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Comparative Fiber Morphology of Four Underutilized Native Tree Species in Maguindanao, Philippines

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ABSTRACT

The focus of this study was to characterize and compare the fiber morphology (fiber length, fiber diameter, lumen diameter, cell wall thickness, and cell wall fraction) and derived values (Runkel ratio, slenderness ratio, flexibility ratio, Mulhsteph ratio, rigidity coefficient, and Luce's shape factor) of four underutilized native tree species grown in the Maguindanao region, namely; Dita (*Alstonia scholaris* (L.) R. Br.), Himbabao (*Broussonetia luzonica* Blanco), Tangisang Bayawak (*Ficus variegata* Blume), and Kalukoi (*Ficus callosa* Willd.). Wood samples from the selected trees (between 10-20 years old) were collected at dbh level (1.30 m) and then macerated for three hours. The macerated wood fibers were observed under a Euromex compound microscope and then measured using ImageJ Software. Results revealed that *F. variegata* had the longest recorded fiber (2.73 mm) with the thickest cell wall (9.57 µm) and highest values for cell wall fraction (36.72%), Runkel ratio (0.74), slenderness ratio (60.48), Mulhsteph ratio (53.63%), rigidity coefficient (0.17), and Luce's shape factor (0.43). As for fiber diameter, *F. callosa* (52.83 µm) was largest. Moreover, *A. scholaris* fibers recorded the largest lumen diameter (38.73 µm) with the highest flexibility ratio (77.74%). Analysis of variance showed significant differences relative to fiber morphology and their derived values, except for slenderness ratio. Results suggested that the four underutilized species are good not only for pulp and paper production, but also have potential for light construction, wooden toys and shoes, pencil slats, matchsticks, toothpicks, ice cream spoons, popsicle sticks, boxes, shelves, molding, veneer and plywood, buoys, and floats. In further validation of the suitability of materials towards intended uses, characterization of other wood properties (e.g., physical and mechanical) and consideration of factors like genetic control, locations/habitats, stand density, elevation, age and diameter classes, height level and wood types are recommended.

1. INTRODUCTION

Escalating demands for wood products, driven by expanding domestic and international markets, have significantly reduced the availability of many commercially valuable wood species. This decline not only jeopardizes critical ecosystem services but also disproportionately impacts various communities (Díaz et al., 2019). In response to these challenges, the Philippine government enacted Executive Order No. 23, series of 2011, to combat deforestation, forest degradation, habitat loss, and illegal logging (Government of the Philippines, 2011). However, despite these efforts, the increasing needs of residential, commercial, and construction projects

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have outstripped the declining supply of timber and other wood products (USDA FAS, 2021).

In light of this, the exploration of sustainable alternatives to traditional wood species has become increasingly urgent, not just to alleviate the material shortage but also as a crucial component of broader climate mitigation and adaptation strategies (Numeron et al., 2023). The Philippines, an archipelago of varied regions, provides the finest environments for the cultivation and growth of some of the most unusual plant species on Earth (Javargas, 2021). With approximately 3,600 native tree species in the Philippines, of which 67% are endemic (De Jesus, 2021), some of these are underutilized (lesser known) species which offer significant potential. Unfortunately, infrastructure development, urbanization, and a lack of public awareness are accelerating the decline of these native and endemic species (IUCN Urban Alliance, 2021).

In South-Central Mindanao, particularly in Maguindanao Province, Ligawasan Marsh Wetland Biodiversity Reserve (LMBWR) is one of the most significant ecosystems in the Bangsamoro Autonomous Region in Muslim Mindanao (BARMM) (Tanalgo et al., 2024). Considering the existence of different native tree species thriving abundantly in areas such as Dita, Himbabao, Tangisang Bayawak, and Kalukoi, it is vital to have comprehensive data on these species as well as inclusively accounting their values towards sustainable ecosystems. These underutilized naturally growing trees in the BARMM, are essential for maintaining local biodiversity and contributing to the timber industry. However, security concerns in the region have limited the characterization of the potential native tree species, with a forest cover of approximately 299,195 ha, (45%) of the region's total land area of 1,293,552 ha (Saiden, 2020). Hence, further study of these available native trees in the region is vital.

Dita (*Alstonia scholaris* (L.) R. Br.) is a fast-growing, typhoon-resistant tree that can reach heights between 30 to 40 m. It is highly effective in controlling soil erosion and is naturally distributed across South Asia, Southeast Asia, and Southern China. This species thrives in lowland environments, flourishing in both primary and secondary forests. The bark of the *A. scholaris* tree, widely harvested in the Philippines and nearby islands, is a significant component of traditional medicinal practices (Florentino et al., 2010). Although classified as a species of least concern by the IUCN (2024), further study is needed to improve its conservation and utilization strategies and fully understand its ecological benefits and role in maintaining forest health (Sutcliffe and Malabrigo, 2020).

Himbabao *(Broussonetia luzonica* Blanco) is a drought-tolerant, fast-growing tree native to the Philippines, capable of reaching heights of up to 25 m, with trunk diameters around 30 cm. It is commonly found in second-growth forests at low to medium elevations throughout the country. While *B. luzonica* is traditionally used as a vegetable in certain parts of Luzon, its widespread presence indicates potential for research aimed at improving its nutritional value and cultivation practices, which could enhance its market potential (Florido, 2010). Additionally, *B. luzonica* is recognized for its medicinal uses, including anti-inflammatory properties and digestive benefits, though its anatomical and morphological features remain underexplored (Quintos et al., 2022).

Tangisang Bayawak *(Ficus variegata* Blume) is native to the Philippines and many other countries such as the Andaman Islands, Australia, China, India, Indonesia, Japan to name a few. This tropical fig tree, part of the Moraceae family, typically grows in warm, humid lowland forests. Generally reaching a height of about 15 m, older specimens can grow up to 30 m. It boasts an erect trunk up to more than 1 m in diameter, adorned with tabular roots, which are flattened roots similar to buttresses, at the base. Its smooth bark, a grey-brown color, is associated with abundant milky sap when it sustains damage (Stuart, 2016; Malabrigo and Umali, 2022).

Kalukoi *(Ficus callosa* Willd.) is another fast-growing fig tree species within the Moraceae family. Native to the Philippines, Southern China, Indochina, and Malesia, *F. callosa* can grow up to 29 m in height, with trunk diameters of approximately 55 cm (Florido, 2010). It usually has a straight bole buttressed in older trees and harvested from the wild for local use as a food and source of wood and fiber. Despite this, its lightweight and durable wood makes it suitable for small-scale livelihood applications, such as boat construction (Osmeña et al., 2000).

