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Fibre-Vessel Structure, Density and Moisture content Analysis of *Zanthoxylum gilletii* Wood with Comparative Evaluation Against *Enthandrophragma cylindricum* for Furniture Use

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ABSTRACT

The density of wood is among several factors that influence the strength and durability of wood. However, scanty research is carried out on the effect of anatomical characteristics of wood. Fibre and vessels were sampled from three Ghanaian timbers, *Zanthoxylum gilletii* (Okuo) and *Enthandrophragma cylindricum* (Sapele) each. The study performed is to assess some key measurements; fibre length (FL), vessel diameter (VD), fibre diameter (FD), fibre lumen width (FLW), and fibre wall thickness (FWT) and density of wood of the selected tree. Results indicated highly significant ($p<0.05$) (Table 2) Specific variations revealed that *Z. gilletii* has the greatest fibre-vessel content and high density than *E. cylindricum* but was less moisture content to *E. cylindricum*. In terms of density, *Z. gilletii* ranged from 716 to 842 kg/m^3, exceeding *E. cylindricum* range of 640 to 758 kg/m^3 (Fig. 1). Fibre diameter for *E. cylindricum* ranged from 19.35 to 24.12 µm, whereas *Z. gilletii* showed slightly narrower fibres between 18.99 and 19.58 µm (Table 1). Overall, the denser, vessel-rich anatomy of *Z. gilletii* indicated a its high strength to buttress its potentials as a durable and efficient substitute for *E. cylindricum* and some well-known timber species (WKS) in furniture and structural applications. The higher

density of *Z. gilletii*, combined with its lower moisture content, suggests enhanced resistance to fungal and insect damage and mechanical strength.

Keywords: *Zanthoxylum gilletii*, parenchyma, vessel, fibre, variability, anatomy.

INTRODUCTION

The global rise in population has driven increasing demand for wood as a raw material, particularly in the furniture industry [1,2,3]. Sustainable utilization of wood depends on a comprehensive understanding of its physical, mechanical, and anatomical properties, including moisture content and density [4,5,6,7,3].

Previous studies have explored species-specific differences in vessel characteristics in relation to climate and highlighted the growing importance of wood density in understanding tree growth strategies in tropical forests [8,9]. However, limited research exists on how environmental, morphological, and species-specific factors collectively influence anatomical traits in tropical trees. This study seeks to bridge this gap by examining within-tree anatomical variation across different tree heights and radial positions, in relation to growth conditions and climatic influences.

The structural and functional differences among wood species are largely determined by the arrangement and proportion of vessels, fibres, and parenchyma cells [4,5,10]. A deep understanding of wood anatomy and variability is crucial in evaluating its suitability for industrial applications [2,11, 12]. In Ghana, furniture production traditionally relies on well-known species such as E. cylindricum (Sapele) due to their established strength and durability, while lesser-used species (LUS) like Z. gilletii remain underutilized [14, 15, 16]. Promoting the use of LUS such as Z. gilletii requires in-depth knowledge of their anatomical and structural attributes, which influence aesthetic value and mechanical performance [16].

Wood strength is governed by a hierarchy of structures of macroscopic cellular, microscopic cell walls and molecular polymer composition [11,16, 26] While softwoods rely on tracheids for both support and conduction, hardwoods possess distinct fibres and vessels for these functions, with structural implications based on their size and distribution [28, 29, 11]. Additionally, the variation in polysaccharide and lignin content across species affects strength performance [29]. According to [11] *Acacia auriculiformis* is predominantly utilised timber in Benin but there is scanty information about its features. Despite the potential of *Z. gilletii*, there is a lack of data on its anatomical characteristics and strength performance. This study therefore explores the relationship between density, anatomical features, and structural capacity of *Z. gilletii*, with the goal of positioning it as a viable alternative to traditional timbers in furniture and structural applications.

