisted in writing the manuscript, Yakub Benu was a researcher in data analysis and statistics. All authors read and approved the final version of the manuscript

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