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Original Article

Leaf and stem anatomy and wood fiber morphology of Seriales (*Flacourtia jangomas*) at different elevations in La Union, Philippines

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ABSTRACT

Seriales *(Flacourtia jangomas)* is an underutilized Philippine indigenous fruit tree with ecological and economic potential but limited anatomical evidence across elevation gradients. We quantified leaf and stem anatomy and wood fiber morphology across three low-elevation bands in La Union, Philippines (55–70masl, 71–85masl and 86–100masl). Mature leaves and young stems of *F. jangomas* were collected, stained, and observed for their leaf and stem anatomical measurements. Wood fibers were macerated and analyzed for fiber length, diameter, lumen diameter, and derived indices. Several leaf traits varied significantly with elevation: lamina and palisade mesophyll were greatest at the lowest site and declined upslope, whereas lower cuticle/epidermis, sclerenchyma, collenchyma, phloem, and collenchyma layers also differed among sites. In contrast, upper cuticle/epidermis, leaf xylem, and spongy mesophyll (~260–303μm) were not significantly different, suggesting conserved internal gas-exchange capacity. Stem anatomy showed decreasing cortex thickness and layer number with elevation, but increasing xylem thickness. Epidermal hairs were longer at the highest site. Wood fiber length shows values similar to tropical species, while mid-elevation trees had smaller fiber and lumen diameters, yielding higher density. High Runkel ratios (>1), low flexibility, and low slenderness indicate poor suitability for pulp and papermaking, but support use for durable woodcraft and small furniture. Overall, *F. jangomas* exhibits anatomical plasticity within a narrow lowland gradient, showing its resilience and value for lowland agroforestry. This study also highlights the need for conservation of this species and further studies that focus on the effect of climatic factors and stressors.

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INTRODUCTION

The Philippines is known as one of the world's megadiverse countries which harbors over 300 edible fruit-bearing species, about 30% of which are indigenous or endemic (Miranda et al., 2018). Indigenous fruit trees contribute food security, rural livelihoods, and ecological stability, due to their high adaptability to local climates, resistance to pests and diseases, and resilience to stresses such as drought and temperature variability. Despite these, many remain underutilized and poorly studied, making them vulnerable to neglect, genetic erosion, and deforestation (FAO, 2014; Khoury et al., 2022).

One such species is Seriales or Ceriales *(Flacourtia jangomas)* from the Salicaceae family (Cimafranca, 2018). This species generally grows in well-drained soils under full sunlight and is valued for both its ecological and economic properties (Sarker et al., 2011). Its fruits are rich in vitamin C, vitamin B3, phosphorus, magnesium, dietary fiber, and monounsaturated fatty acids (Sasi et al., 2018), while its hardwood is traditionally used for making kitchen utensils, small furniture, and household items. Likewise, *F. jangomas* have been found to possess bioactive compounds such as methyl caffeate and flacourtin (Chowdhury et al., 2024) and has antioxidant potential (Tamba et al., 2024).

However, research on this species remains limited, especially on its anatomical adaptations, which are vital for processes such as photosynthesis, transpiration, and structural support, as well as on its wood fiber characteristics that determine its proper utilization (Malesevic et al., 2023). Elevation gradients provide natural settings for studying plant adaptation where narrow changes may alter temperature, humidity, radiation, and soil conditions, which are factors influencing the morphology and anatomy of plants (Cai & Liu, 2013; Vitasse et al., 2013).

Studies have shown that plant structures are sensitive to climatic gradients. Documentation on *Roscoea* gingers in the Himalayas has shown a decrease in height and leaf area with an increase in stomatal density with increased elevation (Paudel et al., 2019). Meanwhile, Nielsen et al. (2017) have also reported that *Betula nana* exhibited significant variation in its xylem across only a 50m difference in elevational (Nielsen et al., 2017).

In fact, recent studies have documented consistent changes in the structure and function of plants across elevation gradients. Zhang et al. (2025) observed varying traits in leaf anatomical characteristics of *Quercus variabilis* planted at 800 and 1500m. Meanwhile, Wang et al. (2025) studied species in karst communities and found that multiple leaf functional traits like specific leaf area, leaf C:N ratio etc, shifted across altitudinal zones. Moreover, morphological variations in tree ferns across elevation gradients have also been observed by Merino et al. (2023). These studies are particularly relevant for predicting plant responses to variation in environmental conditions associated with climate change.

Understanding how *F. jangomas* adapts morphologically and anatomically to such environmental variations is critical for forestry, conservation, and industry. This study was conducted with the following objectives: (1) to characterize the leaf and stem anatomy of *F. jangomas* across three low-elevation ranges in La Union, Philippines (55–100masl) and (2) to evaluate its wood fiber morphology and derived properties for its proper utilization.

MATERIALS AND METHODS

Study Site

The study was conducted in three municipalities of La Union, Philippines, representing distinct lowland elevations: A_1 – Bauang (55–70masl), A_2 – Naguilian (71–85masl), and A_3 – Bacnotan (86–100masl) (Figure 4). These sites are located 15–30km apart, which represents subtle but ecologically meaningful differences across a low-elevation gradient. Bauang features a semi-urban agricultural area with a moderate canopy cover; Naguilian is a transition zone with denser vegetation; and Bacnotan has a higher canopy and is situated in a closed forest. These sites share uniform geological origins characterized by alluvial and sedimentary formations typical of the Ilocos coastal plain (BSWM, 2016).

Although specific environmental parameters (e.g., soil properties, temperature, humidity, and light intensity) were not measured, the sites share comparable topography, vegetation, and substrate characteristics. During the conduct of field observations, the soil texture and moisture conditions were similar across all sites. Hence, the variations in the anatomical characteristics were interpreted primarily as responses to microclimatic gradients related to elevation.