Characterizing the properties of underutilized wood species is crucial for determining suitable processing techniques and ensuring optimal use (Marbun et al., 2019). The characterization of these species will not only provide information regarding their potential as alternative resources to meet the increasing demands of the wood industry but also support conservation and sustainable development efforts. This study underscores the importance of further research into the *A. scholaris*, *B. luzonica*, *F. variegata*, and *F. callosa* tree species found in Maguindanao, particularly on fiber morphology and their derived values, as they are strongly correlated with the other properties of the wood, for their potential contributions to wood-based industries, conservation, and sustainable practices.

2. METHODOLOGY

2.1 Plant materials and sample collection

The wood samples of Dita (*A. scholaris*), Himbabao (*B. luzonica*), Tangisang Bayawak (*F. variegata*), and Kalukoi (*F. callosa*) were collected at Datu Odin Sinsuat, Maguindanao del Norte (07°08' N 124°16′ E), Bangsamoro Autonomous Region in Muslim Mindanao (BARMM), Philippines with an elevation ranging from 85-110 m.a.s.l. (Figure 1), displaying a tropical monsoon climate (Classification: Am). Three mature trees (between 10-20 years old) with a straight bole were selected per species with an average diameter of 20 cm at breast height (DBH) level (1.3 m). Wood samples were extracted at three distinct locations (Due North, East, and West) within the tree's DBH level which were free from defects, knots or 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 zip lock for safekeeping. The extracted wood samples located between the pith and bark portions were used for fiber maceration and measurement.

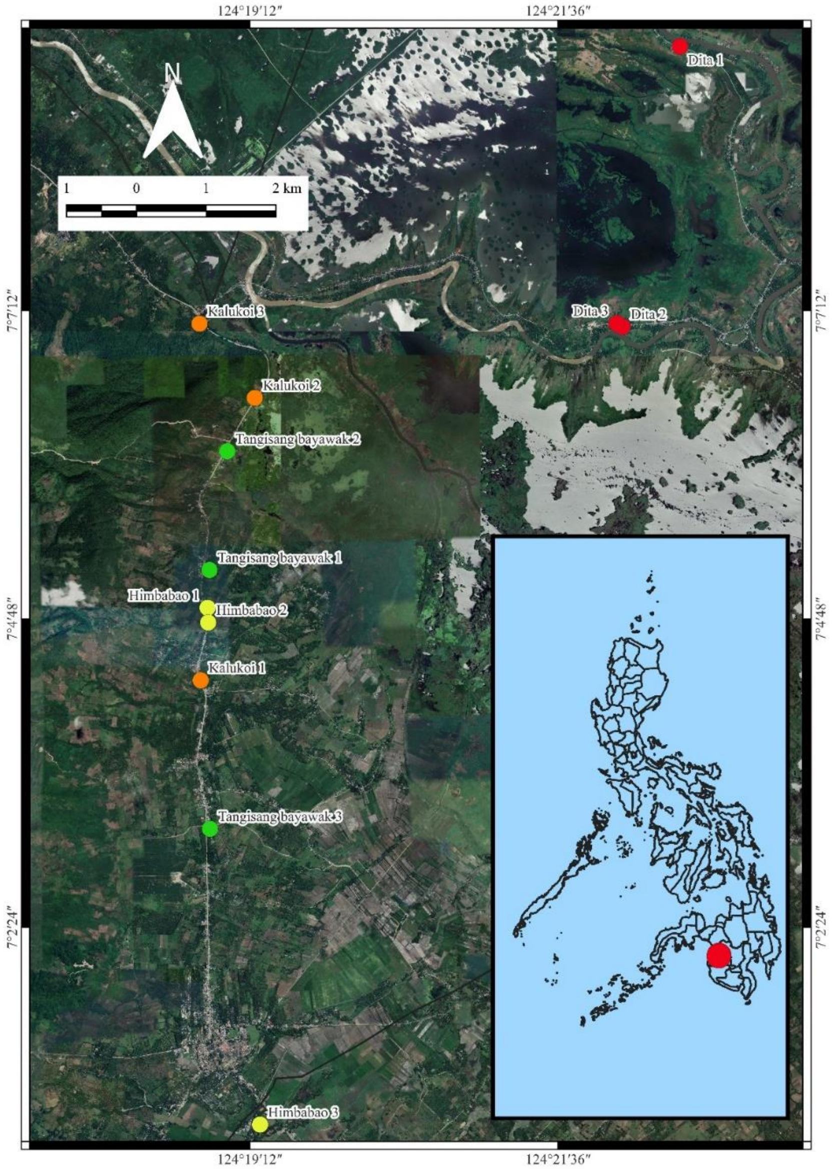

Figure 1. Location map of the four native tree species in Maguindanao del Norte, Philippines

2.2 Wood fiber morphology

2.2.1 Fiber maceration

Matchstick-sized samples were prepared from the collected wood samples and then macerated in equal volumes (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 turned white and became soft to separate individual fibers. Afterward, the samples were then washed with distilled water until acid-free and subjected to microscopic observation and measurement.

2.2.2 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 according 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. Also, cell wall fraction (1) was calculated using the equation used by Eloy et al. (2024).

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

2.2.3 Derived values

Based on the fiber morphology data, the derived values such as Runkel ratio (2), slenderness ratio (3), flexibility ratio (4), Mulhsteph 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. The assessment for the potential of *A. scholaris*, *B. luzonica*, *F. variegata*, and *F. callosa* as raw materials for pulp and paper production was conducted using the Indonesian Timber Assessment Criteria as Raw Materials for Pulp and Paper (Hartono et al., 2022).

$$\text{Runkel ratio} = \frac{2 \text{ x Cell wall thickness}}{\text{Lumen diameter}} \qquad (2)$$

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

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

$$\text{Mulhsteph ratio (\%)} = \frac{\text{Fiber diameter}^2 - \text{Lumen diameter}^2}{\text{Fiber diameter}^2} \times 100 \qquad (5)$$

$$\text{Rigidity coefficient} = \frac{\text{Cell wall thickness}}{\text{Fiber diameter}} \qquad (6)$$

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

2.3 Statistical analysis

One-way analysis of variance (ANOVA) was used to compare the wood fiber morphology and derived values of the species. Also, Tukey's honest significant difference was used to determine the significant differences among the mean values of the data. The statistical analyses were carried out using Jamovi version 2.3 (Jamovi Project, 2022).

3. RESULTS AND DISCUSSION

3.1 Fiber morphology

The fiber morphology of *A. scholaris*, *B. luzonica*, *F. variegata*, and *F. callosa* wood species such as fiber length, fiber diameter, lumen diameter, and cell wall thickness, were presented in Table 1. Likewise, the Tukey's honest significant difference result on the fiber morphology of these four species was shown in Figure 2.

