# Structure of Secondary Xylem in Meliaceae Species and its Potential for Residue Utilization

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**Research Article**

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# STRUCTURE OF SECONDARY XYLEM IN MELIACEAE SPECIES AND ITS POTENTIAL FOR RESIDUE UTILIZATION

**Abstract**

The Meliaceae family is widely used in furniture manufacturing and construction due to the high quality of its wood, resulting in the generation of large volumes of residues in sawmills and carpentry workshops. In addition, similarities in anatomical characteristics among species make identification difficult, combined with a lack of studies on their technological potential for pulp and paper production. This study aimed to anatomically characterize the secondary xylem and compare the fiber characteristics of four forest species of the Meliaceae family (*Cedrela* sp., *Swietenia macrophylla* King, *Khaya* sp., and *Carapa guianensis* Aubl.), in order to evaluate the potential of their wood residues for pulp and paper production. Samples were collected from carpentry workshops in Brasil Novo, Pará, Brazil, and analyzed according to IBAMA, IAWA recommendations and Franklin maceration method. Fiber length, width, lumen diameter, and wall thickness were measured, and technological indices were calculated. Data were subjected to analysis of variance and Tukey's test. The results revealed anatomical differences among species, with *Cedrela* sp. and *Swietenia macrophylla* presenting the most suitable fiber characteristics for pulp and paper production. Findings indicate promising fiber characteristics for pulp production, highlighting the potential of these residues as alternative lignocellulosic resources in sustainable forest-based systems.

**Keywords:** fiber morphology, Meliaceae, pulp and paper, tropical timber, wood anatomy

## INTRODUCTION

The commercialization of Amazonian timber, despite a reduction in production, still persists due to its high mechanical resistance, making wood an irreplaceable material for several applications (Silva et al. 2012). Brazil is one of the world's largest producers of tropical sawnwood, with a production of approximately 32.2 million $m^3$ in 2016 (Aquino 2016). In the municipality of Brasil Novo, Pará State, the trade of tropical timber remains active in carpentry workshops and sawmills, with a log production of 7,958 $m^3$, corresponding to approximately 0.15% of the state production (IBGE 2023). Among the most commercially important groups is the Meliaceae family, recognized for the high quality of its wood and the presence of natural oils extracted from certain species, as well as its adaptability for cultivation (Pennington 1975).

Species of the Meliaceae family are widely used in furniture manufacturing and civil construction due to their superior wood quality (Silva et al. 2022). However, the processing of these timbers generates large amounts of residues, which often lack appropriate disposal and contribute to environmental impacts. The utilization of such residues represents a sustainable alternative, adding value to materials that would otherwise be discarded and reducing pressure on forest resources (Donato & Takenaka 2016).

The family consists predominantly of trees and small trees, rarely shrubs, native but not endemic to Brazil, occurring throughout the national territory. Morphological characteristics include pinnate compound leaves, occasionally bipinnate or digitately compound, generally entire or serrated leaflets, and monoecious or dioecious flowers. Fruits may be capsules, drupes, or berries, and seeds are dry and may be winged or non-winged. In Brazil, the family comprises 12 accepted genera and 102 species, of which 25 are endemic (Flores 2020). Among the most well-known genera are *Cedrela*, *Carapa*, and *Swietenia*.

The family Meliaceae holds major importance in the international timber trade due to the high commercial value and superior wood quality of several species, many of which are classified as premium tropical timbers widely used in furniture making, construction and high-grade carpentry (Pennington & Styles 1975). Despite this relevance, there is a lack of studies evaluating the potential of Meliaceae wood for pulp and paper production, limiting the efficient use of these species. The Brazilian pulp and paper sector is highly competitive in cellulose production but has a limited share in paper manufacturing (Hora et al. 2018). Considering the need for alternative fiber sources, the use of timber residues represents a promising approach.

Wood fiber characteristics such as length, wall thickness, lumen diameter, and width directly influence fiber flexibility, strength, and behavior during paper manufacturing. These properties are commonly evaluated using technological indices, including the Runkel index, flexibility coefficient, wall fraction, and felting index, which allow assessment of fiber quality and pulp suitability (Foelkel & Barrichelo 1975). Recent studies indicate that these variables are closely related to pulp quality and paper properties (Worku et al. 2023).

The increasing global demand for sustainable raw materials has intensified interest in the valorization of forest residues within circular bioeconomy frameworks. Wood residues generated by carpentry workshops and small-scale wood processing units represent an underutilized lignocellulosic resource with potential to supplement conventional fiber sources for pulp and paper production. The efficient use of such residues contributes not only to waste reduction but also to improved resource efficiency and reduced pressure on natural forests, aligning with current sustainability and climate mitigation strategies in the forest sector (Worku et al. 2023; Silva et al. 2022).