Collection of Samples

Within each site, mature and healthy Seriales trees with a diameter at breast height (DBH) of 20–35cm were selected as sources of samples. Trees were carefully selected to be free from visible disease, pest damage, or mechanical injury, thereby avoiding confounding factors in anatomical measurements. In total, leaves and stems were sampled from 15 trees.

Five most recently matured sun leaves were collected from three individual trees, per elevation, using sterilized scissors to minimize tissue damage. Samples were immediately sealed in clean, labeled ziplock bags to prevent desiccation and contamination. Young stems were also collected from actively growing branches of the same trees. Segments with a diameter of approximately 1–2cm were cut into 10–15cm pieces. For the analysis of wood fibers, three cores were extracted from each tree at breast height (1.3m above ground) using a sterilized increment borer. Cores were obtained from different orientations of the trunk to minimize bias and were carefully placed in plastic containers labeled according to site and tree number.

The identity of the collected specimen was confirmed by a licensed forester and subsequently verified by a biologist with expertise in tree species identification. All plant materials were transported to the laboratory on the same day to minimize deterioration and contamination.

Preparation of Leaf and Stem Samples

For the anatomical study of leaves and stems, the freehand sectioning technique was employed. Leaf samples were cut into pieces approximately 1–2cm long, which includes the midrib, while young stems were transversely sectioned into thin slices about 1–2mm thick using a sharp razor blade. To prevent tissue shrinkage or collapse, the sections were immediately placed in petri dishes containing distilled water. They were subsequently stained with safranin for 10–15 seconds to improve tissue contrast, then mounted on glass slides in glycerin solution. Cover slips were placed carefully to avoid air bubbles. Slides were examined under a compound light microscope at magnifications of 40× and 100×. Photomicrographs were taken using a digital camera attached to the microscope, and anatomical structures were measured via ImageJ software (ImageJ 1.45) .

Preparation of Wood Samples

The analysis of wood fibers was based on Espiloy et al. (1999). The wood cores were cut into chips approximately 1–2cm in length and immersed in a 1:1 solution of 50% acetic acid and 50% hydrogen peroxide. The samples were then heated in a water bath at 60-70°C for six hours until the wood softened and had turned whitish in color, which makes it easier for the fibers to be separated. The macerated samples were repeatedly washed with distilled water until the acids were removed. Afterwards, fibers were carefully teased apart using fine needles and were suspended in distilled water to avoid clumping. Fiber measurements were carried out under a compound light microscope, using ImageJ software (ImageJ 1.45). Thirty undamaged fibers per sample were measured.

Data Gathered

The leaf anatomical features included lamina thickness, cuticle thickness (upper and lower), epidermis thickness (upper and lower), sclerenchyma thickness, collenchyma thickness, number of collenchyma layers, phloem and xylem thickness, palisade and spongy mesophyll thickness, and the presence or absence of hair cover (Figure 1). For the stems, measured features included epidermis length, width, and layer number, epidermal hair presence, cortex thickness and number of cortex layers, corner collenchyma thickness, phloem and xylem thickness, pith cell thickness, and the presence or absence of a cuticle (Figure 2).

For the wood fiber morphology (Figure 3), the fiber length, fiber diameter, lumen diameter, and cell wall thickness were measured according to the International Association of Wood Anatomists (IAWA) standard (Wheeler et al., 1989). Based on the fiber morphology data, the derived values such as Runkle ratio (1), slenderness ratio (2), and flexibility ratio (3) were computed following the equation used by Hartono et al. (2022).

$$\text{Runkel Ratio (RR)} = (2 \times \text{Cell Wall Thickness}) / \text{Lumen Diameter} \qquad (1)$$

$$\text{Slenderness Ratio (SR)} = \text{Fiber Length} / \text{Fiber Diameter} \qquad (2)$$

$$\text{Flexibility Ratio (FR)} = (\text{Lumen Diameter} / \text{Fiber Diameter}) \times 100 \qquad (3)$$

