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Research Paper

WOOD FIBER MORPHOLOGY OF TALISAY-GUBAT (*Terminalia foetidissima* Griff.) AND LANIPAU (*Terminalia copelandii* Elmer) GROWN IN MAGUINDANAO, PHILIPPINES

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ARTICLE HIGLIGHTS

- The study examined *Terminalia foetidissima* and *Terminalia copelandii*, native Philippine species that remain underutilized due to limited data despite their strong potential for the wood industry.
- Wood characterization helps evaluate their fiber properties and potential contribution to meeting increasing wood demand.
- The research focused on fiber morphology and derived values of both species grown in Maguindanao, Philippines.
- The findings provide reliable baseline data on the basic wood characteristics of these two native Terminalia species.

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ABSTRACT

Talisay-gubat (*Terminalia foetidissima* Griff.) and Lanipau (*Terminalia copelandii* Elmer) are among the *Terminalia* spp. native to the Philippines. The fiber morphology and derived values of the two species were characterized in this study, following the International Association of Wood Anatomists (IAWA) standard. Wood samples were collected from matured trees (approximately 10 to 20-year-old) grown in Maguindanao del Norte (07°08' N; 124°16' E). Collected samples were macerated for three hours at 100 °C in an equal volume (1 : 1) of acetic acid and hydrogen peroxide. Wood fibers were observed under a microscope, and then measured using the ImageJ Software. Results showed that *T. foetidissima* wood exhibited slightly larger and thicker fiber diameter (41.345 µm), lumen diameter (28.296 µm), and cell wall thickness (6.524 µm) with a little higher flexibility ratio (71.727%). On the other hand, *T. copelandii* exhibited slightly longer fiber length (1.677 mm) with little higher values for cell wall fraction (33.688%), Runkel ratio (0.598), slenderness ratio (51.510), Muhlsteph ratio (51.813%), rigidity coefficient (0.163), and Luce's shape factor (0.390). Moreover, t-test analysis showed no significant differences in the fiber morphology and derived values. The results indicated that both *T. foetidissima* and *T. copelandii* fibers show favorable qualities for pulp and paper production and composite materials. To fully confirm their potential and suitability, however, it is essential to examine other wood properties, including physical, mechanical, and chemical characteristics, as well as factors such as diameter and age classes, height levels, and wood types.

Keywords: derived values, Muhlsteph ratio, native species, pulp and paper, rigidity coefficient

INTRODUCTION

The Philippine wood industry displayed great potentials and capabilities, in consideration with the abundance of the endemic and native tree species thriving in the country as potential source of raw materials. However, many species were not yet studied or have limited data resulting in improper and limited utilization. Also, road expansion, site reclamation, and other forms of urbanization, coupled with a lack of awareness and appreciation, are some of the contributing factors for rapid disappearance of Philippine native trees (Senga 2019). Among those native tree species are Talisay-gubat (*Terminalia foetidissima* Griff.) and Lanipau (*Terminalia copelandii* Elmer), both *Terminalia* species under the family Combretaceae. Genus *Terminalia* is considered the second largest genus under Combretaceae family that comprises about 250 species of large to very large trees that are widely distributed in the tropical and subtropical regions of the world. Generally, *Terminalia* spp. provides economical, medicinal, spiritual and social benefits. Its wood is highly appreciated for constructional timber (Singh *et al.* 2013; Akinsulire *et al.* 2018).

In the island of Mindanao, Philippines, many native tree species were lesser-used due to limited information and promotion, although they may hold enormous potential not only in wood-based industries but also in conservation and biodiversity. Moreover, *T. foetidissima* and *T. copelandii* are among the tree species naturally and abundantly thriving in the area. *T. foetidissima* is native to the Philippines and to several countries in Southeast Asia, such as Myanmar, Thailand, Malaysia, and Indonesia. It is the counterpart of Talisay in the inland, found in higher elevations characterized as a large, deciduous tree growing up to 45 m tall and 80 – 100 cm diameter. Usually, it is used as a dye and as a source of wood for construction purposes and furniture making (Ragasa *et al.* 2019; Malabrigo & Umali 2022). Like *T. foetidissima*, *T. copelandii* is native to the Philippines, Southeast Asia, and various tropical regions around the world under the same family. It can grow up to 30 – 45 m tall and 70 – 80 cm diameter, characterized as a medium-sized tree with a straight, cylindrical bole that dominates the freshwater swamp forests in the country (Malabrigo & Umali 2022; Fern 2022). Under the International Union for Conservation of Nature (IUCN), both *T. foetidissima* and *T. copelandii* were classified as least concern species (IUCN 2025).

Several studies were documented on the wood anatomical properties of some *Terminalia* spp. such as *T. catappa* (Aina *et al.* 2019) in Nigeria, and *T. arjuna*, *T. belerica*, *T. chebula*, and *T. myriocarpa* in India (Singh *et al.* 2013). Also, a study about the leaf and petiole anatomical characters of *T. catapa*, *T. superba*, *T. ivorensis*, *T. mantaly*, and *T. avicennioides* was conducted (Akinsulire *et al.* 2018). In the Philippines, wood properties of *T. foetidissima* were characterized along with other lesser-used species (FPRDI 1996). However, no records yet for *T. copelandii* have been found about its wood properties, particularly in the Philippines. This lack of data on the wood properties of both *T. foetidissima* and *T. copelandii* in the country resulting to their improper and lesser utilization. Studies on this matter would be of great opportunity to unlock the potentials of these species considering variations ascribed from vital factors like geographic location, species-specific properties, etc.