MATERIALS AND METHODS

Determination of Moisture Content and Density

A total of 540 wood samples (each 20 mm^3) was collected for moisture content (MC) and density comprised 270 from *Z. gilletii* and *E. cylindricum* each. These were taken from the bottom, middle, and top sections of each tree. Each tree provided 45 samples radially (including heartwood and sapwood) and axially. To prevent rapid moisture loss, all samples were immediately sealed in polythene sheets. For MC, initial sample weights were recorded using an electronic balance. Samples (20 x 20 x 20 mm) were then oven-dried at 103 ± 2 °C until reaching 12–15% MC, in accordance with [19] Weights were taken every six hours until constant mass was achieved. To determine density, samples were first soaked in water for 24 hours to achieve full saturation. Using the water displacement (immersion) method specified in [32], the swollen volume was calculated. A digital balance (precision: 0.01 g) was used to measure the mass of a water-filled beaker (zeroed before immersion). The increase in weight upon submerging each sample represented the volume of water displaced, equating to the sample's swollen volume (in cm^3, assuming water density = 1 g/cm^3). Following volume measurement, the samples were oven-dried at 103–105 °C to constant mass. Density was then calculated in kg/m^3 as the ratio of oven-dry mass to saturated volume, as outlined [32] This method yields accurate wood density values essential for evaluating mechanical properties, strength classification, and end use potential.

Determination of Vessel-Fibre of *Z. gilletii* and *E. cylindricum*

Wood samples were cut into 10 mm thick microtome slices and placed in heat-resistant test tubes containing a 1:1 mixture of acetic acid and hydrogen peroxide [18, 17]. The tubes were heated at 60 °C to induce maceration and monitored every 24 hours until samples turned completely white, indicating complete maceration [30,17]. Post-maceration, samples were thoroughly rinsed with distilled water and stored in a preservation solution of distilled water, alcohol, and glycerol [18]. A portion of each macerated sample was teased apart to isolate individual elements and mounted on microscope slides. Observations were made using a Fisher Scientific Optic light microscope (19× eyepiece), with digital micrographs taken for analysis [30]. Vessel diameter, fibre diameter, lumen width, and double-wall thickness were measured using ImageJ software for precision.

Image Analysis and Measurement Protocol

Double-wall thickness was determined using the Line tool across radially adjacent fibre cell walls, repeated at least 50 times per sample. Vessel and fibre diameters and lumen widths were measured with straight-line tools on micrographs, following methods consistent with prior anatomical studies in Ghana [17]. Tissue proportions vessels, fibres, and parenchyma were assessed using a 30-point grid overlay on transverse-section images, with intersection counts converted into percentages.

STATISTICAL ANALYSIS

Each anatomical trait was quantified using 30 individual measurements or counts per specimen, including vessel percent, fibre percent, parenchyma percent, vessel diameter, fibre length, fibre width, lumen diameter, and double-wall thickness. Heartwood variation across stem positions was expressed as a percentage. Differences among stem sections were Analysis of variance (ANOVA) and Post-hoc analysis was used to determine their significance.

RESULTS

Moisture Content

Wood moisture content and density represent a critical indicator of strength and stability of wood for both *Z. gilletii* and *E. cylindricum* [18]. The results of moisture content among individual trees, all E. cylindricum recorded the highest than the Z. cylindricum trees counterpart (Fig. 1 & 2). There were significant differences ($p < 0.05$) in moisture content within and between radial and axial directions for both species (Table 1% 2). These variations are attributed to anatomical factors (e.g., cell size, wall thickness, earlywood-to-latewood ratio) as well as environmental and biological influences (e.g., site conditions, climate, and tree age). The higher density of *Z. gilletii* suggests superior mechanical strength and durability, making it more suitable for structural applications compared to E. cylindricum [18]