Wood anatomy remains a challenging field for species identification due to similarities among related taxa, particularly within the same family. In Brasil Novo, Pará, the commercialization of Meliaceae timber is still frequent, and the possibility of misidentification among species is common. Despite the extensive literature on *Swietenia macrophylla* wood anatomy, evidence of illegal trade has been reported in the region. Therefore, this study aimed to anatomically characterize Meliaceae timber species used in furniture production and evaluate the potential of their residues for pulp and paper production, contributing to improved species identification and sustainable utilization of forest resources.

## MATERIALS AND METHODS

### *Material sampling and preparation*

Wood samples were collected from four carpentry workshops in the municipality of Brasil Novo, Pará State, Brazil, corresponding to the following species: *Cedrela* sp., *Swietenia macrophylla* King, *Khaya* sp., and *Carapa guianensis* Aubl. In the laboratory, wood specimens (2 × 2 × 3 cm) were prepared and oriented in the transverse, radial longitudinal, and tangential longitudinal planes for macroscopic and microscopic description, following the usual wood anatomy techniques described by IBAMA.

For the maceration process, longitudinal segments of wood from the four species were obtained and transferred to test tubes containing distilled water, and subsequently immersed in a macerating solution composed of glacial acetic acid and hydrogen peroxide (1:1). The material was placed in an oven at 60 °C for 24 hours, drained, and washed in running water, following the methodology described by Franklin (1945).

*Microscopic wood anatomy*

Wood specimens from the four genera of the Meliaceae family were immersed and boiled in distilled water and glycerin for softening, followed by free-hand sectioning in the transverse, tangential longitudinal, and radial longitudinal planes. The sections were clarified with 2.5% sodium hypochlorite, washed in distilled water, stained with 1% safranin, dehydrated in a butyl–alcohol series, selected, and mounted on glass slides using Canada balsam.

A DIGILAB DI-521T optical microscope coupled with a 48 MP FHD Camera V8 and OPTO-EDU ImageView software was used to capture images of the transverse, tangential longitudinal, and radial longitudinal sections.

The microscopic structure of the wood was described according to the recommendations of the IAWA Committee (1989).

*Fiber morphology and measurements*

For the description of fiber morphology and dimensions, the dissociated cells were stained with 1% safranin and analytical grade formaldehyde and mounted on semi-permanent slides using glycerin. The material was observed under an optical microscope, in which 25 fiber units were measured for each species. Fiber length, fiber width, cell wall thickness, and lumen diameter were obtained in micrometers (µm).

After measurement, the technological indices were calculated:

Runkel index (RI): $\frac{2e}{d}$ (1)

Flexibility coefficient (FC): $\frac{d}{L}.100$ (2)

Felting index (FI): $\frac{C}{L}$ (3)

Wall fraction (WF): $\frac{2e}{L}.100$ (4)

Where: *e* = cell wall thickness (µm); *d* = lumen diameter (µm); *L* = fiber width (µm); *C* = fiber length. (mm)

Statistical analysis for comparison of fiber means was performed using Excel (2024) and Sisvar software (version 5.8).

## RESULTS

*Wood Anatomy*

*Cedrela sp*

The species *Cedrela* sp. presented straight grain and medium texture, with a perceptible odor. Axial parenchyma was paratracheal in marginal bands and vasicentric, visible to the naked eye and under a 10× hand lens, respectively. Numerous whitish deposits were observed in the pores. In the tangential longitudinal plane, rays were not stratified, while in the radial longitudinal plane they appeared weakly contrasted. Wood was semi-ring-porous, with solitary vessels and few multiples of two and three. Vessel cross-section ranged from oval to rounded, with diagonal arrangement, simple perforation plates, alternate intervessel pits, and helical thickenings restricted to vessel tails. Vessel frequency ranged from 20 to 40 vessels per square millimeter, and gums were present inside the vessels. Fibers showed simple to finely bordered pits, both septate and non-septate, thin- and thick-walled, with fusiform parenchyma cells. Rays were one to three cells wide, with ray body composed of procumbent cells and one row of marginal square cells, with 4–12 rays per millimeter. Prismatic crystals were observed in marginal ray cells (Figures 1 and 2).