Table 1. Fiber morphology of *A. scholaris*, *B. luzonica*, *F. variegata*, and *F. callosa* wood species

Property	Wood species				Significant level of difference (p-value)
	A. scholaris	*B. luzonica*	*F. variegata*	*F. callosa*	
Fiber length (mm)	1.79	1.44	2.73	1.82	0.010*
Fiber diameter (μm)	49.50	35.83	52.13	52.83	0.005*
Lumen diameter (μm)	38.73	26.33	33.07	37.40	0.034*
Cell wall thickness (μm)	5.40	4.73	9.57	7.70	<0.001*
Cell wall fraction (%)	21.82	26.40	36.72	29.15	0.088^{ns}

*significant at 0.05 significant level; ns=not significant

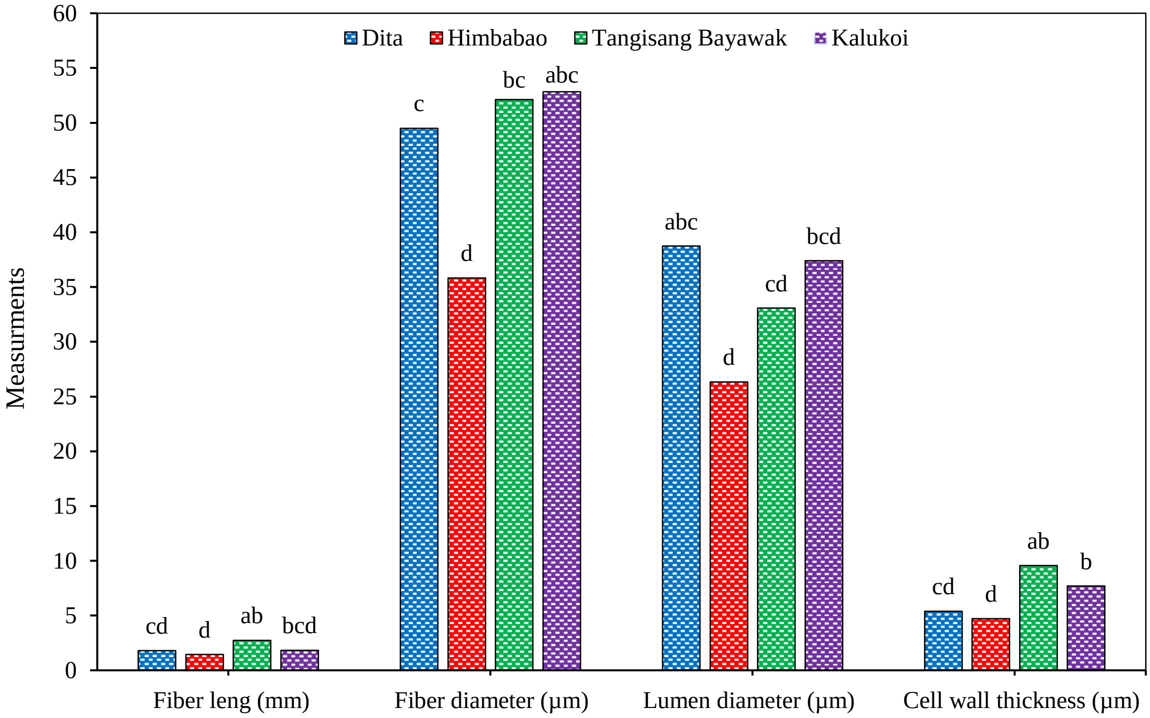

Figure 2. Tukey's honest significant difference result on the fiber morphology of *A. scholaris*, *B. luzonica*, *F. variegata*, and *F. callosa* wood species (In each property, means with common letters (a, b, c, d) are not significant)

3.1.1 Fiber length (mm)

The result of the study showed that *F. variegata* records the longest fiber (2.73 mm), followed by *F. callosa* (1.82 mm), *A. scholaris* (1.79 mm) and *B. luzonica* (1.44 mm). Analysis showed that the fiber length of these four wood species was significantly different with a p-value of 0.010. Moreover, *F. variegata* exhibited 41.79% and 61.75% significantly higher than *A. scholaris* and *B. luzonica* species, respectively. While compared to *F. callosa*, *F. variegata* showed a 40.09% difference, but not significant. On the other hand, the average fiber length results were relatively shorter than the fiber of softwoods (3.50 mm) (Sharma et al., 2011), but longer compared to *Eucalyptus tereticornis* (0.72 mm), *E. grandis* (0.92 mm) (Sharma et al., 2011), *Ficus carica* subsp. *Carica* (0.95 mm) (Yaman, 2014), Plumwood (0.98 mm) (Kiaei et al., 2014), hardwoods (1.00 mm) (Anupam et al., 2016), 3-, 5-, and 7-year-old Falcata trees (1.16, 1.14, and 1.17 mm, respectively) (Alipon et al., 2021), *Ganophyllum falcatum* (1.20 mm) (Villareal et al., 2022b), *Aquilaria cumingiana* (0.98 mm) (Villareal et al., 2022a), and *Melia azedarach* (0.57 mm) (Megra et al., 2022).

Based on Salehi's (2001) characterization, fiber of *F. variegata* falls under 3rd group with > 1.90 mm fibers, while fibers of *F. callosa*, *A. scholaris*, and *B. luzonica* fall under the 2nd group, characterized to have an average fiber length ranging from 0.90 to 1.90 mm. Moreover, Madsen et al. (2013) reported that fibers ranging from 1 to 5 mm are commonly used for making composite materials with in-plane isotropic properties, i.e., composite materials with a non-specific orientation. According to Suansa and Al-Mefarrej (2020), fibers with an average length greater than 0.4 mm are deemed suitable as raw materials for papermaking. Generally, long fibers with thin cell walls were much preferable for pulp and paper manufacturing since the longer the fiber, the higher the tearing tensile, and bursting strength, and folding endurance of the paper (Sharma et al., 2011). Thus, the four underutilized wood species examined in this present study may be used for pulp and paper production and other composite materials. Among the four species, *F. variegata* might exhibit higher bursting strength, tensile strength, tearing strength, and folding endurance given the longer fiber length it showed.