The proper wood characterization of *T. foetidissima* and *T. copelandii* will be beneficial to further assess its fiber properties whether it could significantly fill the limited supply and contribute to the increasing demand of the wood industry in the country. This is to consider the Philippine government declaration for a moratorium on the cutting and harvesting of timber in the entire country's natural and residual forests under Executive Order Number 23, Series of 2011 (Government of the Philippines 2011) that relatively limits the wood supply, yet controls the abusive utilization of the forest resources.

Wood fibers are the principal element that is responsible for the strength of wood. Therefore, this study emphasized the characterization of fiber morphology and derived values of *T. foetidissima* and *T. copelandii* wood grown in Maguindanao Province, Bangsamoro Autonomous Region in Muslim Mindanao (BARMM), Philippines. This study also provided further reliable knowledge on the basic characteristics of two *Terminalia* spp. native in the country, which would be vital for proper utilization, especially for the least concern tree species thriving in BARMM region.

MATERIALS AND METHODS

Plant Materials and Wood Samples Collection

The wood samples of *T. foetidissima* and *T. copelandii* were collected at the Maguindanao del Norte (07°08' N; 124°16' E), BARMM, Philippines, with an elevation ranging from 85 - 110 meter above sea level (m asl) (Fig. 1), displaying a tropical monsoon climate (Classification: Am).

Three matured trees (approximately 10 to 20-year-old) were selected per tree species with a diameter of greater than 20 cm. Wood samples were extracted at three different locations within the DBH level (1.3 m) of the trees which were free from defects, knots, and injuries, using a 5.15 mm diameter by 100 mm long alloy steel increment borer, with a fine-threaded tip. After extraction, wood samples were placed in the respective ziplock bags with proper labelling for safe keeping, while the holes in the trees caused by increment borer were patched with wood and painted to keep away from the degrading organism (i.e., insect and fungi).

Wood Maceration

Matchstick-sized samples were prepared from the collected wood samples and then macerated in equal volume (1 : 1) of acetic acid and hydrogen peroxide (50% concentration), following the procedure of Espiloy *et al.* (1999). The maceration was done in a water bath and heated for three hours at 100 °C until the samples became white, soft and easy to separate into individual fibers. Afterward, the samples were washed with distilled water to become acid-free, and then subjected to microscopic observation and measurement without staining.

Fiber Measurement

Before fiber measurement, the macerated samples inside the test tubes were shaken to ensure the separation of different structural elements. Twenty-five undamaged fibers were observed per replicate under the Euromex compound microscope and measured using ImageJ Software (ImageJ 1.45). The length, diameter, and lumen diameter of each fiber were measured in accordance to the International Association of Wood Anatomists (IAWA) standard (Wheeler *et al.* 1989), while the cell wall thickness was determined based on the difference between the fiber diameter and lumen diameter. Cell wall fraction (1) was also calculated following the equation used by Eloy *et al.* (2024):

$$\text{Cell wall fraction} = \frac{2 \times \text{Cell wall thickness}}{\text{Fiber diameter}} \times 100 \qquad (1)$$

Derived Values

Based on the fiber morphology data, the derived values such as Runkel ratio (2), Slenderness ratio (3), Flexibility ratio (4), Muhlsteph ratio (5), and Rigidity coefficient (6) were computed using the equation used by Hartono *et al.* (2022), while the Luce's shape factor (7) was determined using the equation followed by Takeuchi *et al.* (2016). These values were used to further evaluate the potential of *T. foetidissima* and *T. copelandii* as raw materials for pulp and paper production, and other applications.

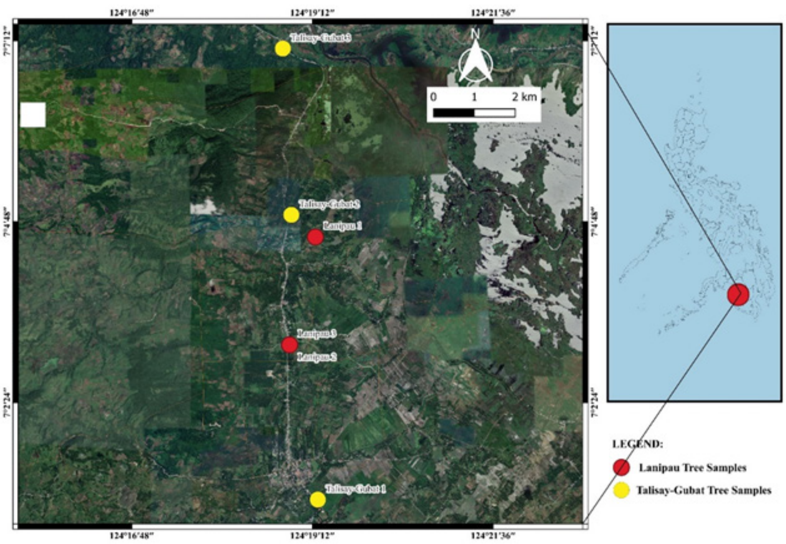

Figure 1 Location of the collected *T. foetidissima* and *T. copelandii* wood samples in Maguindanao, Philippines

