Evaluation of Mechanical and Physical Properties of Zanthoxylum gilletii Wood and Comparative Strength Analysis with Enthandrophragma cylindricum for Furniture Applications

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Abstract

In furniture manufacturing, the mechanical and physical properties of timber play a vital role in determining its strength and suitability for use. This study evaluated these properties in three trees each of *Zanthoxylum gilletii* (Okuo) and *Entandrophragma cylindricum* (Sapele). Samples, free from defects and exhibiting straight grain, were harvested from three stem sections (top, middle, and bottom) at breast height (DBH) of each tree. The moisture content (MC) of heartwood and sapwood for *Z. gilletii* ranged between 34.73 ± 3% and 43.29 ± 4%, while *E. cylindricum* ranged from 38.10 ± 3% to 45.50 ± 4%. Density values for *Z. gilletii* varied from 715.91 ± 8 to 841.94 ± 79.1 kg/m³, compared to 640.04 ± 33.1 to 758.46 ± 38.9 kg/m³ for *E. cylindricum*. At 12% moisture content, the mean modulus of rupture (MOR) and modulus of elasticity (MOE) for *Z. gilletii* ranged from 86.08 ± 4.52 to 132.25 ± 4 N/mm² and 8,474.10 ± 754.3 to 9,263.80 ± 494.1 N/mm², respectively. Corresponding values for *E. cylindricum* ranged from 84.15 ± 2 to 109.50 ± 3 N/mm² (MOR) and 8,292.90 ± 492.9 to 9,616.70 ± 705.9 N/mm² (MOE). These results suggest that *Z. gilletii* demonstrates mechanical properties comparable to or exceeding those of *E. cylindricum*, indicating its potential as a viable alternative for furniture, construction, and structural applications

Introduction

Wood remains a preferred material for furniture and structural applications over plastic and metal due to its versatility and performance (Sudo et al. 2013; Antwi-Boasiako et al. 2017; Abdolzadeh et al. 2015). The structural integrity of wooden furniture largely depends on the mechanical properties of the timber used (Sudo et al. 2013). As noted by dos Santos et al. (2015), the strength properties of wood are critical in determining the failure or durability of furniture and structural components. In countries like Costa Rica and Nicaragua, lesser-known timber species are widely used for furniture and even exported, owing to the availability of well-documented data on their properties (Vlosky, Aguirre 2001; Haviarova et al. 2013). Similarly, dense and durable timbers such as *Nesogordonia papaverifera* and *Diospyros mespiliformis* are recommended for demanding engineering structures like bridges and buildings (Fonti et al. 2010; Scholz et al. 2013). In Malaysia, *Hevea brasiliensis* (rubberwood) is a dominant species in the furniture industry (Puasa et al. 2010).

In Ghana, however, furniture and structural applications rely heavily on a limited number of well-known and are overexploited timber species (WKS) such as *E. cylindricum*, *Milicia excelsa*, *Khaya ivorensis*, *Terminalia ivorensis*, *Aningeria altissima*, and *Nesogordonia papaverifera* (Boadu 2016; Appiah-Kubi et al. 2012; Ohemeng, 2022). This overdependence strains the industry, limiting diversification and contributing to resource depletion, unemployment, and instability within the sector (Haman et al. 2020; Ohemeng et al. 2023). Efforts are ongoing to encourage the use of lesser-used species (LUS) to reduce pressure on WKS and ensure sustainable timber supply for the global furniture market (Ohemeng et al. 2023). However, in Ghana and Malaysia, limited data on the physical and mechanical properties of many lesser-utilised-timber species (LUS) including *Z. gilletii*, hampers their adoption (Hanan et al. 2020). As emphasized by Ratnasingam et al. (2010); Haviarova et al. (2013) and Bessa et al. (2022) having reliable technical information on LUS is essential for their acceptance and utilization is paramount to forest sustainability and survival of wood industry. Given the lack of comprehensive data on *Z. gilletii*, this study aims to evaluate some physical and mechanical properties and compare them with those of *E. cylindricum*, a widely used reference species in Ghana's timber industry

MATERIALS AND METHODS

Material Harvesting and Conversion

Three (3) trees each of *Z. gilletii* and *E. cylindricum* were harvested from the Bobiri Forest Reserve and Butterfly Sanctuary, located in the Juaben Municipal and Sekyere-East Districts of the Ashanti Region, Ghana. This area, covering 54.64 km², falls within the Moist Semi-Deciduous South-East ecological zone, between latitudes 06°40'N to 06°44'N and longitudes 01°15'W to 01°22'W. Selected trees had a diameter at breast height (DBH) between 80–120 cm and heights ranging from 20–45 m.