*Swietenia macrophylla*

The species *Swietenia macrophylla* King exhibited straight grain and medium texture, with imperceptible odor. In the transverse plane, axial parenchyma was paratracheal in marginal bands and scarce, with multiple pores arranged diagonally. In the tangential longitudinal plane, rays were stratified, and in the radial longitudinal plane, rays were contrasted. Wood showed diffuse porosity, with vessels having oval to rounded cross-section, simple perforation plates, and alternate intervessel pits. Vessel frequency ranged from 20 to 40 vessels per square millimeter, and gums were present in the vessels. Fibers showed simple to finely bordered pits, both septate and non-septate, thin- and thick-walled, with 5–8 cells per parenchyma strand. Rays were one to three cells wide, with the ray body composed of procumbent cells and one row of marginal upright cells, with >12 rays per millimeter, and stratified rays (Figures 1 and 2).

*Khaya sp*

The species *Khaya* sp. exhibited straight grain and medium texture, with imperceptible odor. In the transverse plane, axial parenchyma was paratracheal in marginal bands and vasicentric, with diffuse porosity and multiple pores arranged diagonally. In the tangential longitudinal plane, rays were non-stratified, and in the radial longitudinal plane, rays were contrasted. Vessels showed oval to rounded cross-section, simple perforation plates, and alternate intervessel pits, with 20–40 vessels per square millimeter. Fibers were non-septate, both thin- and thick-walled. Rays were commonly four cells wide, with the ray body composed of procumbent cells and one row of marginal square cells, with 4–12 rays per millimeter, and prismatic crystals present in the marginal ray cells (Figures 1 and 2).

*Carapa guianensis*

In the species *Carapa guianensis* Aubl., straight grain and medium texture were identified, with imperceptible odor. In the transverse plane, axial parenchyma was paratracheal vasicentric, visible only under a 10× hand lens, with diffuse-in-rings porosity and multiple pores arranged diagonally. In the tangential longitudinal plane, rays were non-stratified, and in the radial longitudinal plane, rays were contrasted. Vessels showed oval to rounded cross-section, simple perforation plates, alternate intervessel pits, and 40–100 vessels per square millimeter. Fibers were non-septate, both thin- and thick-walled, with axial parenchyma paratracheal vasicentric. Rays were one to three cells wide, rarely four, with the ray body composed of procumbent cells and 2–4 rows of marginal square cells, with 4–12 rays per millimeter (Figures 1 and 2).

*Comparative wood anatomy*

Table 1 presents the similarities and particularities of the studied species. Semi-ring-porous wood was observed only in *Cedrela* sp., whereas the other species showed diffuse-porous wood. *Carapa guianensis* was the only species that presented 40–100 vessels/mm² and two rows of marginal square cells in the ray body. The species *Khaya* sp. was the only one to present rays four cells wide, whereas the other species commonly showed three cells in width. *Swietenia macrophylla* showed ray stratification, ray body with one row of marginal upright cells, scarce axial parenchyma, and 12 rays/mm², distinguishing it from all other species.

*Fiber morphology and statistical analysis*

Based on fiber measurements, statistical analysis was performed, calculating maximum, minimum, mean values, and standard deviation for each studied species (Figures 3–6). These morphological measurements showed distinct patterns among the genera of the Meliaceae family. Analysis of variance (ANOVA) revealed significant differences among the four Meliaceae species for all evaluated anatomical variables ($p < 0.01$). Tukey's test confirmed the existence of statistically distinct groups (Table 2).

Regarding mean fiber length, *Cedrela* sp. showed the highest average among the groups, followed by *Swietenia macrophylla*, whereas *Khaya* sp. and *Carapa guianensis* presented lower values and greater dispersion, with statistical difference confirmed by Tukey's test ($p < 0.05$). *Cedrela* sp. formed a distinct group (a2), presenting significantly longer fibers than the others (Table 2). In contrast, *Khaya* sp., *Carapa* *guianensis*, and *Swietenia macrophylla* did not differ statistically from each other. According to Runkel (1952), fibers between 1.5 mm and 2.0 mm are ideal for papers with intermediate to high strength, placing all species within the recommended range. This dimensional difference is technologically relevant, since fiber length is directly related to the mechanical strength of paper, especially tear resistance, and also contributes to increased durability (Foelkel & Barrichelo 1975; Sousa Júnior et al. 2025).

The mean fiber width ranged from 18.91 µm in *Khaya* sp. to 23.47 µm in *Swietenia macrophylla*, with significant difference ($p < 0.01$). *Khaya* sp. presented thinner fibers, whereas *Carapa guianensis*, *Cedrela* sp., and *Swietenia macrophylla* formed a group with larger diameter (a2).

Regarding lumen diameter, mean values of 14.92 µm were observed for *Khaya* sp., 17.71 µm for *Carapa guianensis*, 19.31 µm for *Cedrela* sp., and 19.76 µm for *Swietenia macrophylla*, also showing significant difference. Tukey's test grouped *Khaya* sp. with lower values (a1), whereas *Cedrela* sp. and *Swietenia macrophylla* exhibited wider lumens (a1), indicating that *Khaya* sp. and *Carapa guianensis* are statistically different compared to the other species.