$$Runkel\ ratio = \frac{2 \times Cell\ wall\ thickness}{Lumen\ diameter} \quad (2)$$

$$Slenderness\ ratio = \frac{Fiber\ length}{Fiber\ diameter} \quad (3)$$

$$Flexibility\ ratio = \frac{Lumen\ diameter}{Fiber\ diameter} \times 100 \quad (4)$$

$$Muhlsteph\ ratio\ (\%) = \frac{Fiber\ diameter^2 - lumen\ diameter^2}{Fiber\ diameter^2} \times 100 \quad (5)$$

$$Rigidity\ coefficient = \frac{Cell\ wall\ thickness}{Fiber\ diameter^2} \quad (6)$$

$$Luce's\ shape\ factor = \frac{Fiber\ diameter^2 - Lumen\ diameter^2}{Fiber\ diameter^2 + Lumen\ diameter^2} \quad (7)$$

Statistical Analysis

A t-test analysis was used to compare the fiber morphology and derived values of *T. foetidissima* and *T. copelandii* wood. This analysis was carried out using Jamovi version 2.3 (Jamovi Project 2023).

RESULTS AND DISCUSSION

Fiber Morphology of *T. foetidissima* and *T. copelandii*

The statistical description (mean and standard deviation) and the result of the t-test analysis on the fiber morphology of the *T. foetidissima* and *T. copelandii* were presented in Table 1, while sample photos of the wood fibers are displayed in Figure 2.

Fiber Length

Results of the study showed that the fibers of *T. foetidissima* and *T. copelandii* measured 1.613 mm and 1.677 mm, respectively. The analysis indicated no significant difference in fiber length between the two species, with a P-value of 0.668, suggesting that the fiber lengths are comparable. The average fiber length results of the present study were relatively longer compared to other *Terminalia* spp. like *T. arjuna* (1.176 mm), *T. bellerica* (1.131 mm), *T. myriocarpa* (0.991 mm) in India (Singh *et al.* 2013), *T. ivorensis* (sapwood, 1.314 mm & heartwood, 1.413 mm) in Ghana (Antwi-Boasiako & Apreko-Pilly 2016), *T. arjuna* (0.512 mm), *T. bellerica* (0.262 mm), *T. chebula* (0.445 mm), and *T. elliptica* (0.490 mm) in India (Ranjan *et al.* 2025). These findings were relatively comparable to the fiber length of *T. foetidissima* (1.650 mm) in Philippines (FPRDI 1996) and *T. catappa* (1.673 mm) in Nigeria (Aina *et al.* 2019). Compared to some underutilized native wood species in the Philippines (Villareal *et al.* 2025) such as *Alstonia scholaris* (1.79 mm), *Ficus callosa* (1.82 mm), and Ficus variegata (2.73 mm), both *T. foetidissima* and *T. copelandii* possessed shorter fibers, except for *Broussonetia luzonica* (1.44 mm). Moreover, *T. foetidissima* and *T. copelandii* fibers were relatively longer than the fibers of *Falcataria moluccana* (3-, 5-, and 7-year-old trees: 1.160, 1.140, and 1.170 mm, respectively), a fast-growing plantation species in the country commonly used for veneer, plywood, pulp and paper, and other light construction applications (Alipon *et al.* 2021).

Based on Salehi's (2001) grouping, both the fibers of *T. foetidissima* and *T. copelandii* fall under the second group, which is characterized by having an average fiber length ranging from 0.9 to 1.9 mm. These results indicate that the fibers of *T. foetidissima* and *T. copelandii* could be favorable raw materials for composite products considering that fibers ranging from 1.0 to 5.0 mm in length can potentially be used for composite products (Madsen *et al.* 2013). Long fibers with thin cell walls were much preferable for pulp and paper manufacturing since the longer the fiber, the higher the paper's tearing resistance (Sharma *et al.* 2011). Suansa and Al-Mefarrej (2020) also stated that fibers with an average of greater than 0.4 mm are considered suitable raw materials for papermaking. Based on the fiber length results, *T. foetidissima* and *T. copelandii* fibers would be favorable for pulp and paper production. Additionally, the DENR Administrative Order No. 2000-63 also classifies both species as suitable materials for furniture and construction applications. However, further research is needed to thoroughly evaluate the potential of these species for various applications.

Fiber and Lumen Diameter

The findings of this study revealed that the *T. foetidissima* fiber diameter was 41.345 μm, while *T. copelandii* fiber diameter was 34.992 μm. Statistical analysis revealed no significant difference in the fiber diameter between these two species, with a P-value of 0.307. The average fiber diameter of *T. foetidissima* and *T. copelandii* was relatively smaller than those of *Terminalia* spp. reported by Singh *et al.* (2013) such as *T. arjuna* (160.40 μm), *T. bellerica* (171.00 μm), *T. chebula* (125.40 μm) and *T. myriocarpa* (256.90 μm) (Singh *et al.* 2013), but larger to *T. foetidissima* (27.00 μm) (FPRDI 1996) and *T. ivorensis* (sapwood, 21.69 μm and heartwood, 19.79 μm) (Antwi-Boasiako & Apreko-Pilly 2016). Moreover, the observed fiber diameter of *T. catappa* (36.37 mm) (Aina *et al.* 2019), and 3-, 5-, and 7-year-old *F. moluccana* (35.40, 37.40, and 38.00 µm) (Alipon *et al.* 2021) were comparable to the present results. Compared to some underutilized native species reported by Villareal *et al.* (2025), the fiber diameters of *T. foetidissima* and *T. copelandii* were smaller than *A. scholaris* (49.50 µm), *F. callosa* (52.83 µm), and *F. variegata* (52.13 µm), except for *B. luzonica* (35.83 µm).

