

VARIATION OF SELECTED PHYSICAL AND ANATOMICAL PROPERTIES OF *LOVOA TRICHILIOIDES* (HARMS) WOOD

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Abstract:

*This study investigates variations in some physical and anatomical properties of *Lovoa trichilioides* (Harms) wood from a disturbed secondary forest in Akwa Ibom State, Nigeria to determine its suitability and utilization. Two thirty-year-old trees free from knots were purposively selected and felled. Boles of 600mm long were obtained at 10%, 30%, 50%, 70%, and 90% along the merchantable height. The boles were further processed to obtain test samples along the axial and radial (outer, middle, and inner wood) positions, and samples with dimensions 20mm × 20mm × 60mm and 20mm × 20mm × 20mm were prepared to test physical and anatomical properties. The results showed that the variation patterns of physical properties, such as moisture content, density, and volumetric swelling coefficient, and the anatomical properties, such as fiber length, fiber diameter, lumen width, and cell wall thickness, decreased along the axial and radial positions. Moisture content, density, and volumetric swelling coefficient varied from 22.85%, 428.55kgm⁻³ and 12.09% at 10% (base) to 20.66%, 396.35kgm⁻³ and 9.84% at 90% (top) axially and radially, the properties ranged from 21.66%, 418.19kgm⁻³ and 10.98% at outer wood to 21.10%, 411.21kgm⁻³ and 10.52% at inner wood. Fiber length, fiber diameter, lumen width and cell wall thickness ranged from 1.20mm to 1.09mm, 19.22μm to 16.47μm, 9.61μm to 8.79μm and 4.80μm to 4.12μm at 10% and 90% along the axial and radially, from 1.15mm to 1.13mm, 17.93μm to 17.19μm, 8.96μm to 8.60μm and 4.48μm to 4.30μm at outer wood and inner wood. The variation pattern of *L. trichilioides* wood along the axial and radial directions does not adversely affect physical properties, and it is a medium-density wood that could be utilized for light construction. The anatomical properties of *L. trichilioides* wood were within the normal range for tropical hardwood, with short fibers, small diameter, and lumen width, and thin cell walls.*

Key words: wood density, swelling, fiber length, lumen width, cell wall thickness, wood variation.

INTRODUCTION

Wood is a natural composite material and a relatively inexpensive building material used for a variety of structural applications. It is a renewable natural resource and has been used by humans for thousands of years before the advent of modern civilization and the use of steel. Wood is the raw material from which forest industries manufacture countless products for homes and offices (Ajuziogu *et al.* 2014).

The natural forests contain a wide variety of tree species of merchantable sizes; over 560 tree species have been reported in Nigerian forests (Akisanmi and Akindele 2002), and the wood properties of some of these trees in the tropical rainforest, which are a vital asset to the country, have not been thoroughly evaluated. Tropical woods are highly sought after for various applications; as a result, in recent years, the demand for timber with high natural commercial value has increased significantly (Haag *et al.* 2020). The intended utilization of wood for any purpose is determined by wood properties (physical and anatomical characteristics) such as wood density, dimensional stability, grain angle, tracheid length, and microfibril angle of the S₂ layer in the cell wall (Tokumoto *et al.* 1997, Wang *et al.* 2021).

Fibers and vessels are the main components of the anatomical structure of wood in trees, and their size, quantity, and shape are important indicators of wood properties (De Mil *et al.* 2018, Liu *et al.* 2020). Wood anatomy, especially the proportions and distribution of the microstructure, is crucial to wood identification, as researchers have over the years used the anatomical structure of wood to identify timber suitable for diverse applications (Akande 2001; Ogunsanwo 2006). Knowledge of the anatomy of wood is fundamental to

determining its utilization, while the most apparent differences between woods lie in microstructure, chemical composition, and structural characteristics (Bowyer and Smith 1998, Tsoumis 1991).

Wood density is an important property, it measures wood quality, and it is related to other properties like timber strength, resistance to deformation (stability), and the appearance of solid wood products (Kimberley *et al.* 2015, Schimleck *et al.* 2018). It is a composite trait affected by fibers, lumen width, cell wall thickness, vessels, annual ring, latewood, etc. (Pacheco *et al.* 2016). It is important for the technological characterization of timber, and it is mainly influenced by genotype, cambium aging, and growth rate (Zhang 1998), and it offers insights into how suitable the wood is for different end uses (Saranpää 2009).