Regarding cell wall thickness, significant differences were observed between *Carapa guianensis* (a3) and *Cedrela* sp. (a1), confirming that *Carapa guianensis* has thicker walls and, therefore, more rigid fibers (Table 2).

The presence of outliers in the graphs suggests variability among fiber measurements within the same species. These differences in fiber structure directly influence the fiber quality indices (Table 3).

*Fiber quality índices*

Runkel index (RI) values ranged from 0.29 in *Cedrela* sp. to 0.54 in *Swietenia macrophylla*, all below 1.0, which according to Runkel (1952) indicates fibers suitable for papermaking, since thin walls and wide lumens favor collapsibility. According to Benites et al. (2015) and Sousa Júnior et al. (2025), RI lower than 1 and flexibility coefficient (FC) higher than 75% are considered optimal parameters for fibers intended for paper production. *Carapa guianensis* presented an index of 0.501, still acceptable, although slightly higher than the others, indicating relatively lower flexibility. Thus, all evaluated species show potential for use in pulp production, especially *Cedrela* sp. The flexibility coefficient (FC) ranged from 78.18% to 84.79%, indicating flexible fibers.

This tendency can also be observed in Graph 1, which relates the Runkel index (RI) and the flexibility coefficient (FC). It is observed that the species with lower RI values, such as *Cedrela* sp. and

*Swietenia macrophylla*, are the same that present the highest FC values, demonstrating the association between thinner walls, greater flexibility, and better potential for fiber collapsibility.

The felting index (FI), which expresses the relationship between fiber length and fiber diameter, ranged from 77.31 in *Swietenia macrophylla* to 89.61 in *Khaya* sp.

The wall fraction (WF), which relates cell wall thickness to fiber width, ranged from 24.5 to 39.3, indicating that the fibers have relatively thin walls in relation to the lumen.

**DISCUSSION**

The species *Cedrela* sp. showed semi-ring-porous wood, a characteristic commonly found in woods from seasonal tropical environments, where alternation between periods of rapid and slow growth occurs, reflecting a physiological adaptation to water availability (IAWA 1989). The presence of simple perforation plates and alternate intervessel pits reinforces the evolutionarily advanced character of the xylem, optimizing the conduction of crude sap (IAWA 1989). The presence of gums in the vessels indicates a defense mechanism against insect and fungal attack, and is also a typical anatomical marker of *Cedrela* sp. (Richter & Dallwitz 2000). Rays one to three cells wide, composed of procumbent cells and marginal square cells, indicate a heterogeneous structure type II according to the IAWA classification (1989). This configuration is associated with efficient radial conduction and uniform distribution of nutrients within the wood.

The species *Swietenia macrophylla* showed diffuse porosity, a characteristic that indicates uniform distribution of vessels along the growth ring. This type of porosity is generally associated with species from humid tropical regions, where there is no marked seasonality between dry and rainy periods (IAWA 1989). A frequency greater than 12 rays per millimeter is a characteristic feature of the genus *Swietenia*, distinguishing it from *Cedrela* sp., which generally presents fewer than 12 rays/mm. In addition, ray stratification is an important diagnostic character and is frequently used to differentiate *Swietenia* from other Meliaceae (Wheeler et al. 2007). The description provided for the species is consistent with those reported in the literature, such as Richter and Dallwitz (2000) and Wheeler et al. (2007).

The characteristics of *Khaya* sp. presented here are consistent with studies reported by Richter and Dallwitz (2000), except for axial parenchyma, which was described as scanty and vasicentric, without marginal bands (Richter & Dallwitz 2000).

The high vessel frequency (40–100 vessels $mm^2$) is consistent with the anatomical description of *Carapa guianensis*, which presents vascular elements of small diameter but in large numbers, increasing hydraulic safety and reducing vulnerability to cavitation (Richter & Dallwitz 2000; Wheeler et al. 2007). This vessel density is higher than that observed in related genera such as *Swietenia* sp. and *Cedrela* sp., constituting a relevant diagnostic trait for distinction within the Meliaceae.

The observed differences in lumen diameter are consistent with the results of Sadiku and Abdukareem (2019), who reported similar variations among tropical species such as *Khaya ivorensis*, with different densities and geographic origins. The thinner cell wall observed in *Cedrela* sp. favors fiber collapse during drying, increasing the bonding area between fibers, as discussed by Foelkel and Barrichelo (1975). In contrast, *Carapa guianensis*, with thicker cell walls, tends to produce more rigid papers with higher tear resistance.