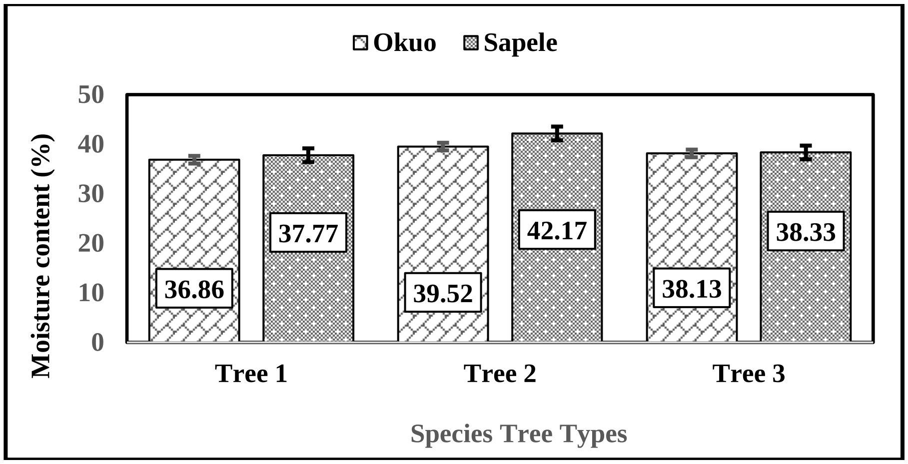

Figure 1: Mean moisture content between and among tree types (Bar – Standard)

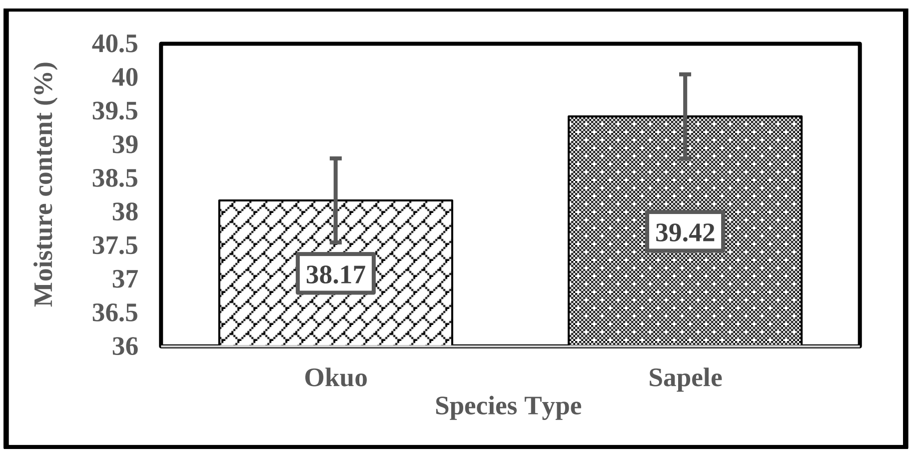

Figure 2: Overall mean moisture content between trees.

Table 1: ANOVA for moisture content and density of *Z. gilletii* and *E. cylindricum.*

Source	df	MC			Density		
		F – value	P – value	Var. (%)	F - value	P - value	Var. (%)
Specie Type (ST)	1	18.563	0.000	3.6	154.687	0.000	23.5
Tree Type (TT)	2	52.616	0.000	17.3	0.262	0.770	0.1
Axial Section (AS)	2	54.051	0.000	17.7	8.890	0.000	3.4
Radial Section (RS)	1	21.615	0.000	4.1	33.901	0.000	6.3
ST * TT	2	6.196	0.002	2.4	29.258	0.000	10.4
ST * AS	2	0.738	0.479	0.3	1.883	0.153	0.7
ST * RS	1	0.002	0.966	0	6.871	0.009	1.3

TT * AS	4	21.700	0.000	14.7	2.091	0.081	1.6
TT * RS	2	0.653	0.521	0.3	.242	0.785	0.1
AS * RS	2	0.139	0.870	0.1	1.268	0.282	0.5
ST * TT * AS	4	0.793	0.530	0.6	1.416	0.227	1.1
ST* TT * RS	2	0.457	0.633	0.2	.279	0.756	0.1
ST * AS * RS	2	0.282	0.754	0.1	1.420	0.243	0.6
TT * AS * RS	4	0.919	0.452	0.7	.155	0.961	0.1
ST * TT * AS * RS	4	0.142	0.967	0.1	.521	0.720	0.4