3.1.2 Fiber and lumen diameter (μm)

The result of the study showed that *F. callosa* fibers having a diameter of 52.83 μm had recorded the largest value, followed by *F. variegata*, *A. scholaris*, and *B. luzonica* with 52.13, 49.50, 35.83 (μm), respectively. Significant difference was shown on the fiber diameter of these four species with a p-value of

0.005. It was also observed that *F. callosa* fibers differ significantly to *B. luzonica* fibers with 38.35% difference. As compared to other wood species like *E. tereticornis* (15.00 µm), *E. grandis* (19.00 µm) (Sharma et al., 2011), *F. carica* (21.40 µm) (Yaman, 2014), hardwoods (25.00 µm), Plumwood (13.77 µm) (Kiaei et al., 2014), *Gmelina arborea* (27.00 µm) (Prabawa, 2017), *G. falcatum* (23.00 µm) (Villareal et al., 2022b), *A. cumingiana* (32.00 µm) (Villareal et al., 2022a), and *M. azedarach* (13.45 µm) (Megra et al., 2022), the fibers of four wood species in this present study were relatively larger. While *B. luzonica* fiber seem to be comparable to softwood (35.00 µm) (Kiaei et al., 2014) and 3-, 5-, and 7-year-old Falcata trees (35.40, 37.40, and 38.00 µm, respectively) (Alipon et al., 2021), but relatively lower than the rest of the wood species of this present study.

In terms of lumen diameter, the present study showed that *A. scholaris* fiber (38.73 µm) was relatively larger than *F. callosa* (37.40 µm), *F. variegata* (33.07 µm), and *B. luzonica* (26.33 µm) fibers. Significant differences in lumen diameter across species were observed with a p-value of 0.034. A significant difference was only seen between *A. scholaris* and *B. luzonica* fibers with 38.12% difference. In view of wood drying, *A. scholaris* wood may dry faster as it has larger lumen diameter where the removal of water from wood is facilitated (Eloy et al., 2024). Eloy et al. (2024) also reported that lumen diameter together with fiber diameter showed a direct effect in the drying of wood, a directly proportional relationship with moisture content, and an inversely proportional relationship with basic density as well as the values of mechanical properties. Moreover, the average lumen diameter results of these four wood species were relatively larger than those of *E. tereticornis* (5.12 µm), *E. grandis* (6.67 µm) (Sharma et al., 2011), *F. carica* (12.50 µm) (Yaman, 2014), Plumwood (5.60 µm) (Kiaei et al., 2014), *G. arborea* (21.00 µm) (Prabawa, 2017), *G. falcatum* (9.36 µm) (Villareal et al., 2022b), *A. cumingiana* (23.40 µm) (Villareal et al., 2022a), and *M. azedarach* (13.03 µm) (Megra et al., 2022). As compared to 3- , 5-, and 7-year-old Falcata trees (28.90, 30.90, and 31.70 µm, respectively) (Alipon et al., 2021), *B. luzonica* fibers was relatively thinner while the rest of the wood species of this present study were moderately larger. Technically, lumen diameter influences the beating process in pulp and paper production because liquid penetrates the fibers' empty spaces (Kiaei et al., 2014). According to Moya Roque and Tomazello-Filho (2007), lumen diameter can be affected by the physiological growth of wood as the tree ages and expands in girth. It was also pointed out by Anupam et al. (2016) that fiber lumen varies for different species. The results of the present study suggest that the four tree species exhibited favorable beating processes that would greatly affect the quality of pulp and paper products.

3.1.3 Cell wall thickness (µm)

The result of the study showed that *F. variegata* fibers exhibited thicker cell wall with 9.57 µm, followed by *F. callosa* (7.70 µm), *A. scholaris* (5.40 µm), and *B. luzonica* (4.73 µm). Significant difference was observed across species with a p-value of <0.001. Among these four species, *F. variegata* cell wall differs significantly with *A. scholaris* and *B. luzonica* cell walls with 55.71% and 67.69% differences, respectively.

The average cell wall thickness results of these four underutilized wood species were relatively thicker than *G. arborea* (3.00 µm) (Prabawa, 2017), 3-, 5-, and 7-year-old Falcata trees (3.30, 3.20, and 3.10 µm, respectively) (Alipon et al., 2021), and *M. azedarach* (2.52 µm) (Megra et al., 2022). As compared to *E. tereticornis* (4.74 µm) (Sharma et al., 2011), Plumwood (4.08 µm) (Kiaei et al., 2014), *F. carica* (4.50 µm) (Yaman, 2014), and *A. cumingiana* (4.36 µm) (Villareal et al., 2022a), the cell wall thickness of *A. scholaris* and *B. luzonica* were relatively comparable. While *F. variegata* and *F. callosa* appears thicker than the others like *E. grandis* (6.27 µm) (Sharma et al., 2011), and *G. falcatum* (6.26 µm) (Villareal et al., 2022b). Basically, cell wall thickness increases towards maturity and usually governs fiber flexibility. With a thicker cell wall, it is expected to produce a bulky and course surfaced with large amount of void volume paper (Sharma et al., 2011). Based on the present result, paper made from *F. variegata* and *F. callosa* fibers will be more rigid but less dense compared to *A. scholaris* and *B. luzonica* fibers, which likely produce denser and well-formed paper.

3.1.4 Cell wall fraction (%)

The result of the study showed that *F. variegata* obtained the highest cell wall fraction with 36.72%, followed by *F. callosa* (29.15%), *B. luzonica* (26.40%), and *A. scholaris* (21.82%). Moreover, *F. variegata* has 22.98% difference to *F. callosa*, 32.70% to *B. luzonica*, and 50.90% difference to

A. scholaris. However, analysis showed no significant difference. The results of the present study showed relatively lower than the findings of Eloy et al. (2024) on *Peltophorum dubium* (64.00%), *Parapiptadenia rigida* (57.80%), and *Eucalyptus grandis*×*Eucalyptus urophylla* (55.20%), while relatively higher than *Schizolobium parahyba* (21.60%). Basically, materials with higher cell wall fraction values would exhibit slower flow of water resulting to a reduced drying speed associated with a smaller proportion of cell lumens that retain less moisture when saturated (Eloy et al., 2024). A cell wall fraction less than 40% indicates to be a good pulpwood material. It also considered as an index for bending resistance which is related to flexibility of fiber (Takeuchi et al., 2016). The cell wall fraction exhibits a direct correlation with the basic density of wood, while inversely correlated with wood moisture (Lima et al., 2014; Eloy et al., 2024). Moreover, a higher CWF increases the basic density of the wood, and improves its mechanical properties, making the wood more resistant (Sette Junior et al., 2012; Tanabe et al., 2016). Based on the present result, *F. variegata* wood may display a slower drying rate, while *A. scholaris* may have the shortest rate of drying. The results also suggest the suitability of the wood species for pulpwood material.