Relative to lumen diameter, the results showed that *T. foetidissima* fiber has an average lumen diameter of 28.296 µm and *T. copelandii* fiber has a lumen diameter of 23.495 µm. The analysis revealed no significant results with a P-value of 0.402, indicating a comparable result for the lumen diameter of *T. foetidissima* and *T. copelandii* fibers. The average lumen diameters of *T. foetidissima* and *T. copelandii* were relatively larger than those of *T. foetidissima* (17.00 µm) (FPRDI 1996), *T. ivorensis* (sapwood, 15.47 µm & heartwood, 13.33 µm) (Antwi-Boasiako & Apreko-Pilly 2016), *T. catappa* (10.00 µm) (Aina *et al.* 2019). Compared to the findings of Villareal *et al.* (2025) on *A. scholaris* (38.73 µm), *F. callosa* (37.40 µm), and *F. variegata* (33.07 µm), both *T. foetidissima* and *T. copelandii* fibers' lumen diameter were smaller, except for *B. luzonica* (26.33 µm). Moreover, Alipon *et al.* (2021) report larger lumen fibers of 5 and 7-year-old *F. moluccana* with 30.90 and 31.70 (µm), respectively, while 3-year-old *F. moluccana* seems to be comparable to *T. foetidissima* fiber. Basically, the lumen diameter significantly influences the beating process of pulp and paper production, as liquid penetrates the empty spaces in the fibers (Kiaei *et al.* 2014). Furthermore, the physiological growth of wood, including tree ages, diameter increase, and species, can influence lumen diameter (Moya Roque & Tomazelo-Filho 2007; Anupam *et al.* 2016). The present lumen diameter results suggest that the beating process of *T. foetidissima* and *T. copelandii* fibers could probably be favorable.

Table 1 Fiber morphology of *T. foetidissima* and *T. copelandii* wood species

Property	Wood species		Significant level of difference (P-value)
	T. foetidissima	***T. copelandii***	
Fiber length (mm)	1.613 (±0.136)	1.677 (±0.198)	0.668ns
Fiber diameter (µm)	41.345 (±0.005)	34.992 (±0. 008)	0.307ns
Lumen diameter (µm)	28.296 (±0.005)	23.495 (±0.007)	0.402ns
Cell wall thickness (µm)	6.524 (±7.51e-4)	5.748 (±3.79e-4)	0.189ns
Cell wall fraction (%)	31.842 (±5.003)	33.688 (±5.567)	0.691ns

Notes: ns = not significant at 0.05 significant level; standard deviations are indicated inside the parentheses.

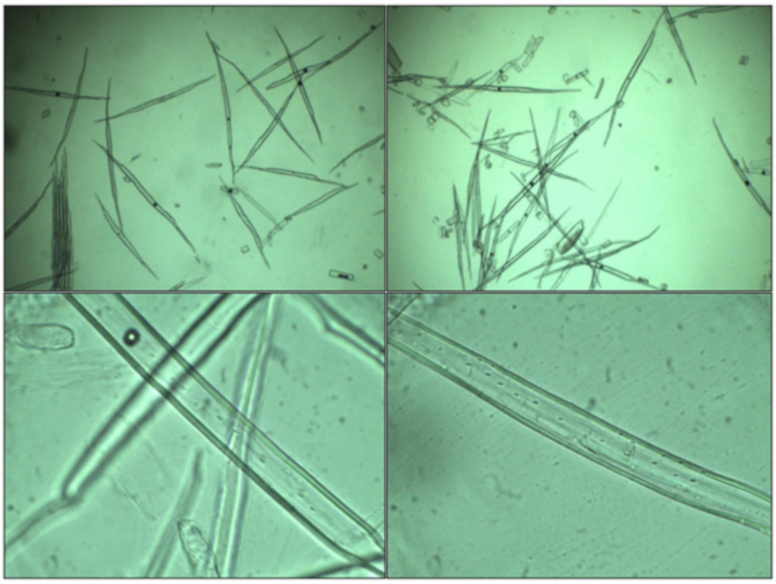

Figure 2 Photos of *T. foetidissima* (left) and *T. copelandii* (right) wood fibers