Table 2: Post-hoc analysis of moisture content and density for *Z. gilletii* and *E. cylindricum*

Tree Type	Tree Axial Section	*Z. gilletii*		*E. cylindricum*	
		MC	Density	MC	Density
Tree 1	Top	38.47 ± 2.98a	715.91±84.79a	39.46 ± 3.32a	672.00±82.64a
	Middle	37.39 ± 2.11b	729.40±71.55a	37.50 ± 1.65b	707.60±38.65a
	Bottom	34.73 ± 3.06c	774.98±95.21b	36.35 ± 1.98c	758.46±38.89b
Tree 2	Top	43.29 ± 4.51a	743.69±70.47a	45.50 ± 4.10a	691.36±44.15a
	Middle	40.22 ± 4.60b	786.72±83.02b	42.77 ± 4.58b	645.40±23.12a
	Bottom	35.05 ±3.12c	782.75±51.52b	38.25 ± 1.53c	671.68±49.61b
Tree 3	Top	38.96 ± 3.40a	804.96±75.25c	38.19 ± 3.65a	640.04±33.08a
	Middle	36.92 ± 3.60b	811.61±72.42c	38.10 ± 3.17b	595.52±25.94a
	Bottom	38.50 ± 3.77c	841.94±79.18c	38.71 ± 4.13c	667.99±38.44b

Density

The study demonstrated that the average wood density at 12% moisture content (MC) varied along the axial gradient (tree height) in both *Z. gilletii* and *E. cylindricum* (Fig. 3). In both the axial and radial directions *Z. gilletii* Tree 3 exhibited the highest density among its samples, whereas for *E. cylindricum*, Tree 1 recorded the highest density values (Fig. 3). Comparatively, *Z. gilletii* consistently displayed higher overall density values than *E. cylindricum* (Fig. 4). The descending order of mean density was Tree 3 > Tree 2 > Tree 1 for *Z. gilletii*, and Tree 1 > Tree 2 > Tree 3 for *E. cylindricum* (Fig. 3).

Statistical analysis (Tables 1 & 2) revealed a significant difference ($p < 0.05$) in wood density both between and within the axial and radial orientations for both species. As defined by [24], wood density refers to the mass of wood substance per unit volume at a specified MC and is strongly associated with some key physical and mechanical properties. In the present study, *Z. gilletii* exhibited density values ranging from 712.1 to 819.5 kg/m^3, placing it within the medium-heavy to heavy density category as per the classifications [35, 33]. These findings align with existing literature indicating that higher wood density typically correlates with greater strength [24, 5, 18]. The observed intra-stem density variation in *Z. gilletii* supports earlier reports of inconsistent density patterns along tree stem. The relatively high density of *Z. gilletii* implies a strong suitability for load-bearing and structural applications, particularly where resistance to bending stress is critical [34, 11]. The variations in density across and within the species may stem from anatomical differences, such as variations in cell wall thickness, cell size, vessel element diameter, the earlywood-to-latewood ratio, and the number of ray cells [36]. The structure and proportion of vessels, cell wall density of wood and the reaction could afford dimensional stability during drying process. Additionally, factors such as chemical deposits, juvenile wood content, environmental and site conditions, climate, geographical location, tree age and silvicultural practices are known to significantly influence wood density [23].