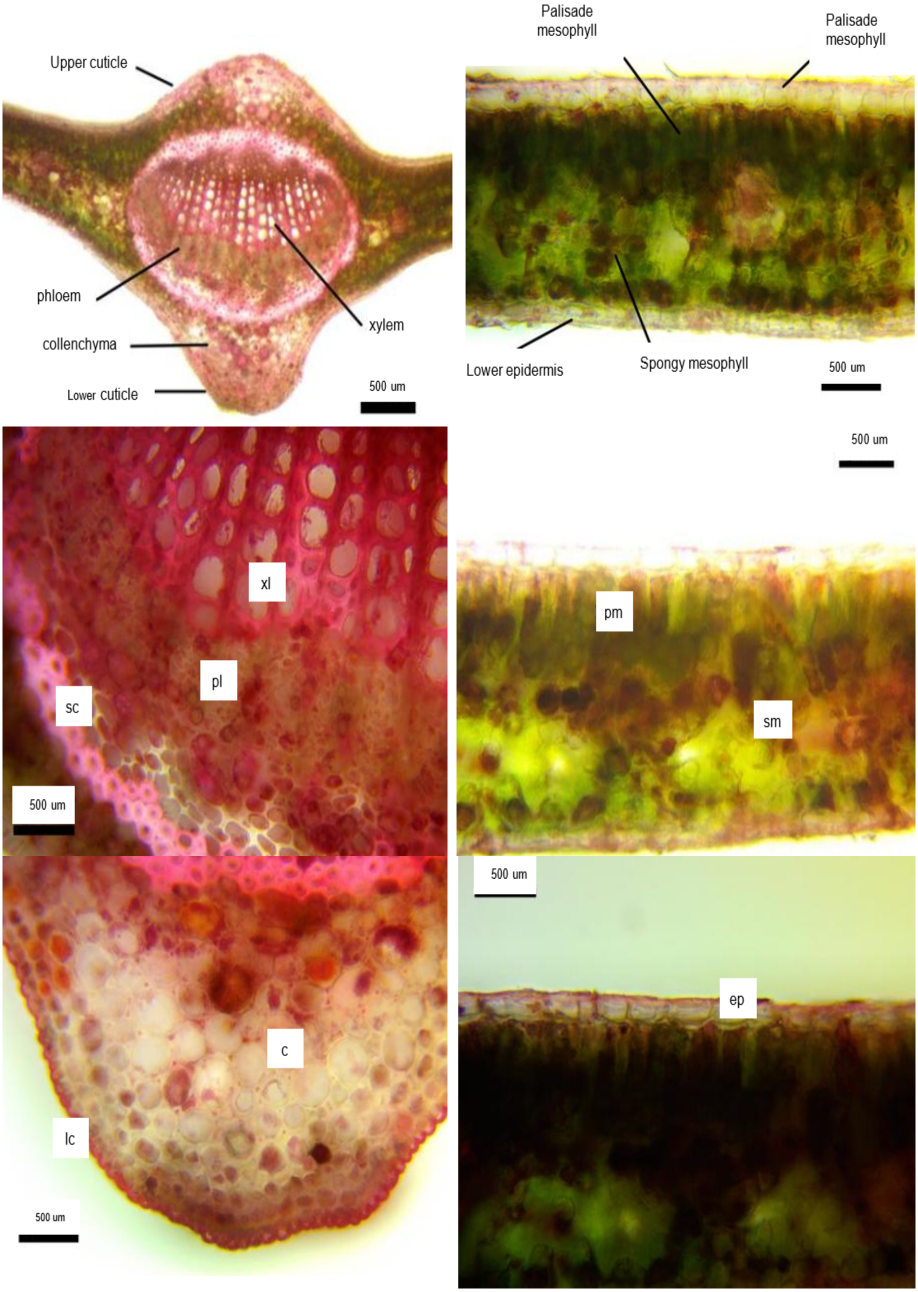


Figure 1. The Leaf Anatomical Structure of *F. jangomas* at Different Elevation Ranges: (A) Midrib (B) Leaf Blade (C) xl-Xylem And pl- Phloem (D) pm-Palisade Mesophyll and sm-Spongy Mesophyll (E) c-Collenchyma and lc-Lower Cuticle (F) ep-Epidermis

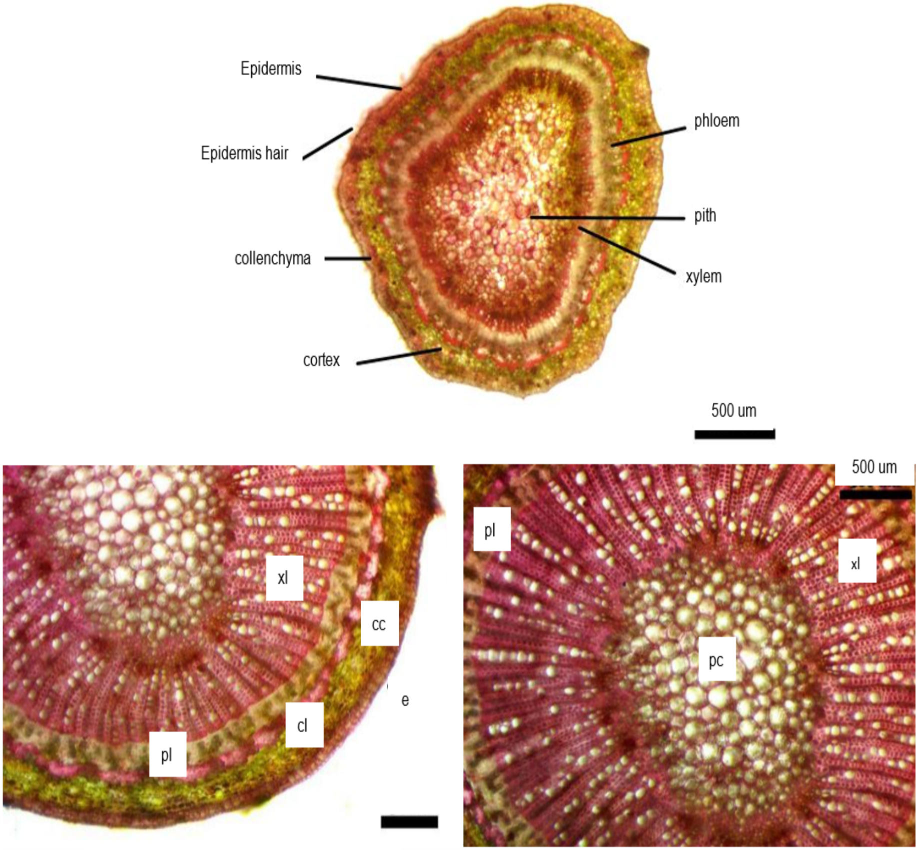


Figure 2. The stem anatomical structure of *F. jangomas* at Different Elevation Range (A) parts of the stem (B) E-epidermis, CC-collenchyma, CL-cortex layer, PL-phloem, XL-xylem (C) pith cell