Cell Wall Thickness

Results of this study indicated that *T. foetidissima* has 6.524 µm and *T. copelandii* has 5.748 µm cell wall thickness. These average results were relatively thicker than those of the cell wall of some *Terminalia* spp. reported by Singh *et al.* (2013) on *T. arjuna* (2.30 µm), *T. myriocarpa* (2.20 µm), *T. bellerica* (2.10 µm), and *T. chebula* (1.80 µm), while thinner than *T. catappa* (16.67 µm) (Aina *et al.* 2019). FPRDI (1996) also reported a slightly thinner cell wall of *T. foetidissima* with an average of 5.00 µm. Moreover, the cell wall of *T. ivorensis* (sapwood, 6.22 µm & heartwood, 6.46 µm) reported by Antwi-Boasiako & Apreko-Pilly (2016) seems to be comparable with the present result of *T. foetidissima* fibers. As compared to 3-, 5-, and 7-year-old *F. moluccana* (3.30, 3.20, 3.1 µm, respectively) (Alipon *et al.* 2021), *A. scholaris* (5.40 µm) and *B. luzonica* (4.73 µm) (Villareal *et al.* 2025), the cell walls of both *T. foetidissima* and *T. copelandii* were thicker, but thinner than *F. callosa* (7.70 µm), and *F. variegata* (9.57 µm) (Villareal *et al.* 2025). Basically, cell wall thickness increases toward maturity which is dependent on the accumulated metabolic products like holocellulose, lignin, and waxes (Ververis 2004; Shmulsky & Jones 2019). Fibers with thick walls adversely affect the bursting strength, tensile strength, and folding endurance of paper (Kiaei *et al.* 2014; Shmulsky & Jones 2019). Based on the present result, *T. foetidissima* and *T. copelandii* fibers could be relatively rigid and may produce less dense paper but higher tearing strength, considering the impact of cell wall to the fiber flexibility and bulkiness of paper (Sharma *et al.* 2011).

Cell Wall Fraction

The result showed that *T. copelandii* recorded 33.688% cell wall fraction, while *T. foetidissima* recorded 31.842% exhibiting 5.634% difference. Although, no significant difference was observed with a P-value of 0.691. This present result was relatively lower compared to other hardwood species usually used for construction purposes like *Peltophorum dubium* (64.00%), *Parapiptadenia rigida* (57.80%), and *Eucalyptus grandis* × *Eucalyptus urophylla* (55.20%) (Eloy *et al.* 2024), while higher than those of underutilized native species in the Philippines (*A. scholaris*, 21.82%; *B. luzonica*, 26.40%; *F. callosa*, 29.15%; *F. variegata*, 36.72%) (Villareal *et al.* 2025), and underutilized fast-growing species in Indonesia (*Macaranga bancana*, 7.00% and *M. pearsonii*, 8.00%) (Takeuchi *et al.* 2016). A higher cell wall fraction slows a material's drying rate by reducing its capacity to hold moisture. This property also serves as a key indicator for industrial use, where a value below 40% suggests suitability for pulpwood and is linked to greater bending resistance through fiber flexibility (Kollmann & Côté 1968; Takeuchi *et al.* 2016; Eloy *et al.* 2024). Additionally, the cell wall fraction is directly linked to wood's basic density and inversely linked to its moisture content. Moreover, a higher cell wall fraction increases wood density and enhances its mechanical strength, making it more resistant (Sette Junior *et al.* 2012; Lima *et al.* 2014; Tanabe *et al.* 2016; Eloy *et al.* 2024). The present results indicated that *T. copelandii* wood may have a slower drying rate, while *T. foetidissima* may exhibit a faster drying rate. These findings also suggest that both wood species could be suitable for pulpwood production.

Derived Values

Derived values of *T. foetidissima* and *T. copelandii* wood species, such as the Runkel ratio, Slenderness ratio, Flexibility ratio, Muhlsteph ratio, Rigidity coefficient, and Luce's shape factor are presented in Table 2.

Runkel Ratio

T. copelandii has a Runkel ratio of 0.598 and *T. foetidissima* has 0.555, showing 7.458% difference. However, the study found no significant difference (0.664 P-value), indicating a comparable Runkel ratio between the two species. The present result was relatively lower than the Runkel ratio of *T. catappa* (2.063) (Aina *et al.* 2019), *F. variegata* (0.74) (Villareal *et al.* 2025), but relatively higher to 3-, 5-, and 7-year-old *F. moluccana* (0.240, 0.220, and 0.260, respectively) (Alipon *et al.* 2021), *A. scholaris* (0.30), *B. luzonica* (0.38), and *F. callosa* (0.48) (Villareal *et al.* 2025). Moreover, the present Runkel result was comparable with the report of FPRDI (1996) on *T. foetidissima* with 0.59. According to Aina *et al.* (2019), fibers with Runkel ratio above 1.0 are expected to be thick-walled fibers forming a bulky paper sheet with lower bonded area and good mechanical strength qualities. Based on the Runkel ratio's results, *T. foetidissima* and *T. copelandii* are relatively suitable as raw materials for pulp and papermaking. With this result, it could be recommended that *T. foetidissima* and *T. copelandii* plantations maybe established to support the production of pulp and paper in the country rather than planting exotic tree species.

Table 2 Derived values of *T. foetidissima* and *T. copelandii* wood species

Property	Wood species		Significant level of difference (P-value)
	T. foetidissima	***T. copelandii***	
Runkel Ratio	0.555 (±0.107)	0.598 (±0.120)	0.664ns
Slenderness Ratio	43.525 (±4.079)	51.510 (±9.529)	0.253ns
Flexibility Ratio (%)	71.727 (±3.278)	67.379 (±4.729)	0.261ns
Muhlsteph Ratio (%)	45.751 (±4.998)	51.813 (±6.485)	0.269ns
Rigidity Coefficient	0.141 (±0.016)	0.163 (±0.024)	0.261ns
Luce's Shape Factor	0.366 (±0.063)	0.390 (±0.071)	0.691ns

Notes: ns = not significant at 0.05 significant level; standard deviations are indicated inside the parentheses.