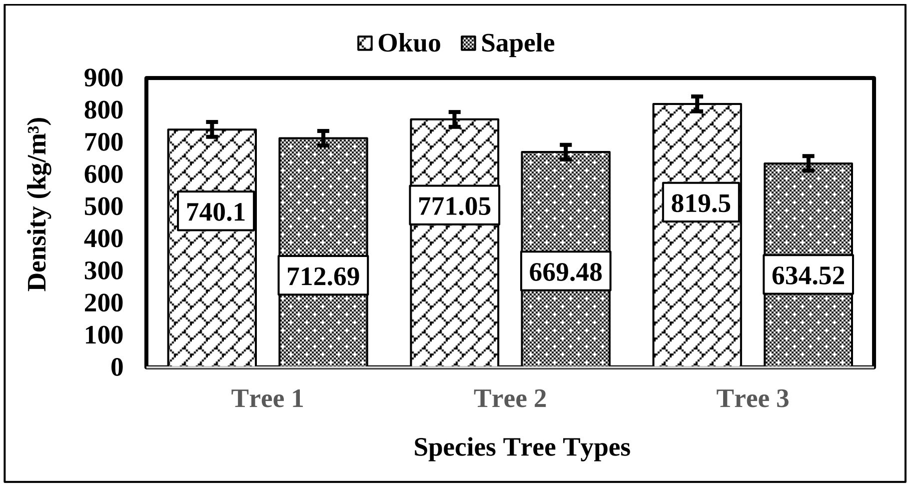

Figure 3: Axial and radial mean density within and among tree types

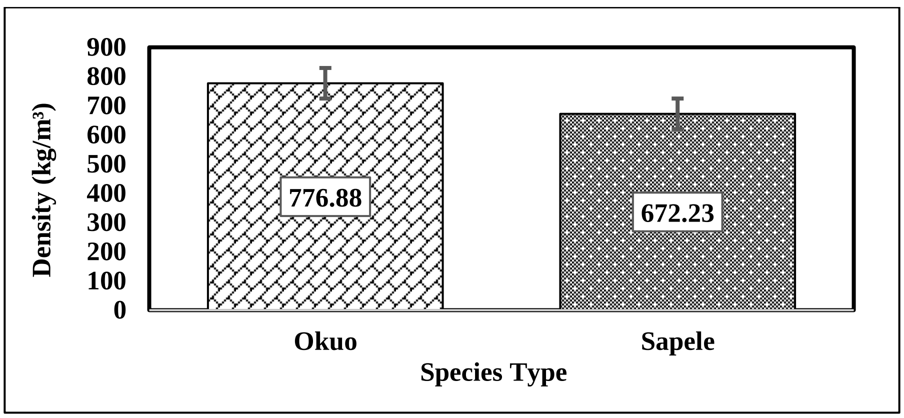

Figure 4: Overall mean density between trees

Fibre–Vessel Morphology

The morphological analysis focused on heartwood fibre and vessel characteristics along the axial stem direction (see Figures 4.17 – 4.20). Results revealed clear interspecific and positional differences:

- Fibre Length (FL):
  Z. gilletii had significantly longer fibres (mean up to 1,479 μm) than *E. cylindricum* (1,140.3 μm) ($p < 0.05$).
- Fibre Diameter (FD):
  E. cylindricum showed significantly broader fibres (mean 21.84 μm) compared to *Z. gilletii* (18.79 μm) ($p < 0.05$).
- Fibre Lumen Width (FLW):
  Mean FLW was 13.03 μm in *E. cylindricum* and 11.16 μm in *Z. gilletii*, again showing statistically very high significant differences ($p < 0.05$).

- Double-Wall Thickness (DWT):
  E. cylindricum fibres had thicker walls (8.22 µm) than those of *Z. gilletii* (7.57 µm) ($p < 0.05$).

Anatomically, *Z. gilletii* is defined by longer fibres with narrower diameters and thinner walls, while *E. cylindricum* has shorter, thicker-walled, and wider fibres and lumens. These traits influence mechanical behavior: longer fibres in *Z. gilletii* may enhance tensile strength and flexibility, while thicker walls in *E. cylindricum* may improve stiffness and compressive resistance. Additionally, *Z. gilletii* had larger vessel diameters, particularly in upper stem regions, which may affect both hydraulic conductivity and mechanical performance.