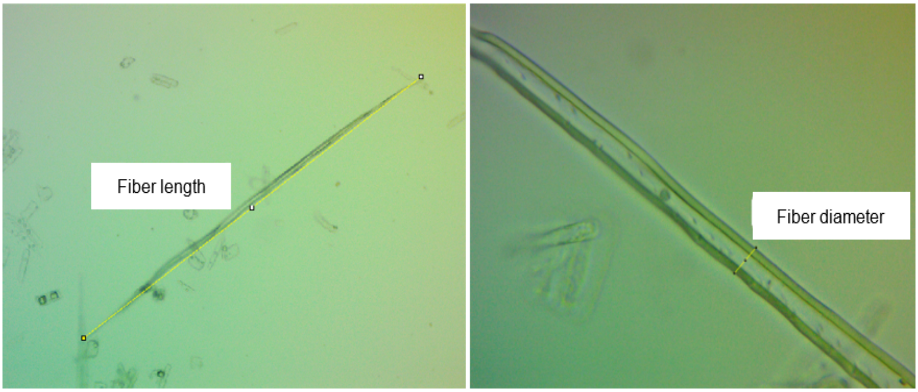


Figure 3. Fiber Diameter, Fiber length and Lumen Diameter measured through ImageJ

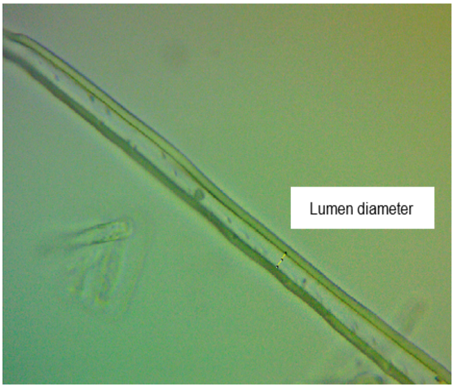


Figure 3. continued

Data Analysis

The data gathered were tested for normality using the Shapiro-Wilk test, and since the assumptions of ANOVA were met, a One-way Analysis of Variance (ANOVA) was performed to determine significant differences in the anatomical and morphological characteristics across the three elevation ranges. Means with significant differences were compared using Tukey's Honest Significant Difference (HSD) test to determine differences among the treatments at $p < .05$ and $p < .01$. Statistical analyses were performed using RStudio (R Core Team, 2023).

RESULTS

Leaf Anatomical Features

Table 1 presents the variations in leaf anatomical features of Seriales at different elevation ranges in La Union. The mean thickness of the upper cuticle, upper epidermis, xylem, and spongy mesophyll showed no significant differences among elevations. On the other hand, significant differences ($p < .05$ - .01) were observed in the lower cuticle, lower epidermis, sclerenchyma, phloem, collenchyma, collenchyma layer, lamina, and palisade mesophyll thickness. Leaf hair cover was present across all sites.

The findings showed that the lower cuticle and epidermis thicknesses are highest at A_1-Bauang (55-70masl), with mean values of 3.97μm and 15.24μm, respectively, indicating a stronger protective barrier at the lower elevation. Hence, trees at the lower sites may invest more in their protective features to cope with environmental stress.

Likewise, the thickness of the collenchyma (31.73-43.00μm) and sclerenchyma (11.88-15.89μm) produced significant differences, though without a consistent trend, which reflects their sensitivity to microclimatic conditions such as wind and moisture. Meanwhile, phloem thickness was highest at the lowest elevation (12.25μm), implying greater carbohydrate transport capacity in lowland areas.

In addition, the mean lamina thickness was highest at A_1, with a value of 548.76μm, which declined significantly at A_2-Naguilian (71-85masl), and partially increased at A_3-Bacnotan (86-100masl) ($p < 0.01$). This indicates a thicker leaf

Table 1. The Leaf Anatomical Features of *F. jangomas* as Affected by Different Elevation Ranges

Anatomical Features	A_1	A_2	A_3
Upper Cuticle Thickness ^{ns} (µm)	3.65^a	2.96^a	3.10^a
Lower Cuticle Thickness ** (µm)	3.97^a	2.76^b	2.54^b
Upper Epidermis Thickness ^{ns} (µm)	15.66^a	14.44^a	16.27^a
Lower Epidermis Thickness * (µm)	15.24^a	14.07^{ab}	12.99^b
Sclerenchyma Thickness ** (µm)	15.89^a	11.88^b	12.13^b
Collenchyma Thickness**(µm)	41.96^a	31.73^b	43.00^a
Collenchyma Layer**	7.41^a	6.59^b	6.37^b
Xylem Thickness ^{ns} (µm)	26.40^a	22.93^a	22.83^a
Phloem Thickness * (µm)	12.25^a	10.66^b	10.73^b
Leaf Lamina Thickness** (µm)	548.76^a	445.34^b	474.78^b
Spongy Mesophyll Thickness^{ns} (µm)	302.84^a	262.19^a	260.26^a
Palisade Mesophyll Thickness** (µm)	183.90^a	155.41^{ab}	124.72^b
Hair Cover	+	+	+

Legend: $p < 0.05$ = significant; $p < 0.01$ = highly significant; ns = not significant ($p \geq 0.05$); "+" = present. Treatment means in each row followed by the same letter are not significantly different according to Tukey's HSD test ($p < 0.05$). A = Bauang (55–70masl); A = Naguilian (71–85masl); A = Bacnotan (86–100masl).

Spongy mesophyll thickness showed no significant differences, implying stable gas-exchange capacity across sites. In contrast, palisade mesophyll thickness decreased with increasing elevation ($A_1 > A_2 > A_3$; $p < 0.01$). This suggests a higher investment in photosynthetic tissues at lower elevations.

Stem Anatomical Features

It is shown in Table 2 that the cortex, epidermal hairs, cortex layers, phloem, and xylem thickness differed significantly ($p < .05 - .01$), whereas corner collenchyma, epidermis length and width, and pith cell thickening had no significant differences. A stem cuticle was also observed in all sites studied.