3.2 Derived values

The derived values of *A. scholaris*, *B. luzonica*, *F. variegata*, and *F. callosa* wood species, such as the Runkel ratio, slenderness ratio, flexibility ratio, Mulhsteph ratio, rigidity coefficient, and luce's shape factor were presented in Table 2. While Figure 3 showed the Tukey's honest significant difference result on the derived values of these four species.

3.2.1 Runkel ratio

The results of the study showed that the highest Runkel ratio was recorded by *F. variegata* with 0.74, while *A. scholaris* recorded the lowest value with 0.30. Analysis of variance revealed that there is a significant difference in the Runkel ratio among the four underutilized wood species. Particularly, *F. variegata* fibers were significantly higher than *A. scholaris* and *B. luzonica* fibers having 84.94% and 64.04% differences. While *F. callosa* fibers were 41.77% lower than *F. variegata*, but not significant.

Table 2. Derived values of *A. scholaris*, *B. luzonica*, *F. variegata*, and *F. callosa* wood species

Property	Wood species				Significant level of difference (p-value)
	A. scholaris	*B. luzonica*	*F. variegata*	*F. callosa*	
Runkel ratio	0.30	0.38	0.74	0.48	0.014*
Slenderness ratio	37.13	42.04	60.48	35.87	0.129^{ns}
Flexibility ratio (%)	77.74	73.02	65.35	71.09	0.018*
Mulhsteph ratio (%)	39.08	46.28	53.63	47.15	0.027*
Rigidity coefficient	0.11	0.14	0.17	0.14	0.018*
Luce's shape factor	0.24	0.30	0.43	0.33	0.008*

*significant at 0.05 significant level; ns=not significant

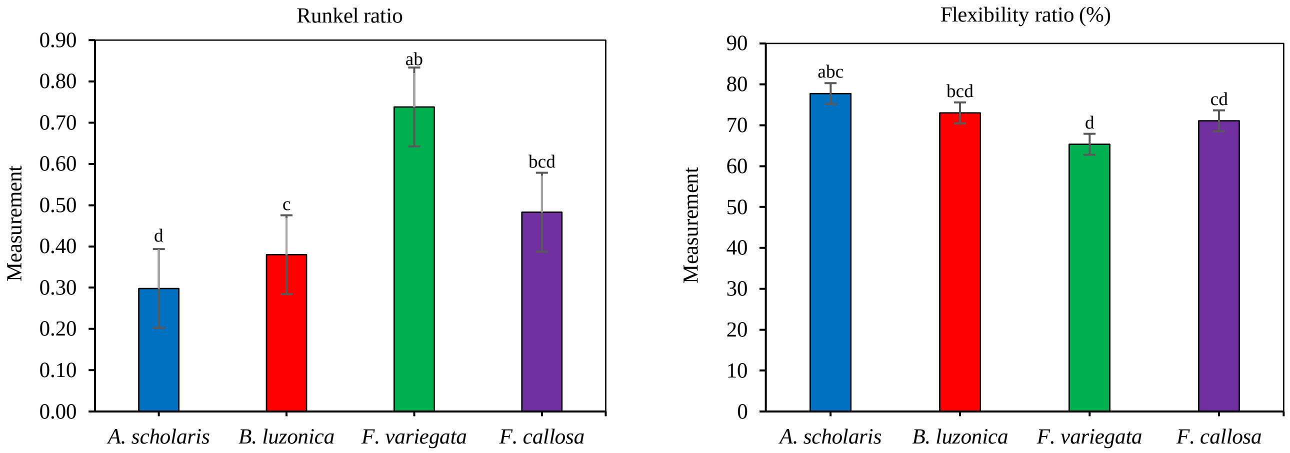

Figure 3. Tukey's honest significant difference result on the derived values of *A. scholaris*, *B. luzonica*, *F. variegata*, and *F. callosa* wood species (In each property, means with common letters (a, b, c, d) are not significant)