For papermaking applications, the combination of longer fiber length with thin walls and adequate lumen diameter, as observed in *Cedrela* and *Swietenia*, is favorable for producing paper with good tensile strength and collapsibility, whereas the greater variability in *Carapa guianensis* may influence sheet quality (Foelkel & Barrichelo 1975).

The results obtained in this study are consistent with those reported by Benites et al. (2015), who observed for *Cedrela fissilis* a mean fiber length of 1.17 mm, mean width of 22.18 µm, lumen diameter of 14.44 µm, and cell wall thickness of 3.87 µm. Neto (2019) reported that *Khaya ivorensis* presented a mean fiber length of 1.88 mm (moderately long), mean diameter of 27 µm, lumen of 17 µm, and cell wall thickness of 4.97 µm, the latter classified as relatively thick (Table 4). Other studies conducted with species of the Meliaceae family show wide variation in values, with mean fiber length ranging from 980 to 1600 µm, width from 9 to 20 µm, and cell wall thickness from 1 to 5 µm (Siegloch et al. 2015). This variation demonstrates considerable differences in the morphological characteristics of species within the same genus but from different floras.

Regarding the indices, similar results were reported for the Runkel index by Benites et al. (2015), who observed an RI value of 0.54 in *Cedrela fissilis*, evidencing morphological differences among species within the same genus. (Table 5)

Flexibility coefficient values are similar to those reported for commercial *Eucalyptus* species (Gebeyehu 2024). These are desirable values for paper production, since the higher the FC, which expresses the relationship between lumen diameter and fiber width, the greater the strength of the final material, due to higher flexibility and better interfiber bonding (Foelkel & Barrichelo 1975).

Felting index values are compatible with those reported by Benites et al. (2015) for tropical species with good performance in pulp production. Fibers with high felting index are longer and more slender, contributing to greater tear and tensile strength (Runkel 1952). For comparison, Benites (2015) reported for *Cedrela fissilis* a wall fraction (WF) of 34.91%, FC close to 65%, and RI of 0.54, values similar to those observed in the present study (Table 5). Neto (2019) obtained a high RI (3.17) and desirable FC (63.1) for *Khaya ivorensis*, indicating that although RI is above the recommended value, FC suggests good fiber bonding and potential for pulp production after technological adjustments.

According to Foelkel and Barrichelo (1975), wall fraction values below 40 are typical of woods with good potential for collapsibility and formation of compact papers. In this sense, *Carapa guianensis* and *Khaya* sp. stood out with the highest wall fraction values, which tends to increase rigidity and tear resistance, whereas *Cedrela* sp. presented thinner fibers, favoring flexibility and sheet formation. Thus, all species showed satisfactory characteristics for pulp production, with *Cedrela* sp. exhibiting the lowest wall fraction.

The anatomical behavior observed is consistent with that described for African and Amazonian tropical woods of medium density. Studies by several authors support these observations, such as Firmino et al. (2019), who reported for *Carapa guianensis* fiber lengths of 1.3 to 1.5 mm and cell wall thickness around 4 μm, and Amorim et al. (2021), who presented values of 1.0 to 1.2 mm and RI close to 0.5 for *Hevea brasiliensis* L., a native Amazonian species (Table 5). Species with low RI and high FC, such as *Cedrela* sp., tend to produce papers with better strength and surface smoothness, whereas those with thicker cell walls, such as *Carapa guianensis*, contribute to material rigidity.

Differences between the values obtained in this study and those reported by other authors may be related to tree age, sampling position (juvenile or mature wood), and growth conditions. Foelkel and Barrichelo (1975) highlighted that cell wall thickness increases with age and that wood density influences pulp yield and paper properties. In studies of radial variation, Sunardi et al. (2020) observed that fibers near the base of the trunk are longer and have thicker walls, which may explain small discrepancies among studies.

Although the anatomical and fiber quality indices indicate promising technological potential for pulp and paper production, the present study is limited to morphological characterization. Basic density, pulping yield, and paper strength properties were not experimentally evaluated, which restricts direct industrial extrapolation. Future studies incorporating physicochemical analyses and pulping trials are recommended to validate the technological applicability of these wood residues.

**CONCLUSION**

Ray stratification is the main characteristic for identification and distinction of mahogany (*Swietenia macrophylla*).

Macroscopically, the perceptible odor combined with porosity are characteristics that can be used for identification and distinction of cedar (*Cedrela* sp.).

For the species *Carapa guianensis*, the ray body is the characteristic that differentiates it from the other species.

Ray width is the main characteristic for distinguishing African mahogany (*Khaya* sp.).