Table 2. The Stem Anatomical Features of *F. jangomas* as Affected by Different Elevation Ranges

Anatomical Features	A_1	A_2	A_3
Corner Collenchyma Thickness^{ns}(µm)	13.77^a	13.82^a	14.39^a
Cortex Thickness**(µm)	29.80^a	24.32^b	23.78^b
Epidermis Hair**(µm)	0.56^b	0.00^c	1.00^a
Epidermis Length^{ns} (µm)	4.88^a	5.13^a	5.72^a
Epidermis Width^{ns} (µm)	3.30^a	3.54^a	3.63^a
Epidermis Layer	1	1	1
Number of Cortex Layer**	6.00^a	5.11^b	5.03^b
Phloem Thickness* (µm)	7.27^a	6.09^b	6.34^{ab}
Xylem Thickness**(µm)	9.22^c	11.11^b	12.74^a
Pith Cell Thickness^{ns} (µm)	20.21^a	19.76^a	22.06^a
Cuticle	+	+	+

Legend: $p < 0.05$ = significant; $p < 0.01$ = highly significant; ns = not significant ($p \geq 0.05$); "+" = present. Treatment means in each row followed by the same letter are not significantly different according to Tukey's HSD test ($p < 0.05$). A = Bauang (55–70masl); A = Naguilian (71–85masl); A = Bacnotan (86–100masl)

The findings revealed that the cortex thickness declined with elevation ($p < .01$), being thickest at A_1 (29.80μm), which suggests finer adjustments to cooler and moister conditions at the higher elevations.

Meanwhile, the stem epidermal hairs varied significantly across sites, being longest at the highest elevation (1.00μm), present at the lowest elevation (0.56μm), and entirely absent at the mid-elevation (0.00μm). This implies that hair development is a plastic trait responding to site-specific conditions, which protects plants at higher elevations.

The number of cortex layers followed the same trend ($A_1 > A_2, A_3$; $p < .01$), indicating greater cortical support at lower elevations. Phloem thickness was highest at A_1 and at higher elevations ($A_1 > A_3 > A_2$), while xylem thickness increased with elevation ($p < .01$), emphasizing enhanced water conduction under cooler air.

Epidermis dimensions and pith cell thickening were relatively stable, confirming structural consistency across the gradient. The presence of a stem cuticle was noted consistently across all sites, confirming its role as a universal protective layer.

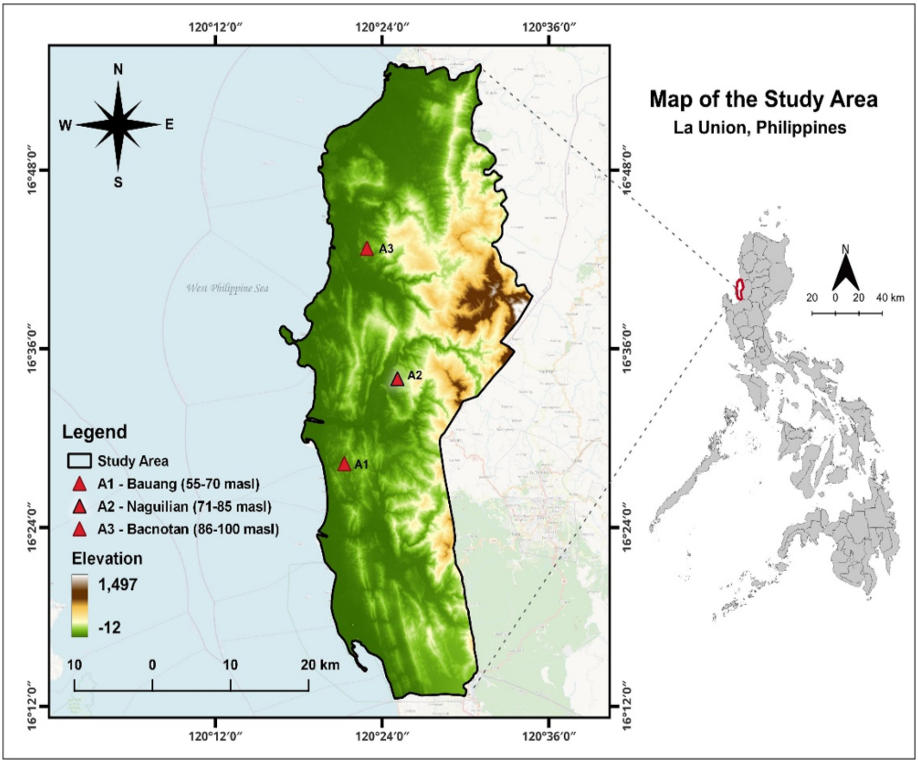


Figure 4. Location Map generated via QGIS 3.28

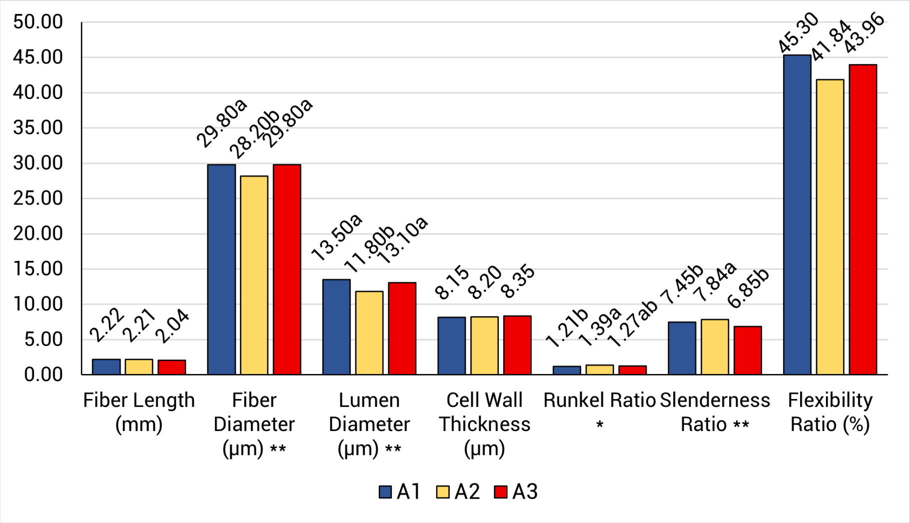
Wood Fiber Morphology

Figure 5 illustrates the variations in wood morphology and derived values of *F. jangomas* across different elevation ranges in La Union, which shows that fiber length (2.04-2.22mm) remained statistically consistent across the three elevations. This suggests that elongation processes in fiber development are unaffected by the small changes in lowland elevation studied.