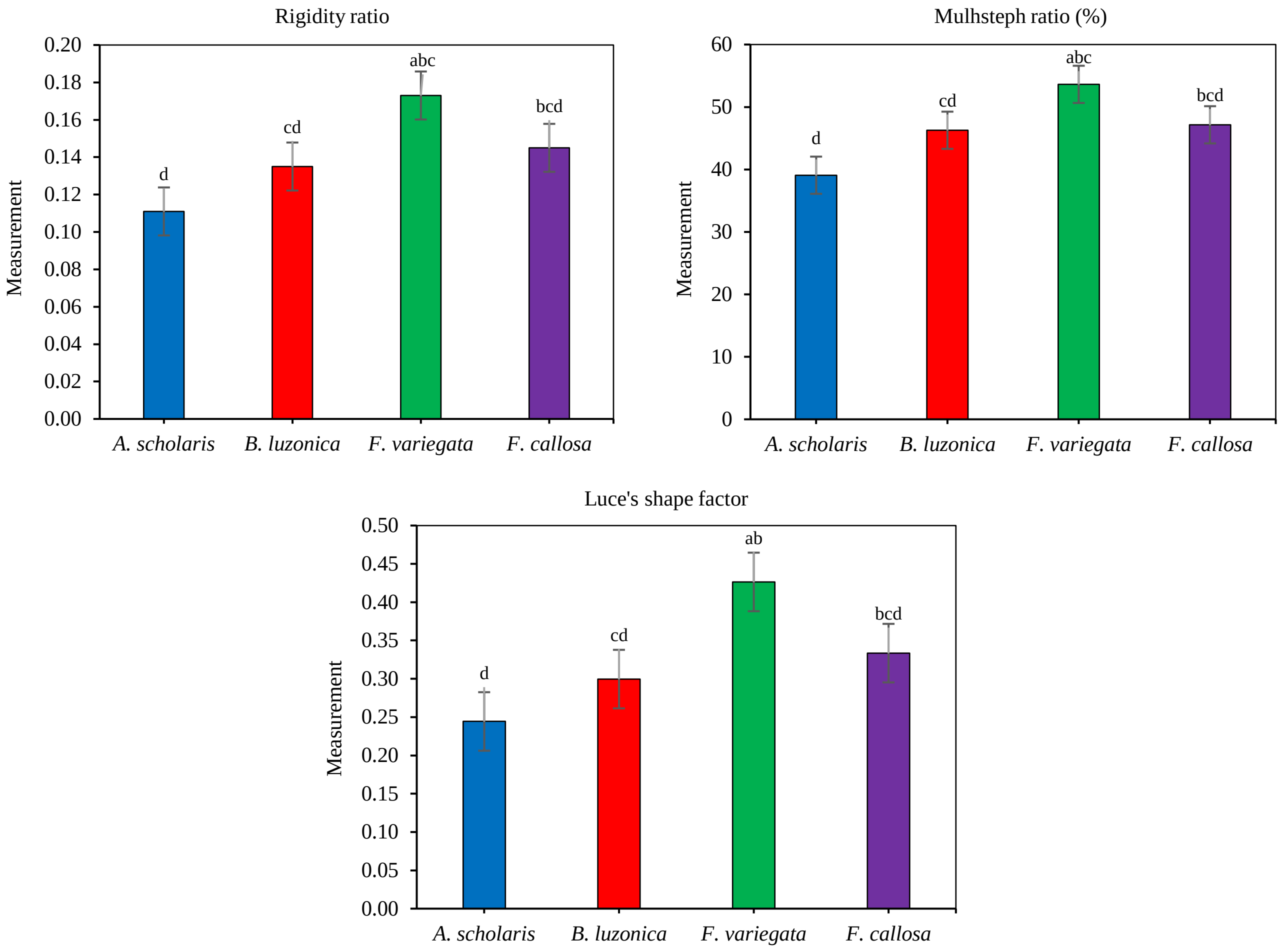

Figure 3. Tukey's honest significant difference result on the derived values of *A. scholaris*, *B. luzonica*, *F. variegata*, and *F. callosa* wood species (In each property, means with common letters (a, b, c, d) are not significant) (cont.)

The present result was relatively lower than the Runkel ratio of *G. falcatum* (1.62) (Villareal et al., 2022b), but higher to 3-, 5- and 7-year-old *Falcata* trees (0.24, 0.22, and 0.26, respectively) (Alipon et al., 2021). Compared to *A. cumingiana* (0.39) (Villareal et al., 2022a), and *M. azedarach* (0.39) (Megra et al., 2022), the Runkel ratio result of *B. luzonica* was relatively comparable, while lower than *F. variegata* and *F. callosa* results. Accordingly, a Runkel ratio below 1.0 tends to indicate thin-walled fibers with good mechanical strength properties and are considered as the standard values that are relatively favorable in the viewpoint of papermaking (Sharma et al., 2011; Kiaei et al., 2014). Thus, the Runkel ratio results suggested that the four wood species are likely suitable for pulp and paper making and other materials were strength and durability are not critical requirements.

3.2.2 Slenderness ratio

F. variegata recorded the highest slenderness value with 60.48, while *F. callosa* got the lowest value of 35.87. Moreover, *F. variegata* fibers showed 35.96%, 47.86%, and 51.08% differences of slenderness results for *B. luzonica*, *A. scholaris*, and *F. callosa* fibers. However, no significant difference was observed signifying a comparable value of the slenderness ratio of the four wood species.

The slenderness ratio results of the study were relatively higher than those of 3-, 5-, and 7-year-old *falcata* trees (34.33, 31.98, and 31.90, respectively) (Alipon et al., 2021), and *A. cumingiana* (30.95) (Villareal et al., 2022a), while lower compared to Plumwood (73.28) (Kiaei et al., 2014). Except for *F. variegata*, the previous slenderness results of *M. azedarach* (42.47) (Megra et al., 2022) and *G. falcatum* (56.71) (Villareal et al., 2022b) exhibited higher values. The present slenderness results were within the permissible range value of 33 or above (Kiaei et al., 2014). This further suggests the suitability of materials to pulp and paper making.

3.2.3 Flexibility ratio (%)

The results of the study showed that *A. scholaris* fibers have the highest flexibility ratio having 77.74%, while *F. variegata* fibers got the lowest value with 65.35%. A significant difference was observed across species. *A. scholaris*, with the highest flexibility ratio varied significantly with *F. variegata* showing 17.32% difference. The present results of the study were relatively higher than those of Plumwood (41.38%) (Kiaei et al., 2014) and *G. falcatum* (42.09%) (Villareal et al., 2022b), while lower compared to 3-, 5-, and 7-year-old Falcata trees (81.99, 82.78, and 82.84%, respectively) (Alipon et al., 2021), and *M. azedarach* (96.90%) (Megra et al., 2022). In comparison with *A. cumingiana* (72.31%) (Villareal et al., 2022a), the flexibility results of *A. scholaris* and *B. luzonica* found higher, while *F. variegata* and *F. callosa* results found lower.

In relation to flexibility classifications devised by Bektas et al. (1999), *A. scholaris* fibers were considered highly elastic fiber (greater than 75%) while the other three wood species were characterized as elastic fibers (ranging from 50-70%). This indicates efficiency and appropriateness for paper manufacture since the flexibility expresses the fibers' ability to collapse during beating or drying of the paper web providing more bonding area (Zobel and Van Buijtenen, 1989). Thus, the flexibility ratio results, especially fibers of *A. scholaris* will likely display higher tensile strength and further suggest the suitability of materials for pulp and paper making. Hartono et al. (2022) stated that with a higher flexibility ratio, it is expected to display higher tensile strength.

3.2.4 Mulhsteph ratio (%)

The result of the study revealed that the highest Mulhsteph ratio was obtained by *F. variegata* (53.63%) while the lowest was recorded by *A. scholaris* (39.08%). A significant difference was observed across species. *F. variegata* was 31.38% significantly higher than *A. scholaris*, while 12.85% and 14.71% differences were observed towards *F. callosa* and *B. luzonica*, respectively. Regardless of wood species, the Mulhsteph ratios result fall in class II with values ranging from 30-60% based on the classification used by Hartono et al. (2022). The Mulhsteph ratio value 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 observed results, fibers of these four species could produce a paper that is relatively conducive in terms of smoothness and pliability which difficult to tear when folded.

3.2.5 Rigidity coefficient

F. variegata showed relatively higher rigidity coefficient with 0.17 compared to *F. callosa* (0.14), *B. luzonica* (0.14), and *A. scholaris* (0.11). Moreover, *F. variegata* showed 43.66% difference for *A. scholaris*, 24.68% for *B. luzonica*, and 17.61% for *F. callosa*, but only *F. variegata* and *A. scholaris* differed significantly. Except for *F. variegata* that falls under class III (>0.15 values), the present rigidity coefficient results fall under class II ranges from 0.10-0.15 based on the classification used by Hartono et al. (2022). Fibers with a low value of rigidity coefficient signify a substantial value wherein the fiber will be more flexible, and the paper produced will not easily be torn when given a tensile load (Hartono et al., 2022). With the present results, papers from the fibers of four wood species have considerable rigidity and stiffness, especially papers made from *A. scholaris* which recorded the lowest value; hence, it will not be easily torn-apart when given a tensile load.