Wood properties differ along different axes (tangential, radial, and longitudinal), within trees of the same species and among different species, thus predicting the behaviour of wood (Amtzen and Charles 1994, Okon 2014). Radial variation within trees is caused by the formation of xylem at various cambium ages, and it is the primary source of wood property variation. The main challenge to reliable utilization of timber in any application is the lack of sufficient data on the variation pattern of a given species, which ensures that relevant performance criteria are met, as specified by relevant standards and codes.

Lovoa trichilioides is a tropical wood of the family meliaceae that grows naturally across some West African countries. It is readily available and extensively used in many parts of Nigeria. It is a known timber utilised in structures and panels, such as lightweight structures, plywood, inside face and outside face, sliced veneer, carpentry and interior fittings such as doors and door frames, interior panelling and claddings, furniture and cabinetmaking.

Studying the variation pattern of *L. trichilioides* will be beneficial for the utilization of the wood in multiple applications. It is necessary to understand some of its properties and how they vary. The objective of this study is to examine the variations in some physical properties, such as moisture content, density, and volumetric swelling coefficient, as well as anatomical properties, including fibre length, fibre diameter, fibre lumen width, and cell wall thickness along the axial direction from base to top (10%, 30%, 50%, 70% and 90%) and the radial direction from outer to inner wood.

MATERIALS AND METHODS

30-year-old *Lovoa trichilioides* (Harms) trees free from cracks, knots, resin pockets, discoloration, or decay were purposively selected (ASTM 143-22, 1987) from a disturbed secondary forest at Afaha Obio Eno village, Ibiono Ibom Local Government Area, Akwa Ibom State, Nigeria. Permission was obtained from the State Directorate of Forestry before felling the trees, after identification and marking during a reconnaissance survey. The area lies between latitudes 5° 5' and 5° 7' N and longitudes 7° 47' and 7° 52' E.

A destructive method was used to collect the sampled trees for the evaluation of physical and anatomical properties. Bolts of 600mm were cut from the felled trees at 10%, 30%, 50%, 70%, and 90% along the axial direction (Figs. 1 and 2) and were used to prepare samples for the experiment. The logs were transported to the Department of Forestry and Wildlife's Wood Workshop for processing. They were further converted and partitioned, and samples were obtained from the inner wood, middle wood, and outer wood in the cross-section (radial) direction (Ogunsanwo and Onilude 2001), from the pith to the bark (core, inner, and outer wood) for the experiments (Fig. 1). Samples with dimensions 20mm x 20mm x 60mm (T - tangential x R - radial x L - longitudinal) and 20mm x 20mm x 20mm were used to determine physical properties (moisture content, density, and volumetric swelling coefficient) and anatomical properties (fiber length, fiber diameter, lumen width, and cell wall thickness) (Fig. 2) (ASTM, 1991). The samples were conditioned at 20°C with 65% relative humidity to attain 12% moisture content.

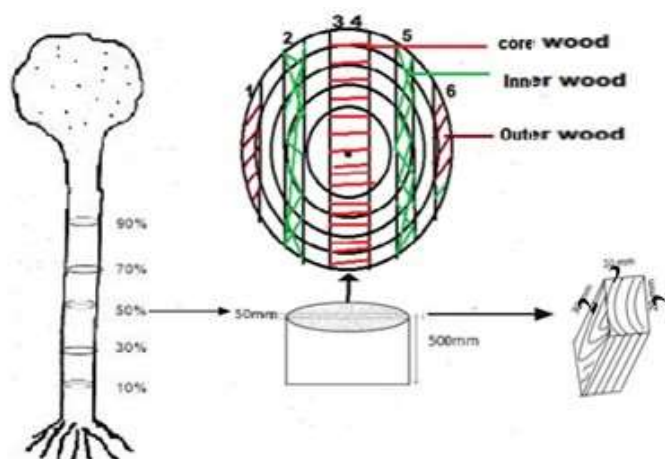


Fig. 1.
Schematic steps for
preparing wood samples
for physical and
anatomical properties
tests.



a. Converted logs to planks



b. Converting planks to billets



c. Planing



d. Plane billets



e. Converted to test samples of different dimensions

Fig. 2.
Sample preparation for physical and anatomical properties tests.