The evaluated Meliaceae species exhibited fiber dimensions and quality indices consistent with materials suitable for pulp and paper production. All species presented Runkel index values below 1.0 and high flexibility coefficients, indicating favorable fiber collapsibility and inter-fiber bonding potential. Cedrela sp. showed particularly promising characteristics due to its low Runkel index and high flexibility coefficient, whereas C. guianensis demonstrated greater wall fraction, suggesting contribution to structural rigidity.

Although the results indicate technological potential, further studies involving pulping performance and physicochemical characterization are recommended to confirm industrial applicability. Overall, the findings reinforce the potential of wood residues from Meliaceae species as alternative lignocellulosic resources within sustainable forest-based production systems.

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Figure 01. Macroscopic images. A – C *Cedrela* sp: A - transverse, B - tangential, C - radial; D – F *Swietenia macrophylla*: D - transverse, E - tangential, F - radial; G – I *Khaya* sp: G - transverse, H - tangential, I – radial; J – L *Carapa guianensis*: J - transverse, K - tangential, L – radial.

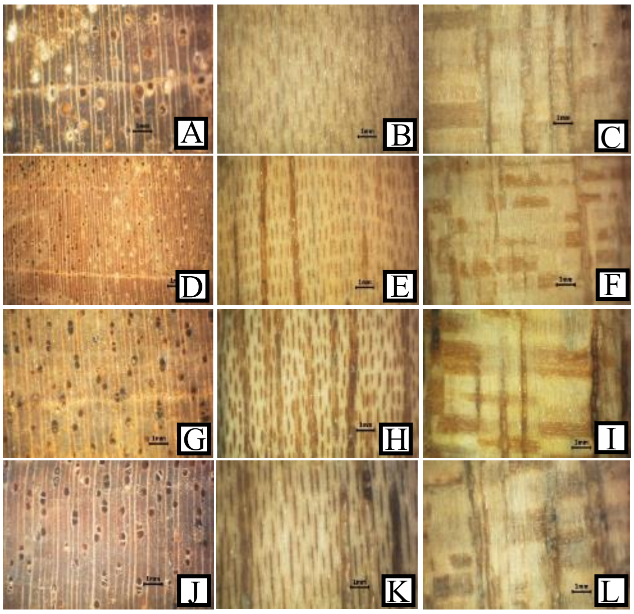


Figure 02. Microscopic images. A – C *Cedrela* sp: A - transverse, B - tangential, C - radial; D – F *Swietenia macrophylla*: D - transverse, E - tangential, F - radial; G – I *Khaya* sp: G - transverse, H - tangential, I – radial; J – L *Carapa guianensis*: J - transverse, K - tangential, L – radial.

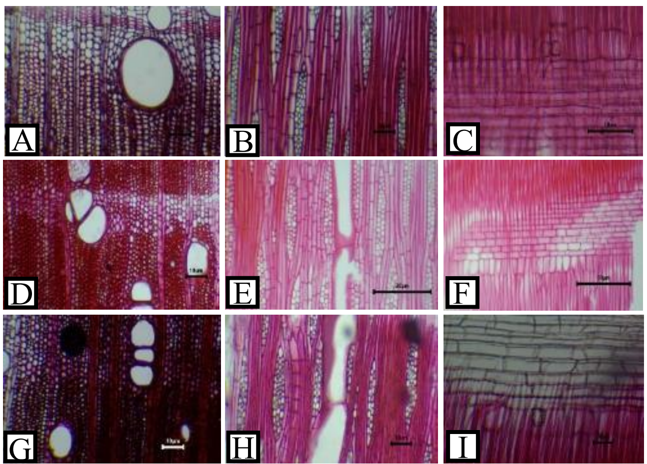

Table 1: Comparative table of the characteristics of the four species of Meliaceae

| Structure | | Characteristics | Species: *Cedrela* sp | *Swietenia macrophylla* | *Khaya* sp | *Carapa guianensis* |
|---|---|---|---|---|---|---|
| Vessels | Arrangement of the vessels | Diagonal | X | X | X | X |
| | Porosity | Diffuse ring | | X | X | X |
| | | Semi-porous | X | | | |
| | Vessels/mm² | 20-40 vessels/mm² | X | X | X | |
| | | 40-100 vessels/mm² | | | | X |
| | Intervessel pitting | | X | X | X | X |
| | Perforation plaques | | X | X | X | X |
| | Deposits in the vessels | | X | X | | |
| Axial parenchyma | Paratracheal | Vasicentric | X | | X | X |
| | | Scarce | | X | | |
| | In bands | Marginal | X | X | X | |
| Fibers | Fiber body | Non-septate | | | X | X |
| | | Septate and non-septate | X | X | | |
| Rays | Width of the rays | 1-3 cells wide | X | X | | X |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | 4 cells wide | | | X | |
| | Rays body | 1 row of square marginal cells | X | | X | |
| | | 1 row of upright marginal cells | | X | | |
| | | 2 rows of square marginal cells | | | | X |
| | Rays/$mm^2$ | 4-12 rays/$mm^2$ | X | | X | X |
| | | 12 rays/$mm^2$ | | X | | |
| | Stratified rays | | | X | | |
| | Contrasted rays | | X | X | X | X |
| | Prismatic crystals | | X | | X | |