3.2.6 Luce's shape factor

The result showed that the luce's shape factor of *F. variegata* (0.43) was relatively higher than *F. callosa* (0.33), *B. luzonica* (0.30), and *A. scholaris* (0.24). Analysis of variance revealed a significant difference in the luce's shape factor across species. Specifically, *F. variegata* was significantly higher than *B. luzonica* and *A. scholaris* with 35.62% and 56.72% difference, respectively. The present results were comparable with the two *Eucalyptus* species examined by Ona et al. (2001): *E. camaldulensis* (0.34) and *E. globulus* (0.32). Luce's shape factor was considered as an index for the beating resistance of the pulp, where a lower value indicates a less resistance to beating (Takeuchi et al., 2016). It is also a significant fiber index which related to paper sheet density and a value of less than 0.5 luce's shape factor would signifies favorable value associated with good strength for pulp and paper making (NagarajaGanesh et al., 2023). Thus, the result of luce's shape factor further confirms the potential of *A. scholaris*, *B. luzonica*, *F. variegata*, and *F. callosa* fibers for paper production.

Results suggested that the four underutilized native wood species are good not only for pulp and paper production, but also potential for light construction wherein strength and durability are not critically important including wooden toys and shoes, pencil slats, matchsticks, toothpicks, ice cream spoons, popsicle sticks, boxes, shelves, molding, sash, door, veneer and plywood, buoys, and floats, etc. Further, the diverse factors like genetic control, locations/habitats, stand density, elevation, age and diameter classes, height level and wood types, etc. (Alipon et al., 2021; Adimahavira et al., 2023), would likely be the contributors to the significant differences observed in the results.

4. CONCLUSION

The present study underscored the fiber morphology (fiber length, fiber diameter, lumen diameter, cell wall thickness, and cell wall fraction) and derived values (Runkel ratio, slenderness ratio, flexibility ratio, Mulhsteph ratio, rigidity ratio, and luce's shape factor) of the four underutilized native tree species thriving in the Maguindanao province, Philippines. The result revealed that *F. variegata* records the longest and thickest fibers having 2.73 mm length and 9.57 µm cell wall. Likewise, *F. variegata* records the highest values in terms of cell wall fraction, Runkel ratio, slenderness ratio, Mulhsteph ratio, rigidity coefficient, and luce's shape factor having 36.72%, 0.74, 60.48, 53.63%, 0.17, and 0.43, respectively. As to fiber diameter, *F. callosa* (52.83 µm) was the largest, while *A. scholaris* recorded the largest lumen diameter (38.73 µm) and the highest flexibility ratio (77.74%). Moreover, except for the slenderness ratio, the result showed significant differences on the fiber morphology and their derived values. Results suggested that the four underutilized native wood species are good not only for pulp and paper production, but also potential for light construction wherein strength and durability are not critically important including, wooden toys and shoes, pencil slats, matchsticks, toothpicks, ice cream spoons, popsicle sticks, boxes, shelves, molding, veneer and plywood, buoys, and floats, etc.

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AUTHOR CONTRIBUTIONS

Conception and design of study; Jayric F. Villareal, Rafael U. Untong, Anisa U. Mispil, Cindy E. Poclis, Charry Mae S. Numeron, Oliver S. Marasigan. Acquisition of data; Jayric F. Villareal, Rafael U. Untong, Anisa U. Mispil, Cindy E. Poclis. Analysis and/or interpretation of data; Jayric F. Villareal, Rafael U. Untong, Anisa U. Mispil, Cindy E. Poclis, Oliver S. Marasigan. Drafting the manuscript; Jayric F. Villareal, Rafael U. Untong, Anisa U. Mispil, Cindy E. Poclis, Charry Mae S. Numeron, Oliver S. Marasigan. Revising the manuscript for significant intellectual content; Jayric F. Villareal, Cindy E. Poclis, Oliver S. Marasigan. Approval of the version of the manuscript to be published; Jayric F. Villareal, Cindy E. Poclis, Oliver S. Marasigan.

DECLARATION OF COMPETING INTERESTS

The authors declare no conflict of interest.

REFERENCES

Adimahavira A, Lukmandaru G, Pujiarti R, Prastiwi FW, Nugroho WD. The anatomical structure of the root, stem, and branch of *Gyrinops versteegii* trees from different growing sites. Biodiversitas 2023;24(8):4590-98.

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

Anupam K, Sharma AK, Lal PS, Bist V. Physicochemical, morphological, anatomical properties of plant fibers used for pulp and papermaking. In: Ramawat K, Ahuja M, editors. Fiber Plants. Cham: Springer; 2016. p. 235-48.

Bektas I, Tutus A, Eroglu H. A study of the suitability of Calabrian Pine (*Pinus brutia* Ten.) for pulp and paper manufacture. Turkish Journal of Agriculture and Forestry 1999;23(3):589-99.

De Jesus A. Why we need to plant native Philippine trees [Internet]. 2021 [cited 2024 Jul 26]. Available from: https://business.inquirer.net/319013/why-we-need-toplant-native-philippine-trees.

Díaz S, Settele J, Brondízio ES, Ngo HT, Agard J, Arneth A, et al. Pervasive human-driven decline of life on Earth points to the need for transformative change. Science 2019;366(6471):1-10.

Eloy E, Mangini TS, Nardini C, Caron BO, Trevisan R, Santos ADd. Correlation of anatomy with physical properties of wood species from an agroforestry system. Revista Árvore 2024;48(1):1-11.

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

Florentino CM, Supnet GAR. The antihelminthic activities of Dita (*Alstonia scholaris*) bark and tamarind (*Tamarindus indicus*) seeds: A comparative study. JPAIR Multidisciplinary Journal 2010;5(1):84-96.

Florido HB. Kalukoi *(Melia dubia* cav.) and Malambingan *(Broussonetia luzonica* (Blanco) for boat making. In: Amaro MC, Florido LV, Baltazar EM, Asis LE, Cambay MV, Rimando EF, et al. editors. Rise Information Series on Ecosystems. Laguna: Ecosystems Research and Development Bureau; 2010. p. 5-11.

Government of the Philippines. Executive order no. 23, s. 2011 [Internet]. 2011 [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 AH, Priadi T, Sutiawan J. 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 2022;1115:Article No. 012084.

International Union for Conservation of Nature (IUCN). The IUCN red list of threatened species - version 2024-2 [Internet]. 2024 [cited 2024 Aug 12]. Available from: https://www.iucnredlist.org/en.

International Union for Conservation of Nature (IUCN) Urban Alliance. Cities and biodiversity: the issues [Internet]. 2021 [cited 2024 Aug 12]. Available from: https://iucnurbanalliance.org/cities-and-biodiversity-the-issues/.