Meanwhile, *F. jangomas* trees at A_2 (mid-elevation, 71–85masl) produced thinner fiber diameter (28.20µm) and lumen diameter (11.80µm) than the fiber and lumen diameters of A_1 and A_3

Moreover, values observed in the thickness of the cell wall are statistically similar, indicating that fiber stiffness remains generally consistent from the lowest up to the highest elevation.

In terms of the derived values, the Runkel (1.39) and slenderness ratios (7.84) at A_2 (mid-elevation) exhibited the highest values and also differed significantly to other elevations. This means that fibers at this elevation are stiffer and less flexible, taller and narrower fibers, making this species not suitable for pulp production. On the other hand, the flexibility ratio (41.84%–45.30%) did not vary significantly among elevations.



Legend: *-significant at p<0.05; **-highly significant at p<0.01; A1 (Bauang, 55-70masl); A2 (Naguilian, 71-85masl); A3 (Bacnotan, 86-100masl)

Figure 5. The Wood Fiber Morphology Structures of *F. jangomas* as Affected by Different Elevation Range

DISCUSSION

Leaf Anatomical Characteristics

These changes show that elevation gradients drive adaptive responses in the leaf anatomy of *F. jangomas*. With the increase in elevation from Bauang (55–70masl) to Bacnotan (86–100masl), the lower cuticle and epidermis thickness decreased, reflecting a reduction in investment in epidermal protection during cooler and more humid conditions. Given the similar soil texture and moisture conditions observed across the three study areas, differences in anatomical traits are best attributed to microclimatic variation along the elevational gradient, particularly in respect to temperature, humidity, and irradiance.

These results agree with global studies on the role of altitude in determining leaf structural change. DeLucia and Berlyn (1984) found that cuticle thickness in *Abies balsamea* decreased with increasing elevation in concert with reduced transpirational stress. More recently, Yang et al. (2022) and Zhang et al. (2025) demonstrated decreases in the thickness of epidermal and mesophyll tissues in *Betula albosinensis* and *Quercus variabilis*, respectively, with increasing elevation. Guo et al. (2018) documented decreases in lamina and tissue thickness in *Pleioblastus amarus* from 200–800m altitudinal range, attributing these changes to reduced irradiance and temperature. For the Mediterranean region, *Quercus ile*x has been found to have thicker cuticles and mesophyll layers in sun-exposed versus shaded sites and in semi-arid as compared to semi-humid sites. This emphasizes that leaf anatomy adjusts plastically to gradients of aridity and light intensity. Taken together, these studies confirm that as elevation rises and the air becomes cooler and moister, evaporative demand declines, leading to thinner epidermal and cuticular layers and a reduced structural investment in protective tissues.

However, elevation trends are not consistent across all taxa. Indeed, Feng et al. (2022) and Zhao et al. (2022) reported thicker cuticles and lower stomatal density at higher altitudes, suggesting that for some species, reinforcing their cuticles may counteract the increased UV radiation or wind stress. These contrasting trends emphasize that the responses related to elevation are species- and habitat-specific, depending on whether temperature, radiation, or water limitation is the dominant stress factor (Fortunel et al., 2012). Considering that *F. jangomas* is a tropical lowland species, the robust epidermal and cuticular tissues at the lower sites can help in countering heat and irradiance stresses, while thinner tissues at higher elevations reflect reduced environmental pressure.

This interpretation is further supported by the decline in both palisade mesophyll and the overall thickness of the lamina at higher elevations. Reduced leaf thickness is a consistent response to decreased temperature and light intensity with altitude (Tian et al., 2016; Hernandez & Park, 2022). Similar reductions have been observed in *Pterocarpus indicus* (Flores et al., 2021) and *Parashorea malaanonan* (Ebale et al., 2024), both of which developed thinner laminae and mesophyll tissues when grown at higher elevations. Thinner leaves at higher altitudes optimize resource-use efficiency and reduce construction costs, reinforcing that elevation drives structural optimization for maintaining photosynthetic efficiency under cooler, low-light conditions.

Fine-scale elevation effects were also reflected in structural tissues in *F. jangomas*. Sclerenchyma thickness showed non-linear variation, decreasing in the mid-elevation before increasing again at higher altitudes. This is most probably because of local differences in wind exposure and canopy density. Such flexibility in structural investment has been reported for montane broadleaf trees where microclimates vary (Thadani et al., 2009). Collenchyma thickness, on the other hand, showed a significant decline in Naguilian (A_2). This indeed supports that light intensity influences mechanical tissue development, similar to what has been observed in seedlings of *Swietenia macrophylla* exposed to full sun (Agoto Jr. et al., 2024).

In addition, phloem thickness was reduced at mid and high elevations, reflecting the lower assimilate transport capacity under cooler and unfavorable conditions. Similar trends were observed in Philippine hardwoods (Escobin et al., 2015). This could relate to the decrease in metabolic activities with the rise in altitude. Spongy mesophyll thickness did not change, indicating the internal CO_2 diffusion capacity was preserved independent of external climatic variations (Taiz & Zeiger, 2010).