Slenderness Ratio

Results of the study showed that *T. copelandii* recorded 51.510 slenderness ratio, while *T. foetidissima* recorded 43.525 showing 16.804% difference of results. However, the study found no significant difference (0.253 P-value), indicating a comparable slenderness ratio between the two species. The result of the study was relatively higher than those of 3-, 5-, and 7-year-old *F. moluccana* (34.33, 31.98, and 31.90, respectively) (Alipon *et al.* 2021), *A. scholaris* (37.13), *B. luzonica* (42.04), and *F. callosa* (35.87) (Villareal *et al.* 2025). As to the value obtained on *T. catappa* (45.567) by Aina *et al.* (2019), *T. copelandii*'s slenderness ratio was higher while *T. foetidissima* showed a little lower. Compared to *F. variegata* (60.48) (Villareal *et al.* 2025), the present result was lower. Furthermore, *T. foetidissima* and *T. copelandii*'s slenderness results fell within the permissible range of 33 or above, as reported by Kiaei *et al.* (2014), showing potential to pulp and papermaking purposes.

Flexibility Ratio

This study revealed that *T. foetidissima*'s flexibility ratio was 71.727% and *T. copelandii* was 67.379%, showing 6.251% difference. Statistically, there was no significant difference between the results, indicating a comparable value for the flexibility ratio. The present results of *T. foetidissima* and *T. copelandii* were relatively higher than *T. catappa* (35.667%) (Aina *et al.* 2019), 3-, 5-, and 7-year-old *F. moluccana* (81.990%, 82.780%, and 82.840%, respectively) (Alipon *et al.* 2021), and *F. variegata* (65.35%) (Villareal *et al.* 2025), while lower than *A. scholaris* (77.74%), and *B. luzonica* (73.02%) (Villareal *et al.* 2025). Based on Bektas *et al.*'s (1999) flexibility classifications, both *T. foetidissima* and *T. copelandii* fibers fell under elastic fiber (ranging from 50 – 75%). This result indicates efficiency and appropriateness for paper manufacture. Technically, the flexibility ratio is one of the key indicators of a fiber's suitability for papermaking, as it measures its ability to collapse during beating or drying. This collapse creates a greater bonding area, and the degree of fiber bonding is largely dependent on the flexibility of the individual fibers (Zobel & Van Buijtenen 1989). A higher flexibility ratio demonstrates higher tensile strength (Hartono *et al.* 2022). Furthermore, the flexibility ratio results of the present study suggest the suitability of *T. foetidissima* and *T. copelandii* fibers for pulp and papermaking.

Muhlsteph Ratio

Results of this study revealed that *T. copelandii*'s Muhlsteph ratio (51.813%) showed 12.427% difference with the *T. foetidissima*'s Muhlsteph ratio (45.751%). However, the difference in results was not significant. Both *T. foetidissima* and *T. copelandii* Muhlsteph ratios fell in class II (values ranged from 30 – 60%) based on the classification used by Hartono *et al.* (2022). This present result fell on the same Muhlsteph ratio class reported by Villareal *et al.* (2025) on the underutilized native species grown in Maguindanao, Philippines, such as *A. scholaris* (39.08%), *B. luzonica* (46.28%), *F. callosa* (47.15%), and *F. variegata* (53.63%). The Muhlsteph ratio affects the pulp's density, as well as the smoothness of paper and the plasticity between the fibers (Hartono *et al.* 2022). Based on the result, *T. foetidissima* and *T. copelandii* fibers could produce a paper with favorable smoothness and pliability which not easily torn off when folded.

Rigidity Coefficient

The study's findings revealed that *T. copelandii* has a rigidity coefficient of 0.163 and *T. foetidissima* has 0.141, showing 14.474% difference. However, the difference in the results between *T. foetidissima* and *T. copelandii* was not significant. Based on the classification used by Hartono *et al.* (2022), *T. foetidissima* fiber falls under class II (ranges from 0.10 – 0.15), similar class with *F. callosa* (0.14), *B. luzonica* (0.14), and *A. scholaris* (0.11), while *T. copelandii* fiber falls under class III (greater than 0.15), similar class with *F. variegata* (0.17). Technically, a low rigidity coefficient indicates greater fiber flexibility, which enhances the paper's resistance to tearing under tensile stress (Hartono *et al.* 2022). Thus, the present result suggests that papers made from *T. foetidissima* and *T. copelandii* fibers have a substantial rigidity and stiffness properties.

Luce's Shape Factor

The Luce's shape factor of *T. copelandii* (0.390) showed 6.349% difference compared to the *T. foetidissima* (0.366). Although, no significant difference of the result was observed between species with a P-value of 0.691. Compared to the findings of Villareal *et al.* (2025) (*F. callosa*, 0.33; *B. luzonica*, 0.30; and *A. scholaris*, 0.24), the present result was relatively higher, except for *F. variegata* with 0.43. Luce's shape factor serves as an index for the beating resistance of pulp, with lower values indicating less resistance to beating (Takeuchi *et al.* 2016). This factor is also an important fiber index directly related to the density of paper sheets. A Luce's shape factor below 0.5 suggests an ideal value for pulp and paper production, indicating good strength (NagarajaGanesh *et al.* 2023). Therefore, the current findings on Luce's shape factor further affirm the suitability of *T. foetidissima* and *T. copelandii* fibers for papermaking.