Jamovi Project. jamovi (version 2.3) [Internet]. 2022 [cited 2024 Aug 12]. Available from: https://www.jamovi.org.

Javargas O. Philippine plants 101: Ten different kinds of plants in the Philippines and their uses [Internet]. 2021 [cited 2024 Aug 12]. Available from: https://onetotree.org/author/optimind-javargas.

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

Lima RS, Coelho JCF, Silva JC, Araújo JA, Calderon CMA. Influence of wood anatomy on physical properties of the wood *Iryanthera grandis* Ducke. Enciclopédia Biosfera 2014; 10(19):1188-98.

Madsen B, Brondsted P, Andersen TL. Biobased Composites: Materials and Potential Applications as Wind Turbine Blade Materials. Elsevier; 2013. p. 363-86.

Malabrigo PL, Umali AGA. Alay: Philippine Native Trees at the Victor O. Ramos Arboretum. Quezon City, Philippine: Philippine Native Tree Enthusiasts (PNTE); 2022. p. 1-322.

Marbun SD, Wahyudi I, Suryana J, Nawawi DS. Anatomical structures and fiber quality of four lesser-used wood species grown in Indonesia. Journal of Korean Wood Science and Technology 2019;47(5):617-32.

Megra MB, Bachheti RK, Tadesse MG, Worku LA. Evaluation of pulp and papermaking properties of *Melia azedarach*. Forests 2022;13:Article No. 263.

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

NagarajaGanesh B, Rekha B, Mohanavel V, Ganeshan P. Exploring the possibilities of producing pulp and paper from discarded lignocellulosic fibers. Journal of Natural Fibers 2023;20(1):Article No. 2137618.

Numeron CMS, Bigcas EV, Bedoya NA. Reviving nature's guardians: Linking landscape restoration to climate change mitigation. BIODIVERS-BIOTROP Science Magazine 2023;2(2):Article No. 2093.

Ona T, Sonoda T, Ito K, Shibata M, Tamai Y, Kojima K, et al. Investigation of relationships between cell and pulp properties in *Eucalyptus* by examination of within-tree property variations. Wood Science and Technology 2001;35(3):229-43.

Osmeña L, Yao CE, Ybañez R. *Ficus callosa*: Unheralded species shows promise as livelihood source for coastal communities. The Online Magazine for Sustainable Seas 2000;3(3):AID 492-0444-C-00-6028-00.

Prabawa SB. The influence of stem position on physical properties and fiber dimension of Gmelina from thinning activity. Journal of Tropical Wood Science and Technology 2017;15(1):19-28.

Quintos JN, Acollador GM, Ubaldo EJJ, Aga QBC. Potential properties of Himbabao (*Broussonetia luzonica* B.) as anticancer, antifungal and antimicrobial. International Journal of Academic Multidisciplinary Research 2022;6(4):37-51.

Saiden A. BARMM plants 5k trees for environment month. Philippine New Agency [Internet]. 2020 [cited 2024 Aug 12]. Available from: https://www.pna.gov.ph/articles/1107035#:~:text=COTABATO%20CITY%20%E2%80%93%20Environment%20officials%20in%20the%20Bangsamoro,culmination%20activity%20for%20the%20Philippine%20Environment%20Month%20celebration.

Salehi K. Study and Determine the Properties of Chemi-mechanical Pulping High Yields from Bagasse. Wood and Paper Research No. 232. Iran: Research Institute of Forests and Rangelands; 2001.

Sette Júnior CR, De Oliveira IR, Tomazello-Filho M, Yamaji FM, Laclau JP. Effect of age and sampling position on density and anatomical characteristics of wood in eucalyptus trees. Journal of Brazilian Science 2012;36(6):1183-90.

Sharma AK, Dutt D, Upadhyaya JS, Roy TK. Anatomical, morphological, and chemical characterization of *Bambusa tulda*, *Dendrocalamus hamiltonii*, *Bambusa balcooa*, *Malocana baccifera*, *Bambusa arundinaceae*, and *Eucalyptus tereticornis*. Bioresources 2011;6(4):5062-73.

Stuart GU. Tangisang-bayauak [Internet]. 2016 [cited 2024 Jul 26]. Available from: https://www.stuartxchange.org/Tangisang-bayauak.

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

Sutcliffe LG, Malabrigo PL. A Guide to Westgrove's Native Trees. Silang, Philippines: Ayala Westgrove Heights Homeowners Association, Inc.; 2020. p. 11-2.

Takeuchi R, Wahyudi I, Aiso H, Ishiguri F, Istikowati WT, Ohkubo T, et al. Wood properties related to pulp and paper quality in two *Macaranga* species naturally regenerated in secondary forests, Central Kalimantan, Indonesia. Tropics 2016;25(3):107-15.

Tanabe J, Ishiguri F, Nakayama M, Ohshima J, Iizuka K, Yokota S. Properties of juvenile and mature wood and their effects on the bending properties of lumber in *Pinus taeda* growing in Tochigi. Forest Products Journal 2016;66(7):428-32.

Tanalgo KC, Manampan-Rubio M, Alvaro-Ele RJ, Hilario-Husain BA, Murray SA, Delos Reyes JL, et al. Ecological indicators of water quality and marshland impact area (MARia) index of Ligawasan Marsh: A critically important wetland in the Southern Mindanao, Philippines. Discover Environment 2024;2:Article No. 113.

U.S. Department of Agriculture Foreign Agricultural Service (USDA FAS). Philippines: Philippine wood products report [Internet]. 2021 [cited 2024 Aug 12]. Available from: https://fas.usda.gov/data/philippines-philippine-wood-products-report.

Villareal JF, Abasolo WP, Mendoza RC, Maldia LSJ. Fiber morphology and extractive content of *Aquilaria cumingiana* (Decne.) Ridl. wood from Davao Oriental, Philippines. Philippine Journal of Science 2022a;151(5):1623-31.

Villareal JF, De Guzman WB, Cortado JG, Poclis CE. Fiber Morphology of arangen (*Ganophyllum falcatum* Blume) stemwood and branchwood in San Gabriel, La Union, Philippines. Ecosystems and Development Journal 2022b; 12(2):97-102.

Wheeler EA, Baas P, Gasson PE. IAWA list of microscopic features for hardwood identification. IAWA Bulletin 1989; 10(3):219-332.

Yaman B. Anatomical differences between stem and branch wood of *Ficus carica* L. subsp. *carica*. Modern Phytomorphology 2014;6:79-83.

Zobel BJ, Van Buijtenen JP. Wood Variation: Its Causes and Control. Heidelberg, Germany: Springer; 1989.