Table 2 - Means and standard deviation of fiber dimensions of the analyzed species.

| **Species** | **Fiber length (mm)** | **Width (µm)** | **Lumen Diameter (µm)** | **wall thickness (µm)** |
|---|---|---|---|---|
| *C. guianensis* | 1.76 ± 0.24 (a1) | 22.46 ± 3.52 (a2) | 17.64 ± 3.83 (a1a2) | 4.41 ± 1.12 (a3) |
| *Cedrela* sp. | 1.99 ± 0.23 (a2) | 22.78 ± 5.57 (a2) | 19.32 ± 5.25 (a2) | 2.79 ± 0.72 (a1) |
| *Khaya* sp. | 1.70 ± 0.23 (a1) | 18.91 ± 4.22 (a1) | 14.79 ± 4.04 (a1) | 3.39 ± 0.97 (a2) |
| *S. macrophylla* | 1.81 ± 0.28 (a1) | 29.60 ± 5.43 (a2) | 19.77 ± 4.86 (a2) | 3.52 ± 0.75 (a2) |

(Identical letters in the same column do not differ statistically from each other, according to Tukey's test at 5%.)

Figure 3. Box plot of wall thickness dimensions (µm) for the species analyzed.

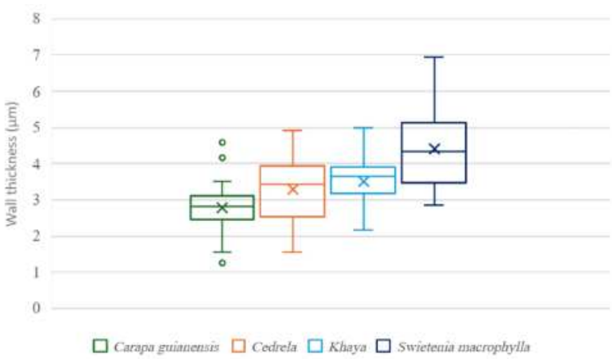


Figure 4. Box plot of lumen diameter dimensions (µm) for the analyzed species.

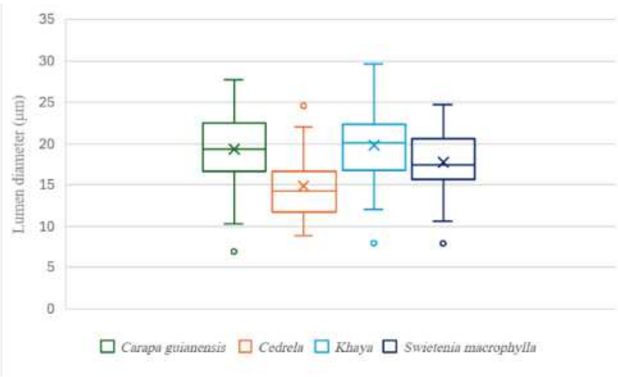


Figure 5. Box plot of fiber width dimensions (µm) for the species analyzed.

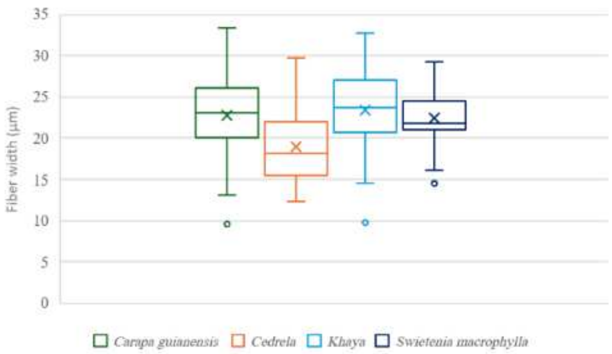


Figure 6. Boxplot of fiber length dimensions (µm) for the species analyzed.