Overall findings suggest that *T. foetidissima* and *T. copelandii* species are well-suited not only for pulp and paper production but also for light construction applications and composite materials where extreme strength and durability are not essential. Both species can also be utilized for various products like wooden toys, shoes, pencil slats, matchsticks, toothpicks, ice cream spoons, popsicle sticks, boxes, shelves, moldings, sashes, doors, veneer, plywood, buoys, and floats. Any differences in the properties are likely influenced by several factors, including genetic composition, site conditions, soil elevation, silvicultural practices, and stand density (Shmulsky & Jones 2019; Alipon *et al.* 2021). To fully confirm their potential and suitability, however, it is vital to examine other wood properties, including physical, mechanical, and chemical characteristics.

CONCLUSION

This study offered valuable insights for the wood industry, academic institutions, and the scientific community about the fiber morphology and related characteristics of *T. foetidissima* and *T. copelandii*. Result revealed that *T. foetidissima* exhibited slightly larger and thicker fibers, and a little higher flexibility ratio, whereas *T. copelandii* displayed slightly longer fibers along with a little higher cell wall fraction, Runkel ratio, slenderness ratio, Muhlsteph ratio, rigidity coefficient, and Luce's shape factor. However, the differences in fiber morphology and derived values were not significant. These findings suggest that both *T. foetidissima* and *T. copelandii* fibers could be suitable for pulp and paper production, light construction applications, and composite materials. However, to fully assess their potential, additional research is needed on the physical, mechanical, and chemical properties, as well as factors such as diameter and age classes, height levels, and wood types. As interest in native tree species continues to rise, *T. foetidissima* and *T. copelandii* may have the potential to compete with industrial plantation species. Further research is essential to optimize key technological processes including seasoning, drying, veneering, and machining, while also developing effective propagation methods and establishing sustainable plantations for these species.

REFERENCES

Akinsulire OP, Oladipo OT, Akinloye AJ, Illoh HC. 2018. Structure, distribution and taxonomic significance of leaf and petiole anatomical characters in five species of *Terminalia* (L.) (Combretaceae: Magnoliopsida). Brazil J Biol Sci 5(10):515-28. DOI:10.21472/bjbs.051027

Alipon MA, Bondad EO, Gilbero DM, Jimenez JP, Emmanuel PD, Marasigan OS. 2021. Anatomical properties and utilization of 3-,5-, and 7-yr-old Falcata (*Falcataria moluccana* Miq. Barneby & J.W. Grimes) from CARAGA Region, Mindanao Philippines. Philippine J Sci 150(5):1307–19.

Antwi-Boasiako C, Apreko-Pilly S. 2016. Tissue dimensions and proportions of the stem and branch woods of *Aningeria Robusta* (A. Chev) and *Terminalia Ivorensis* (A. Chev). African J Wood Sci For 4(8):254-73.

Anupam K, Sharma AK, Lal PS, Bist V. 2016. Physicochemical, morphological, and anatomical properties of plant fibers used for pulp and papermaking. In: Ramawat K, Ahuja M (Editors), Fiber Plants, Sustainable Development and Biodiversity. Cham (CH): Springer International Publishing. p. 235–48. DOI:10.1007/978-3-319-44570-0_12

Bektas I, Tutus A, Eroglu H. 1999. A study of the suitability of Calabrian pine (*Pinus brutia* Ten.) for pulp and paper manufacture. Turkish J Agric For 23(3):589–99.

[DENR] Department of Environment and Natural Resources 2000. DENR Administrative Order No. 2000-63: New rates of forest charges pursuant to Republic Act No. 7161 (R.A. 7161) and based on the 1999 FOB market price of forest products. Manila (PH): Department of Environment and Natural Resources.

Eloy E, Mangini TS, Nardini C, Caron BO, Trevisan R, Santos AD dos. 2024. Correlation of anatomy with physical properties of wood species from an agroforestry system. Revista Árvore 48(1):1-11. DOI:10.53661/1806-9088202448263657

Espiloy ZB, Espiloy EB, Moran SR. 1999. Basic properties of two-lesser used bamboo species: Laak (*Bambusa* sp. 2) and Kayali (*Gigantochloa atter*). Forest Product Research and Development Institute Journal 25(1&2):1–18.

Fern K. 2022. Useful Tropical Plants Database. *Terminalia procera*. [Internet]. [Cited 2024 July 26]. Available from: https://tropical.theferns.info/viewtropical.php?id=*Terminalia+procera*

[FPRDI] Forest Products Research and Development Institute. 1996. Utilization of lesser-used species (LUS) as alternative raw materials for forest-based industries. Project Summary Report – Phase I: PD 47/88 Rev. 3(1). Manila (PH): Forest Products Research and Development Institute.

Government of the Philippines. 2011. Executive Order No. 23, s. 2011. Manila: Official Gazette of the Republic of the Philippines. [Internet]. [cited: 2024 Aug 12]. Available from: https://www.officialgazette.gov.ph/2011/02/01/executive-order-no-23-s-2011/

Hartono R, Purba FVA, Iswanto A, Priadi T, Sutiawan J. 2022. Fiber quality of yellow bamboo (*Bambusa vulgaris* Vitata) from forest area with special purpose Pondok, Buluh, Simalungun Regency, North Sumatera Province. IOP Conference Series: Earth and Environmental Science 1115(1):1315-755. DOI:10.1088/1755-1315/1115/1/012084

[IUCN] International Union for Conservation of Nature. 2025. The IUCN Red List of Threatened Species. Version 2025-2. [Internet]. [Cited 2025 Nov 26]. Available from: https://www.iucnredlist.org

Kiaei M, Tajik M, Vaysi R. 2014. Chemical and biometrical properties of plumwood and its application in pulp and paper production. Maderas Ciencia y Tecnologia 16(3):313–22. DOI:10.4067/S0718-221X2014005000024

Kollmann FFP, Côté WA. 1968. Principles of Wood Science and Technology: Solid Wood. Berlin (DE): Springer-Verlag.