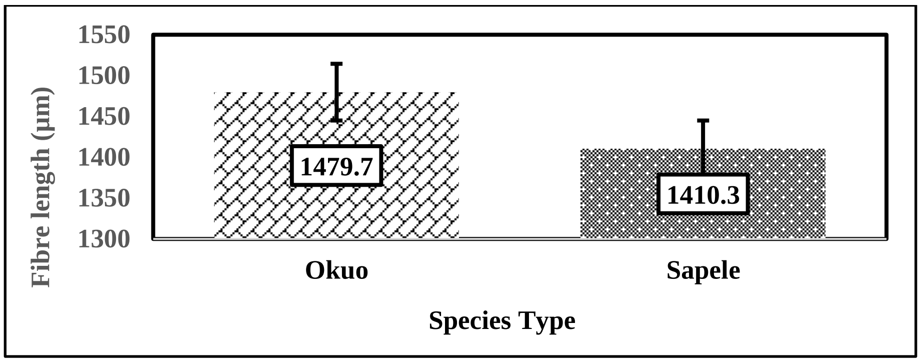

Figure 5: Total mean Fibre length of the species

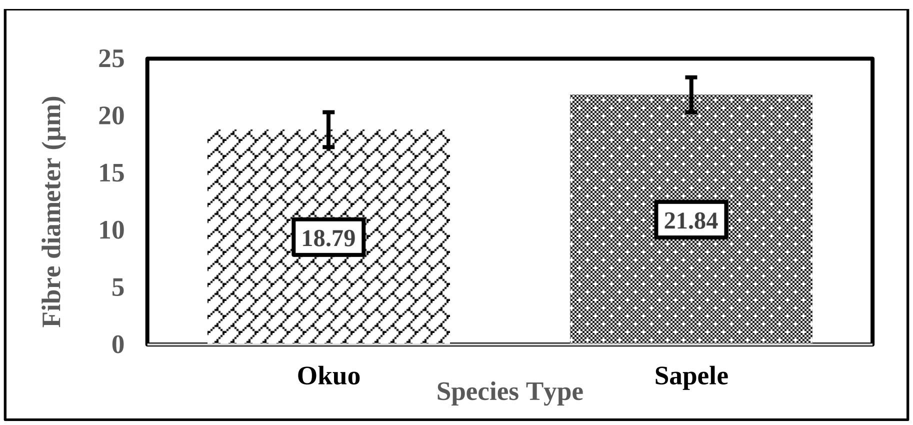

Fig. 6: Total mean fibre diameter of *Z. gilletii* and *E. cylindricum* trees

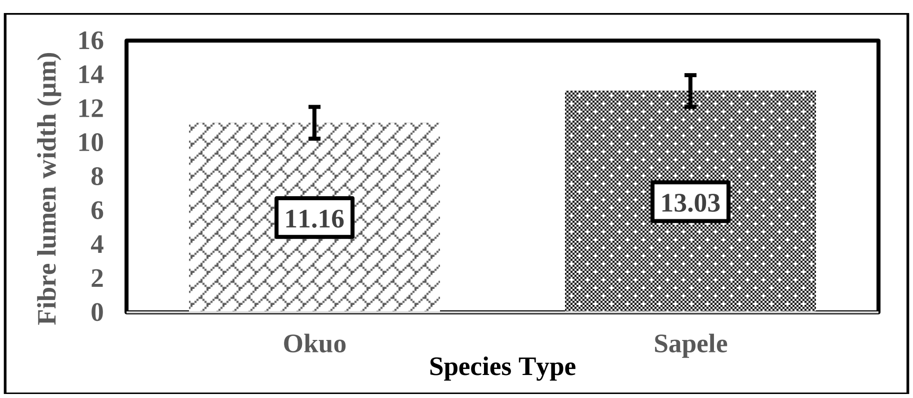

Figure 7: Total mean of Fibre-lumen-width of the species

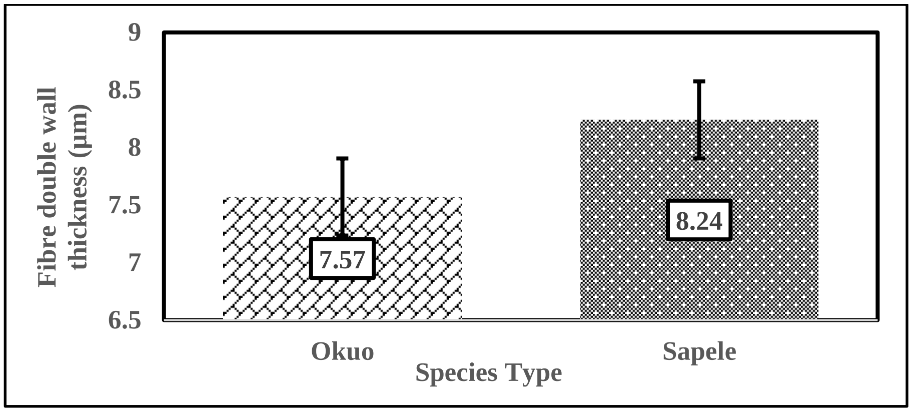

Figure 8: Total mean of Fibre-double-wall-thickness of the species.

Table 3: Mean heartwood anatomy values of *Z. gilletii* and *E. Cylindricum*

	Okuo	Sapele	Okuo	Sapele	Okuo	Sapele	Okuo	Sapele	Okuo	Sapele
Axial	**FL**	**FL**	**FD**	**FD**	**FLW**	**FLW**	**DWT**	**DWT**	**Vessel D**	**Vessel D**
Top	1657.20 ±57.41a	1541.30±61.22a	19.58±1.11a	24.12±2.51a	11.64±0.83a	14.37±2.07a	7.87±0.45a	8.75±1.20ab	162.35±4.80a	160.89±3.06a
Middle	1443.90 ±87.71b	1376.90±99.67b	18.99±2.14b	22.04±2.77b	11.47±2.22a	13.17±2.53a	7.35±0.75bc	8.47±1.47ab	152.17±3.36b	147.88±3.55b