Moisture content was calculated using Equation (1) (ASTM D 4442-84, 1989). The initial weight of the test samples was recorded, and the samples were oven-dried at $103 \pm 2^\circ\text{C}$; their final weight was recorded. Oven-drying and weighing were repeated every 24 hours until the difference in weight between two successive measurements was constant; the drying process was terminated. The final oven-dry weight of the test samples was recorded, and the samples were bagged in an airtight nylon bag to prevent moisture loss.

$$\text{MC (\%)} = \frac{W_m - W_o}{W_o} \times 100 \quad 1$$

where: MC = Moisture Content

W_m = Weight of the green test samples (g)

W_o = Weight of the oven-dry test samples (g)

Density was calculated using Equation (2). Test samples were oven-dried at $103 \pm 2^\circ\text{C}$ temperature to a constant weight. The oven-dried weight and dimensions of the test samples were measured to 0.001g and 0.01mm sensitivity, then the volume of the samples was calculated (ASTM D 2395-17, 2017).

$$\rho \text{ (kg/m}^3\text{)} = \frac{M}{V} \quad 2$$

where: ρ = Density

M = Oven-dried weight of the test samples (kg)

V = Volume (length, width, and thickness) of the test samples (m^3)

Volumetric swelling coefficient was calculated using Equation (3), based on the procedure in the ASTM D1037-06 (2006) standard. The initial weight and dimensions of the samples were recorded, then the samples were soaked in a water bath filled with distilled water for 72 hours. The saturated samples were removed, the surface was wiped with absorbent paper, and the weight and dimensions were measured. The volume of the wood samples was calculated from the dimensions before and after soaking in distilled water.

$$VS \% = \frac{V_2 - V_1}{V_1} \times 100 \quad 3$$

where: VS = volumetric swelling coefficient

V_1 = Initial volume (mm³)

V_2 = Saturated volume (mm³)

Thin sections of wood (slivers) *cut with a microtome* were placed in an equal volume (1:1) of 30% hydrogen peroxide and 10% glacial acetic acid, then boiled in the oven for 16 hours at 103°C until they bleached to white and softened (ASTM D 1413-61 2007). The slivers were decanted and washed and were placed in 30ml test tubes with 20ml distilled water and shaken vigorously to separate the fibre bundles into defibred fibres (Areo and Omole 2020). The fibres were placed on slides, covered with a microscopic coverslip for the measurement of fibre dimensions such as fibre length, fibre diameter, lumen width, and cell wall thickness in a swollen condition using a binocular light microscope (Nikon, ECLIPSE 80i) with magnification of 10x, equipped with a calibrated ocular eyepiece. Twenty-five fibres were measured for fibre length and fibre diameter, and lumen width and cell wall thickness were calculated according to Equations (4 and 5).

$$\text{Lumen width} = \frac{FD}{2} \quad 4$$

$$\text{Cell-wall thickness (CW)} = \frac{FD - LW}{2} \quad 5$$

where: FD = fibre diameter

LW = lumen width

The experimental design was a two-factor split-plot analysis with the main plot arranged in a Completely Randomized Design (CRD). Data obtained were subjected to Analysis of Variance (ANOVA) to evaluate the variance in the physical and anatomical properties of the wood, and where there was a significant difference, separation of means was carried out using Duncan's Multiple Range Test (DMRT) at 0.5% probability level.

RESULTS AND DISCUSSION

Physical properties of *Lovoa trichilioides* wood

A summary of the means of some physical properties (moisture content, density, and volumetric swelling coefficient) of the wood along the axial and radial positions is shown in Table 1.

Moisture content

The moisture content of *L. trichilioides* wood along the axial position ranged from 22.85% at 10% to 20.66% at 90%. In the radial position, the moisture content ranged from 21.10% in the inner wood to 21.66% in the outer wood (Table 1). The results showed that moisture content decreased from the base to the top along the axial position and increased from the inner wood to the outer wood radially. There was a significant difference between the moisture content at 10% compared to 90% along the axial position ($F = 10.20$, $P < 0.0433$). This pattern of variation was previously reported by Jimoh and Adefemi (2006) in *Azelia bipindensis* wood. *L. trichilioides* wood has a low moisture content (21%), which ensures structural stability, improves strength, prevents decay, and allows for more durable finishes (i.e., reducing the activity of bio-deterioration agents) such as fungi, since high moisture content increases the susceptibility of wood to decay. This finding aligns with the trend reported by Lausberg *et al.* (1995) and Shupe *et al.* (1995), who stated that variation in wood moisture content decreases from base to top axially and that the radial pattern shows moisture content decreasing from inner to outer wood. *L. trichilioides* wood can be a suitable substitute for some depleted commercially exploited timbers, such as *Milicia excelsa*, *Cordia millenii*, *Mansonia altissima*, *Khaya ivorensis*, *Trilochiton scleroxylon*, *Khaya senegalensis*, *Azelia africana*, etc., used for structural applications.