Lima RS, Coelho JCF, Silva JC, Araújo JA, Calderon CMA. 2014. Influência da anatomia nas propriedades físicas da madeira de *Iryanthera grandis* Ducke. [Influence of wood anatomy on physical properties of the wood *Iryanthera grandis* Ducke.]. Enciclopédia Biosfera 10(19):1188-98.

Madsen B, Brondsted P, Andersen TL. 2013. Biobased composites: Materials and potential applications as wind turbine blade materials. In: Liu T, Summerscales J, Grove C (Editors), Advances in Wind Turbine Blade Design and Materials. Cambridge (UK): Woodhead Publishing Limited. p. 363–86. DOI:10.1533/9780857097286.3.363

Malabrigo PL, Umali AGA. 2022. Alay: Philippine Native Trees at the Victor O. Ramos Arboretum. Quezon City (PH): Philippine Native Tree Enthusiasts (PNTE).

Moya Roque R, Tomazelo-Filho M. 2007. Relationship between anatomical features and intra-ring wood density profiles in *Gmelina arborea* applying x-ray densitometry. CERNE 13(4):384–92.

NagarajaGanesh B, Rekha B, Mohanavel V, Ganeshan P. 2023. Exploring the possibilities of producing pulp and paper from discarded lignocellulosic fibers. J Nat Fibers 20(1):1-10. DOI:10.1080/15440478.2022.2137618

Ragasa CY, Gumafelix RD, Ng VAS, Camacho DH. 2019. Triterpenes and sterols from *Terminalia foetidissima* Griff. Asian J Chem 31(11):2669-71. DOI:10.14233/ajchem.2019.22201

Ranjan R, Srivastava D, Prasad M. 2025. Wood anatomy of timber yielding species of *Terminalia* Linn. (Combretaceae) growing in the Terai region of Uttar Pradesh, India and their taxonomic significance. Int J Bot Stud 10 (9):46-53.

Salehi K. 2001. Study and determine the properties of chemi-mechanical pulping high yields from bagasse. Wood and Paper Research No. 232. Tehran (IR): Research Institute of Forests and Rangelands.

Senga J. 2019. Haribon tree trek: Learn proudly pinoy trees. [Internet]. [Cited 2024 Jul 26]. Available from: https://haribon.org.ph/haribon-tree-trek-learn-proudly-pinoy-trees/

Sharma AK, Dutt D, Upadhyaya JS, Roy TK. 2011. Anatomical, morphological, and chemical characterization of *Bambusa tulda, Dendrocalamus hamiltonii, Bambusa balcooa, Malocana baccifera, Bambusa arundinacea,* and *Eucalyptus tereticornis*. Bioresources 6(4):5062–73. DOI:10.15376/biores.6.4.5062-5073

Shmulsky R, Jones PD. 2019. Forest Products and Wood Science: An Introduction. Seventh Edition. Hoboken (US): Wiley-Blackwell. DOI:10.1002/9781119426400

Singh MK, Sharma MB, Sharma CL. 2013. Wood anatomical variations in some *Terminalia* species of Assam. Int J Bot Res 3(2):13-8.

Suansa NI, Al-Mefarrej HA. 2020. Branchwood properties and potential utilization of this variable resource. Bioresources 15(1):479–91.

Takeuchi R, Wahyudi I, Aiso H, Ishiguri F, Istikowati WT, Ohkubo T, …, Yokota S. 2016. Wood properties related to pulp and paper quality in two *Macaranga* species naturally regenerated in secondary forests, Central Kalimantan, Indonesia. Tropics 25(3):107-15. DOI:10.3759/tropics.MS15-23

Tanabe J, Ishiguri F, Nakayama M, Ohshima J, Iizuka K, Yokota S. 2016. Properties of juvenile and mature wood and their effects on the bending properties of lumber in *Pinus taeda* growing in Tochigi, Japan. For Prod J 66(7):428-32. DOI:10.13073/FPJ-D-15-00069

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. Ind Crop Prod 19(3):245-54. DOI:10.1016/j.indcrop.2003.10.006

Villareal JF, Untong RU, Mispil AU, Poclis CE, Numeron CMS, Marasigan OS. 2025. Comparative fiber morphology of four underutilized native tree species in Maguindanao, Philippines. Environ Nat Resour J 23(4):299-310. DOI:10.32526/ennrj/23/20240311

Wheeler EA, Baas P, Gasson PE. 1989. IAWA list of microscopic features for hardwood identification. IAWA Bulletin 10(3):219–332. DOI:10.1163/22941932-90000496

Zobel BJ, Van Buijtenen JP. 1989. Wood Variation: Its Causes and Control. Berlin (DE): Springer-Verlag. DOI: 10.1007/978-3-642-74069-5