Bottom	1338±64.02c	1312.80±66.63c	17.80±1.91c	19.35±2.44c	10.37±1.92b	11.55±1.74b	7.50±0.88bc	7.49±1.74c	150.76±3.69c	137.79±3.41c

Table 4: ANOVA

		Fibre Length			**Fibre Diameter**			**Fibre-Lumen-Width**			**Double Wall Thickness**			**Vessel Diameter**		
Source	**df**	**F-value**	**P-value**	**Var. (%)**	**F-value**	**P-value**	**Var. (%)**	**F-value**	**P-value**	**Var. (%)**	**F-value**	**P-value**	**Var. (%)**	**F-value**	**P-value**	**Var. (%)**
Specie Type (ST)	1	39.185	0.000	18.4	85.440	0.000	32.9	33.572	0.000	16.2	13.338	0.000	7.1	128.691	0.000	42.5
Axial Section (AS)	2	212.988	0.000	71.0	33.331	0.000	27.7	13.832	0.000	13.7	6.712	0.002	7.2	344.431	0.000	79.8
ST × AS	2	5.586	0.004	6	6.887	0.001	7.3	1.990	0.140	2.2	3.521	0.032	3.9	39.702	0.000	31.3

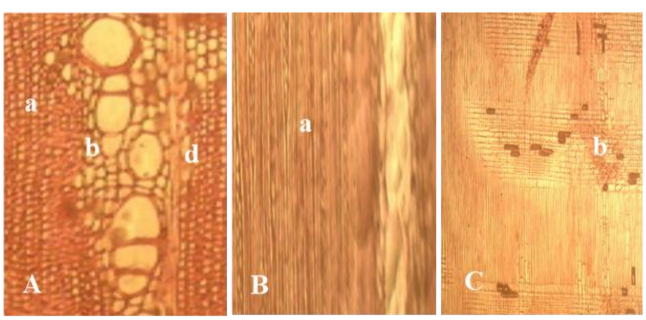

Plate 1: Heartwood anatomy sections of *Z. gilletii*
Note: Transverse section (A); Tangential (B), and Radial (C)
(Scale bar 100 µm).