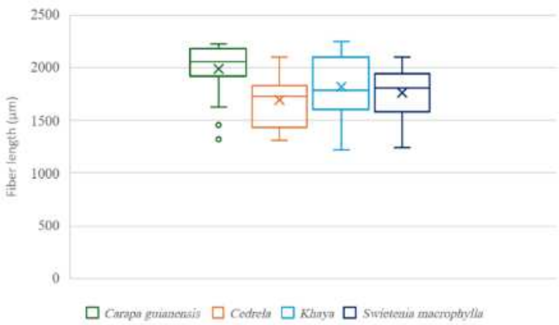


Table 3 - Runkel Index (RI) and fiber quality coefficients of the evaluated species.

| Species | RI | FC (%) | FI | WF (%) |
|---|---|---|---|---|
| *C. guianensis* | 0.501 ± 0.25 | 78.54 ± 10.15 | 78.29 ± 16.91 | 39.35 ± 9.56 |
| *Cedrela* sp. | 0.289 ± 0.14 | 84.79 ± 16.47 | 87.28 ± 38.63 | 24.50 ± 12.10 |
| *Khaya* sp. | 0.444 ± 0.20 | 78.19 ± 7.2 | 89.62 ± 23.65 | 34.69 ± 11.40 |
| *S. macrophylla* | 0.356 ± 0.08 | 84.21 ± 2.9 | 77.31 ± 26.04 | 29.94 ± 6.19 |

Figure 7. Relationship between RI and FC of fibers, indicating the recommended technological limits.

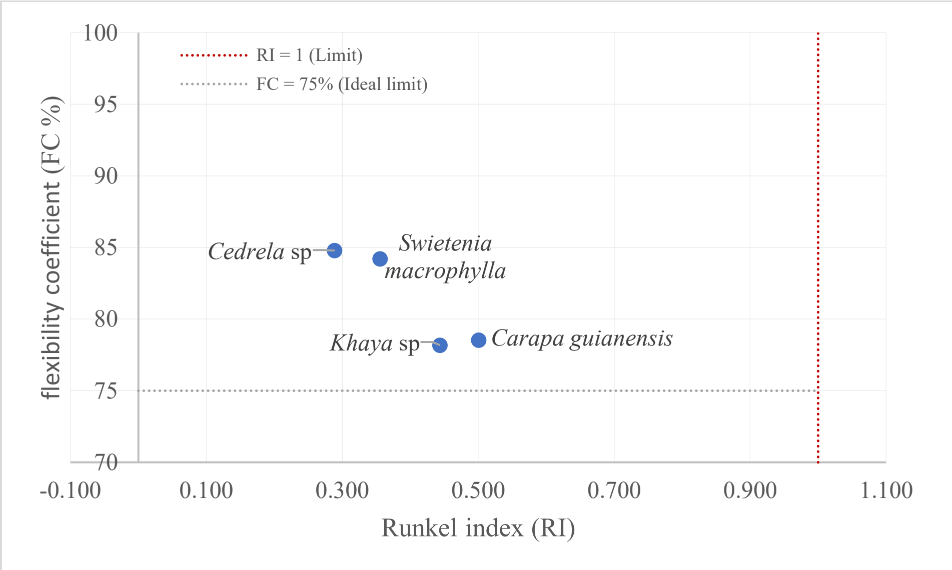


Table 4. Comparison of fiber dimensions between the present study and previous reports for Meliaceae species

| Species | Fiber length (mm) | Width (µm) | Lumen (µm) | Wall (µm) | Reference |
|---|---|---|---|---|---|
| *Cedrela* sp. (this study) | 1.99 | 22.78 | 19.32 | 2.79 | — |
| *Cedrela fissilis* | 1.17 | 22.18 | 14.44 | 3.87 | Benites et al. 2015 |
| *Khaya* sp. (this study) | 1.70 | 18.91 | 14.79 | 3.39 | — |
| *Khaya ivorensis* | 1.88 | 27.00 | 17.00 | 4.97 | Neto 2019 |
| Meliaceae spp. (range) | 0.98–1.60 | 9–20 | — | 1–5 | Siegloch et al. 2015 |

Table 5 - Comparison of fiber quality indices between the present study and previous reports.

| Species | RI | FC (%) | WF (%) | Reference |
|---|---|---|---|---|
| *Cedrela* sp. (this study) | 0.29 | 84.79 | 24.50 | — |
| *Cedrela fissilis* | 0.54 | ~65 | 34.91 | Benites et al. 2015 |
| *Khaya* sp. (this study) | 0.44 | 78.19 | 34.69 | — |
| *Khaya ivorensis* | 3.17 | 63.10 | — | Neto 2019 |
| *C. guianensis* (this study) | 0.50 | 78.54 | 39.35 | — |
| *Hevea brasiliensis* | ~0.50 | 65.50 | 34.62 | Amorim et al. 2021 |

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