Table 1

Mean of some physical properties of *Lovoa trichilioides* wood along the axial and radial positions

Wood Properties	Moisture content (%) Mean±SD	Density (kg/m ³) Mean±SD	Volumetric swelling (%) Mean±SD
Axial position			
10%	22.85±3.34 _b	428.55±15.20 _c	12.09±1.21 _c
30%	21.13±0.72 _a	420.29±13.27 _c	11.15±1.88 _c
50%	21.10±0.84 _a	416.79±14.77 _c	10.54±1.06 _{ab}
70%	21.03±1.07 _a	408.94±10.73 _b	10.04±0.37 _a
90%	20.66±1.40 _a	396.35±16.12 _a	9.84±1.32 _a
Mean	21.35±1.47	414.18±14.02	10.73±1.17
Radial position			
Outer wood	21.66±1.66	418.19±13.30	10.98±0.97
Middle wood	21.30±1.21	413.15±12.92	10.70±1.36
Inner wood	21.10±1.54	411.21±15.82	10.52±1.17
Mean	21.35±1.47	414.18±14.02	10.73±1.17

Means ± standard deviation (SD), means with the same alphabet in each column are not significantly different at $p < 0.05$.

Density

The density of *L. trichilioides* wood ranged from 428.55 kgm⁻³ at 10% to 396.35 kgm⁻³ at 90%, indicating that the wood density decreased from base to top (Table 1). Radially, the density ranged from 418.19 kgm⁻³ at the outer wood to 411.21 kgm⁻³ at the inner wood, with a variation pattern indicating that density increased from the inner wood to the outer wood. There was a significant difference in wood density at $p < 0.05$ along the axial position. According to Tsoumis (1991), wood density increases with increasing moisture content and decreases axially from the base to the tip of the tree. The density of *L. trichilioides* wood in this study was slightly lower compared to the density of *Aningeria robusta* wood (430kg/m³) (Ajala and Ogunsanwo 2011). These results align with the findings reported by Malaysia Timber Company – MTC (2018), Rincon *et al.* (2004), Orwa *et al.* (2009) and Ragone (2011), who observed density values ranging from 400 to 560 kg/m³ in their research. The density obtained from this study indicates that *L. trichilioides* wood is classified as medium-density wood. The decreasing trend in density from the base to the top was reported in *Azadirachta excels* (Lathsamy 1998) and *Trilepisium madagascariensis* woods (Oyagade and Fasulu 2005). The decrease in density of *L. trichilioides* was attributed to a decrease in cell wall thickness and the presence of juvenile wood near the tip of the wood. Other factors, such as growth rate, may also influence wood density because of changes in the relative proportions of the secondary cell wall, cell lumen, and the relative amounts of chemical components in the cell wall (Kiaei 2011). Previous study reported that density is higher at the base of the wood due to a higher proportion of heartwood formation at the butt and a higher proportion of juvenile wood at the top (Sotande *et al.* 2010). Density is a good indicator of wood's strength and properties, such as dimensional stability influences its usability in various applications. *L. trichilioides* wood could be used where hardwoods are required for construction and could substitute for those economic species that are scarce in the market. Wood density is used as a single indicator to express wood quality and the utilization potential of any species. Timber from *L. trichilioides* may be utilized for furniture and structural applications.