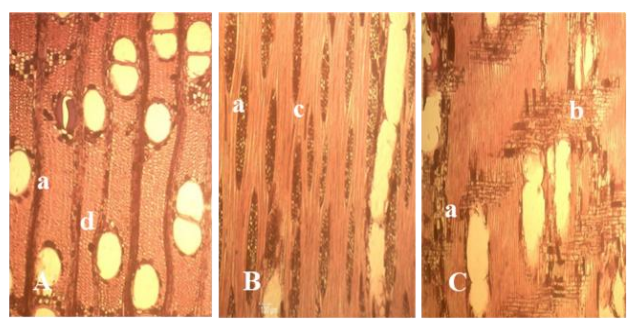

Plate 2: Heartwood anatomy sections of *E. cylindricum*

Key on arrows: a = Vessel; b = Fibre; c = Rays; d = Parenchyma surrounding the vessels;

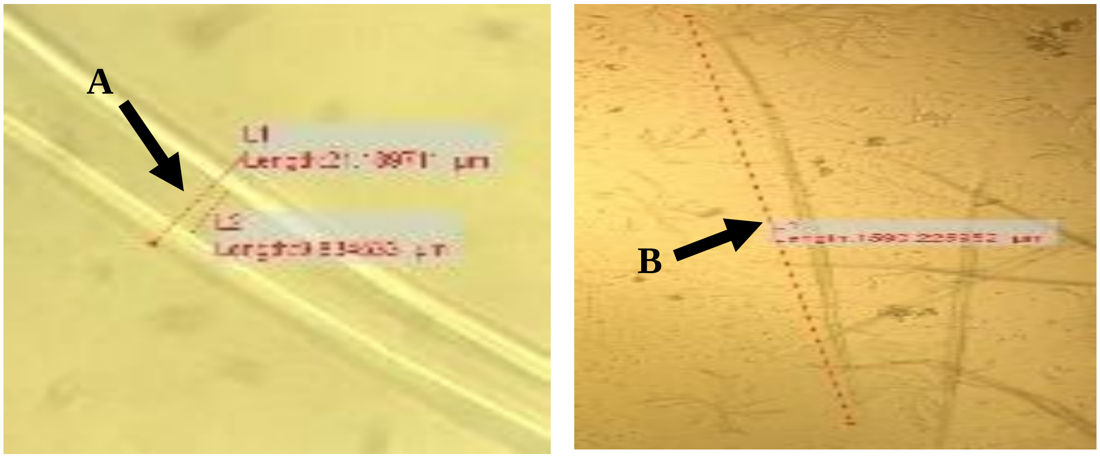

Fig 11: Measurement of Fibre-diameter (A) and fibre length (B)

Discussion

The anatomical distinctions between *Z. gilletii* and *E. cylindricum* is notably in fibre length, moisture content, density, and cell wall-thickness characteristics indicate functional differences in mechanical behavior. The higher density and longer fibres of *Z. gilletii* suggest an enhanced strength and durability, supporting its suitability for more demanding furniture and structural uses. These findings align with previous hardwood anatomical studies and underscore the importance of species selection for specific wood applications. Therefore, future research is worth could be conducted on *Z. gilletii* and other lesser-known species in order to advance their potential utilization in the furniture and construction industry. The implication of this study provided adequate data about the moisture, density and anatomical characteristics of *Z. gilletii* for promotion and utilization to avert the high demand for the near-extinct Well-Known timber species.

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