Leaf trichomes were uniformly present in all sites, showing the hair cover is a constitutive adaptation rather than a localized response. Previous studies related leaf hairs to thermoregulatory activity and reduced water loss (Wuenscher, 1970; Hernandez & Park, 2022), probably being one more reason for the resilience of *F. jangomas* along this gradient.

Leaf anatomical responses to elevation also reflect broader ecological and evolutionary patterns. Studies conducted at the Qinghai-Tibet and Mongolian Plateaus showed that leaf anatomical traits, under stressful environments, are highly conservative, maintaining stable relationships despite variations in temperature, aridity, and radiation (Liu et al., 2024). Such findings suggest that even under environmental stress, key anatomical traits remain evolutionarily constrained while enabling subtle adaptive plasticity. This therefore mirrors the pattern in *F. jangomas*, where the anatomical structures remain functionally consistent but their fine adjustment along the elevational gradient reflects an adaptive modification within a conservative structural framework.

Stem Anatomical Characteristics

The reduction in cortex thickness and number of layers at higher sites indicates a shift in resource allocation driven primarily by elevation-related factors. In our case, the study sites are situated within a small geographic range sharing similar soil type, moisture conditions, and vegetation cover; the differences observed can be attributed mainly to the gradual changes in temperature and humidity associated with elevation. In the Philippines, Escobin et al. (2015) showed comparable variation in cortex and phloem tissues among Philippine trees with different ecological groupings. Likewise, reduced inner-bark (cortex/phloem) investment and concurrent shifts toward greater xylem development at harsher sites, consistent with resource reallocation to structural tissues under less favorable conditions, were also reported by Tripathi et al. (2023). The present results show how stem anatomical adjustments help maintain structural and functional balance even under small elevational differences.

The thickness of the xylem increased linearly, reflecting an adaptive enhancement of water-transport capacity to cope with the cooler air conditions at higher sites. Similarly, *Abies fargesii* var. *faxoniana* seedlings tend to allocate more xylem at higher altitudes to maintain efficient hydraulic transport under increased tension and lower temperatures (Zhang et al., 2021). Apart from this, elevation-driven modifications in xylem anatomy have also been reported in temperate and tropical trees, where vessel diameter and wall thickness adjust predictably with altitude as plants balance transport efficiency and hydraulic safety (Garcia-Cervigon et al., 2018). In this study, the increase in xylem thickness in *F. jangomas* at the highest elevation reflects a comparable strategy to safeguard hydraulic function under cooler, high-altitude conditions.

Longer stem epidermal hairs were noted at the highest elevation. Epidermal hairs reduce ultraviolet radiation damage, water loss, and excessive transpiration (Holmes & Keiller, 2002; Manetas, 2003). In the Philippines, Hernandez et al. (2016) documented diverse trichome types in *Tectona philippinensis*, highlighting their xeromorphic function. It appears that the absence of hair in one site reflects local microclimatic variation, such as reduced wind exposure.

Phloem thickness declined at mid and higher elevations. This supports the idea that there is a lowered carbohydrate transport capacity under conditions of lowered photosynthetic activity at higher elevations. Similar vascular reorganization under environmental stress has also been documented by Hernandez et al. (2019), who reported the development of a sclerenchymatic phloem cap and other phloem adjustments of *Wrightia candollei*. A key observation from other studies shows that drought and elevational stress reduce phloem growth and alter phloem anatomy (Salmon et al., 2019; Qaderi et al., 2019; Nie et al., 2023). These findings support the interpretation that *F. jangomas* likely represents a trade-off favoring hydraulic support tissues over transport tissues, a common adaptation under less favorable, elevation-linked conditions.

Notably, pith cell thickness did not vary significantly across elevations. Carlquist (2012) emphasized that pith parenchyma is generally conservative, with limited anatomical plasticity under environmental stress. This is probably the reason why the structural investment of *F. jangomas* was concentrated in vascular tissues rather than in pith, consistent with the plant's need to maintain mechanical and hydraulic integrity under varying microclimates.

The cuticle was present in stems across all sites, a trait consistent with general observations in woody dicotyledons (Fahn, 1990; Evert, 2006). In the Philippines, Espiloy et al., (1999) reported that stem cuticle is a universal feature of native trees, providing essential protection against desiccation, pests, and pathogens. It seems plausible that the presence of the cuticle across elevations primarily influenced internal anatomical adjustments rather than external protective traits.

Wood Fiber Morphology

The length of the fibers remained consistent across elevations, which is slightly longer than many tropical hardwoods reported by Sharma et al. (2011) on *Eucalyptus tereticornis* (0.72mm) and *E. grandis* (0.92mm), Alipon et al. (2021) on 3-, 5-, and 7-year-old *F. moluccana* (1.16, 1.14, and 1.17mm, respectively), Villareal et al. (2022) on *Ganophyllum falcatum* (1.20mm), Villareal et al. (2025) on *Alstonia scholaris* (1.79mm), *Broussonetia luzonica* (1.44mm), and *Ficus callosa* (1.82 mm). While relatively shorter than the softwood fibers (3.50mm) reported by Sharma et al. (2011) and *Ficus variegata* (2.73mm) (Villareal et al., 2025) . Zobel (2012) emphasized that longer fibers enhance mechanical strength, making the wood highly desirable for construction and wood-based products. Comparatively, Espiloy et al. (1999) reported only values ranging from 1.0-2.5mm for *Pterocarpus indicus* and *Swietenia macrophylla*, which are valued for furniture and construction, further indicating that *F. jangomas* fibers might less suitable for pulp and paper, while can be utilized for composite material, furniture, and building material. Regardless of elevation, *F. jangomas* fibers might exhibited favorable strength properties like bursting, tensile, tearing and folding endurance.