Volumetric swelling

The volumetric swelling coefficient of *L. trichilioides* wood ranged from 12.09% at 10% to 9.84% at 90%, and radially, it ranged from 10.52% at the inner wood to 10.98% at the outer wood (Table 1). These results indicated that the volumetric swelling coefficient decreased from base to top along the axial direction and increased from inner wood to outer wood radially. There was a significant difference in the volumetric swelling coefficient of the wood at $p < 0.05$ along the axial position. *L. trichilioides* wood is likely to be stable in service based on the volumetric swelling results, and it could season very well with little or no defects, since wood with low moisture content tends to have low water movement in service. Stamm (1964) attributed high water absorption in wood to the presence of hemicellulose, which is hydrophilic. Hemicelluloses exhibit the highest sorptive capacity compared to other cell wall constituents, followed by cellulose and lignin (Hunkel and Liithgens 1959). Earlier research indicates that hardwoods swell more than softwoods (Schroeder 1972) because of differences in cell walls, especially since the secondary wall is mainly responsible for swelling, and

hardwoods have a higher fiber saturation point. Wood swells when moisture is absorbed, primarily in the tangential direction, followed by the radial direction (about half), and finally in the longitudinal direction of the fibers (Carll and Wiedenhoef 2009). However, if the moisture content exceeds the fiber saturation point, there will be no effect on strength properties, because the variations depend on free water in the wood cells (Leonardo da Vinci Project 2008).

Anatomical properties of *L. trichilioides* wood

Table 2 shows the summary of the mean of some anatomical properties (fibre length, fibre diameter, lumen width, and cell wall thickness) of *L. trichilioides* wood along the axial and radial positions.

Fiber length

The fiber length of *L. trichilioides* wood ranged from 1.20mm at 10% to 1.09mm at 90%. Radially, the fiber length of the wood ranged from 1.13mm at the inner wood to 1.15mm at the outer wood (Table 2). Fiber length decreased from the base to the top along the axial direction and increased from the inner wood to the outer wood in the radial direction. The variation pattern observed in this study is in line with a previous study by Okon (2014) in *Gmelina aborea* wood, attributing the increase in fiber length to an increase in the length of the cambial initial with increasing cambial age. Helene (2004) reported that variations in fiber length within radial planes were due to annual ring increments, genetic traits, and silvicultural treatments. The fibers from *L. trichilioides* wood were classified as short fibres, since the mean fibre length was less than 1.60mm (Areo and Omle 2020). This is consistent with earlier research by Oluwadare (2007), who reported a fibre length of 0.65mm for *Leucaena leucocephala* and Ogunjobi *et al.* (2014) for *Vitex doniana*.

Table 2

Mean of some anatomical properties of *Lovoa trichilioides* wood along the axial and radial positions.

Wood properties	Fiber length (mm)	Fiber diameter (μ m)	Lumen width (μ m)	Cell wall thickness (μ m)
Axial position				
10%	1.20 $\pm$ 0.27 _a	19.22 $\pm$ 4.99 _b	9.61 $\pm$ 2.50 _b	4.80 $\pm$ 1.25 _b
30%	1.17 $\pm$ 0.33 _a	17.74 $\pm$ 5.26 _{ab}	8.87 $\pm$ 2.63 _{ab}	4.43 $\pm$ 1.32 _{ab}
50%	1.14 $\pm$ 0.30 _a	17.44 $\pm$ 4.44 _a	8.72 $\pm$ 2.22 _{ab}	4.36 $\pm$ 1.11 _{ab}
70%	1.12 $\pm$ 0.31 _a	17.00 $\pm$ 5.23 _a	8.50 $\pm$ 2.59 _a	4.25 $\pm$ 1.29 _a
90%	1.09 $\pm$ 0.28 _a	16.47 $\pm$ 0.21 _a	8.24 $\pm$ 2.23 _a	4.12 $\pm$ 1.11 _a
Means	1.14$\pm$0.30	17.57$\pm$4.03	8.79$\pm$2.43	4.39$\pm$1.22
Radial position				
Outer wood	1.15 $\pm$ 0.28	17.93 $\pm$ 4.04	8.96 $\pm$ 2.51	4.48 $\pm$ 1.26
Middle wood	1.15 $\pm$ 0.31	17.61 $\pm$ 4.04	8.80 $\pm$ 2.42	4.40 $\pm$ 1.21
Inner wood	1.13 $\pm$ 0.32	17.19 $\pm$ 4.02	8.60 $\pm$ 2.37	4.30 $\pm$ 1.18
Means	1.14$\pm$0.30	17.57$\pm$4.03	8.79$\pm$2.43	4.39$\pm$1.22

Means $\pm$ standard deviation, means with the same alphabet in each column are not significantly different at $p < 0.05$.