Fiber and lumen diameters produced significant results, with the smallest values in the mid-elevation. According to Plomion et al. (2001), narrower fibers are typically linked to denser and stronger wood. This was also reported by Mayr et al. (2003) in Himalayan conifers, where smaller tracheids enhance mechanical strength at higher elevations. Similarly, tropical hardwoods show reduced lumen size which increases density and durability under stressful conditions (Zanne et al., 2010). In this study, narrower fibers at the mid-elevations may imply mechanical resilience, while broader fibers at lower and higher sites support greater elasticity. The present results on fiber and lumen diameters were relatively thinner than the previous findings on 3-, 5-, and 7-year-old *F. moluccana* (Alipon et al., 2021) and Ficus species (Villareal et al., 2025); however, larger than E. tereticornis and *E. grandis* (Sharma et al., 2011), and *G. falcatum* (Villareal et al., 2022).

Cell wall thickness showed no significant differences between sites, though slightly higher values were observed at the highest elevation. Thicker walls enhance the wood's stiffness and durability, which are valued for construction. Similar patterns have been noted in *Carpinus betulus* at higher altitudes (Kiaei et al., 2019) and in *Shorea contorta* (Espiloy et al., 1999). This likely reflects comparable adaptation to localized stress. Normally, thicker walls enhance stiffness and durability, which are valued for construction. Compared to cell wall thickness of *E. tereticornis* and *E. grandis* (Sharma et al., 2011), 3-, 5-, and 7-year-old *F. moluccana* (Alipon et al., 2021) and Ficus species, except for *F. variegata* (Villareal et al., 2025), the cell wall of *F. jangomas* fiber was thicker.

The derived indices provide insight into the industrial potential of *F. jangomas*. In this study, the Runkel ratio exceeded 1.0 in all the sites, which are greater than the recommended threshold of <1.0 for papermaking (Sharma et al., 2011; Kiaei et al., 2014). This means that the *F. jangomas* fibers are stiff and poorly flexible, not likely good for pulp and paper making, but may perform well in constructions, furnitures and other applications (Ververis et al., 2004). Dutt and Tyagi (2011) demonstrated that fibers with high Runkel ratios are unsuitable for fine pulp production. The present Runkel ratio result was higher than 3-, 5-, and 7-year-old *F. moluccana*, reported by Alipon et al. (2021), and Ficus species (Villareal et al., 2025), but relatively lower to *G. falcatum* (Villareal et al. 2022).

Moreover, the slenderness ratio was highest at the mid-elevation, while lower than the permissible range value of 33 or above (Kiaei et al., 2014). This further confirms the unsuitability of *F. jangomas* fibers for pulp and papermaking, along with a higher Runkel ratio result. The present slenderness ratio result of *F. jangomas* fibers was lower than the previous studies conducted by Kiaei et al. (2014), Alipon et al. (2021), Villareal et al. (2022) and Villareal et al. (2025). Espiloy et al. (1999) similarly noted that there are only a few hardwoods that can be used for papermaking.

Flexibility ratio values for *F. jangomas* (41.84 % - 45.30 %) were consistently low across sites, which affirms its limited suitability for pulp and papermaking (Espiloy et al., 1999). According to the flexibility ratio groups devised by Bektas et al. (1999) the flexibility ratio of *F. jangomas* fiber was classified as rigid fibers ranges from 30 % – 50 %, signifying no efficient elasticity and are not suitable for paper production. Compared to other findings, the present result was relatively lower to 3-, 5-, and 7-year-old *F. moluccana* (Alipon et al., 2021), and Ficus species (Villareal et al., 2025), but relatively comparable to *G. falcatum* (Villareal et al., 2022).

CONCLUSIONS

This study demonstrated that *F. jangomas* exhibits plasticity across a narrow lowland elevational gradient in La Union, Philippines. Leaf anatomical traits such as lamina thickness, palisade mesophyll, and epidermal layers were greater at lower elevations, indicating enhanced investment in photosynthetic and protective tissues under warmer and more irradiated conditions, while the stability of spongy mesophyll suggests a conserved capacity for gas exchange. Stem anatomy also reflected adaptive reallocations, showing thicker cortex at lower elevation and increased xylem thickness and epidermal hair density at higher elevation, enhancing hydraulic efficiency and protection against microclimatic stress.

Wood fiber characteristics of *F. jangomas* were comparable to tropical hardwoods. The high Runkel ratio and low flexibility ratio indicate less suitability of this species for pulp and paper production. These findings show the ecological resilience and economic potential of this underutilized native fruit-bearing species.

The plasticity of *F. jangomas* allows it to maintain its functional stability across varying microclimates. Consequently, it may be suitable for reforestation and agroforestry systems in lowland areas. This promotes its cultivation for landscape diversification, ecological balance, and improved rural livelihoods.

This study recommends measuring temperature, humidity, and soil composition to further confirm the drivers of anatomical variation, in addition to elevation. Future studies may also consider wider elevational gradients, with consideration of stress conditions.

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Author Contributions

CFC and RMS created and designed the paper, conducted data gathering, and performed measurements. JFV and RGOQ edited the manuscript. JGC analyzed the data.

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Availability of Data and Materials

All data and materials generated or analyzed during this study are included in this article. Its supplementary files are available from the corresponding author upon request.

Ethical Considerations

This study did not involve human participants or animals. The research focused solely on plant samples (leaf and stem anatomical characteristics and fiber wood morphology) collected in backyards with limited sampling; therefore, ethics approval was not required.

Competing Interest

The authors declare no competing interests.

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