Fiber diameter

The fibre diameter of *L. trichilioides* wood ranged from 19.22 μ m at 10% to 16.47 μ m at 90% axially. Radially, it ranged from 17.19 μ m at the inner wood to 17.93 at the outer wood (Table 2). There was a significant difference in fiber diameter at 10% compared to 90% at $p < 0.05$ along the axial position. The variation pattern showed that fibre diameter decreased from base to top along the axial direction and increased from the inner wood to the outer wood, possibly due to a decrease in cell wall thickness. Cell wall growth, according to Fahn (1990), is dependent on the accumulation of metabolic products such as cellulose, hemicelluloses, lignin, etc., which increases with maturity. This variation pattern differs from reports by Areo and Omole (2020), which indicate that fibre diameter decreases from base to middle and marginally increases to the top axially, and increases from core wood to inner wood and decreases to outer wood radially. On the other hand, studies by Izekor and Fuwape (2011) on *Tectona grandis* and Okon (2014) on *Gmelina arborea* are in line with this study. Plomion *et al.* (2001) and Roger *et al.* (2007) attributed variation along the axial and the radial positions to the increase in the age of trees (i.e., juvenile wood produces narrower fibres and mature trees produce wider

fibres), molecular and physiological changes that occur in the vascular cambium, and the increase in the cell wall thickness throughout the tree growth.

Lumen width

The lumen width of *L. trichilioides* wood ranged from 9.61µm at 10% to 8.24µm at 90%, and from 8.60µm in the inner wood to 8.96µm in the outer wood in the axial and radial directions (Table 2). Lumen width was statistically significant at $p < 0.05$ along the axial position and showed a consistent pattern of variation along and across the wood. It decreased from the base to the top and increased from the inner wood to the outer wood. This is in line with Izekor and Fuwape (2011) and Okon (2014), both studies reported a decrease in the lumen width of *Tectona grandis* and *Gmelina arborea* woods, attributed to cell multiplication at the cambium (i.e., growth of trees with age) as the tree increases in girth. As cambial age increases, lumen width tends to increase and become more stable in mature wood (Tsuchiya and Furukawa 2009), and changes in lumen width are influenced by cell wall thickness (Frimpong-Mensah 1992).

Cell wall thickness

The cell wall thickness of *L. trichilioides* wood ranged from 4.80µm at 10% to 4.12µm at 90%, and from 4.30µm in the inner wood to 4.48µm in the outer wood along the axial and radial directions (Table 2). Cell wall thickness of the wood decreased from the base to the top and increased from the inner wood to the outer wood along and across the wood and was statistically significant at $p < 0.05$ along the axial position. This variation pattern aligns with Izekor and Fuwape (2011) in their research on *Tectona grandis*. Habibi *et al.* (2003) confirmed that cell wall thickness increases from the pith toward the bark and that cell wall thickness is a vital anatomical property that varies between species and within trees, and it significantly affects wood quality and strength properties. Additionally, variation in cell thickness is influenced by tree genetics, physiology, and silvicultural practices.

CONCLUSION

This study presents important data on the variation pattern of some properties of *Lovoa trichilioides* wood from a disturbed secondary forest, highlighting its potential for multiple applications. The results provide detailed information on the variation pattern in the physical and anatomical properties of *L. trichilioides* wood along the axial from 10% (base) to 90% (top) and across the radial positions from the outer wood to the inner wood. The physical properties - moisture content, density, and volumetric swelling coefficient decreased axially from 10% to 90% and radially from outer wood to inner wood. This implies that quality wood can be obtained within 10% to 70% of the merchantable height, and *L. trichilioides* is a medium-density wood suitable for light construction. The results of physical properties revealed significant variations at $p < 0.05$ along the axial position.

The variation pattern of anatomical properties showed that fiber length and diameter, lumen width, and cell wall thickness decreased along the axial (10% to 90%) and radial (outer wood to inner wood) positions and were significantly different along the axial position. These results highlight the adaptability of *L. trichilioides* wood for interior design applications and indicate that it can be a sustainable option. The anatomical properties of *L. trichilioides* wood are within the normal range for tropical hardwood timber, with short fibers, small diameter and lumen width, and thin cell walls.

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