Each tree was felled using a chainsaw and crosscut into three sections; top, middle, and bottom each measuring 2500 mm in length and labeled for easy identification. These sections were further sawn into beams of 2500 × 300 × 200 mm for ease of transport. The beams were taken to the Forestry Commission Training Center (FCTC) at Akyaakrom, Kumasi and milled into 2500 × 300 × 50 mm lumber using a 14 HP petrol/5.4 kW electric LT5START Wood-Mizer. Finally, the lumber was transported to the Council for Scientific and Industrial Research–Forestry Research Institute of Ghana (CSIR-FORIG), Fumesua, where they were processed into the required sample sizes for testing.

Physical Properties

Determination of moisture content

A total of 540 samples (20 mm^3) comprising each 270 samples from bottom, middle, and top sections from each *Z. gilletii* and *E. cylindricum* trees respectively, were used for moisture content (MC) and density. Samples were prepared consisting of 45 samples both radially (heartwood and sapwood) and axially of each of the three trees. To prevent rapid moisture loss, the samples were immediately sealed in polythene sheets. MC samples were first weighed using an electronic balance to determine their initial MC. Subsequently, the samples were oven-dried at a temperature of 103 ± 2°C until they reached a moisture content of 12–15%, following the EN 13183–1: 2002 standard. The samples were weighed at six-hour intervals until a constant weight was achieved.

To determine the density, samples were soaked in water for 24 hours to ensure full saturation after initial wet weight. Density was then measured based on the oven-dry mass and swollen volume using the water displacement (immersion) method, as outlined in BS 373:1957. A digital balance with a precision of 0.01 g was used to ascertain the weight of beaker filled with water, which was then zeroed. Each sample was submerged in the water, and the new mass of the beaker, water, and sample was recorded.

The increase in weight due to the submerged sample equated to the volume of water displaced, which corresponds numerically (cm^3) to the swollen volume of the sample, assuming the density of water is 1 g/cm^3. Following volume measurement, the samples were oven-dried at a temperature of 103–105°C until a constant mass was achieved, representing the oven-dry weight. The density of each sample was then recorded in kg/m^3 based on the ratio of oven-dry mass to saturated volume. This method provides accurate wood density values, which are critical for understanding mechanical behavior, strength classification, and potential end-use applications (BS 373:1975

Determination of Mechanical Properties

The static bending strength of MOR and MOE samples (20 × 20 × 300 mm), Compression parallel to grain (20 x 20 x 60 mm) and Shear parallel to grain

(50 x 50 x 50 mm) was used for the tests. A total of 720 clear, straight and defect free samples of *Z. gilletii* and *E. cylindricum* (360 each), comprised of 120 heartwood and sapwood samples each from the bottom, middle and top sections of the three trees of *Z. gilletii* and *E. cylindricum* respectively (Shanavas and Kumar 2006; Haman et al. 2020).The test was performed using a three-point bending method, where each specimen was loaded at the center while supported at both ends. An Instron Universal Testing Machine (Inspekt 50 – 1) [UTM] was used on test samples in accordance with BS 373:1957. The

maximum load (N/mm^2) operating load cell capacity of the UTM was 30 kN at a speed rate of 10 min/mm (Ohemeng et al. 2023). The maximum load that caused the sample to fail or fracture on each sample was recorded (Haman et al. 2020).

RESULTS AND DISCUSSIONS

Moisture Content

Across both axial and radial directions, Tree 2 of *Z. gilletii* and *E. cylindricum* recorded the highest mean moisture content values compared to Trees 1 and 3 (Fig. 1). The mean MC values for *Z. gilletii* ranged from 36.86–39.52%, while *E. cylindricum* ranged from 37.77–42.17% (Fig. 1). Notably, all portions of *E. cylindricum* consistently exhibited higher mean MC values than those of *Z. gilletii*. In terms of trend, both species followed the same order: Tree 2 > Tree 3 > Tree 1 (Fig. 1). The overall mean MC across all portions was 38.17% for *Z. gilletii* and 39.42% for *E. cylindricum*, with the later showing slightly higher values (Fig. 2). These findings align with a study conducted by Appiah-Kubi et al. (2012), they reported that MC values for some lesser-used species (LUS) in Ghana ranged from 16.1% in *Antiaris toxicaria* to 51.0% in *Albizia ferruginea*. ANOVA analysis revealed a significant difference ($p < 0.05$) between axial and radial directions for both species (Table 1). The relatively high MC observed in *Z. gilletii* suggests its potential to develop desirable strength properties for furniture and structural applications. There is high significance between the trees (Tables 1 & 2). Furthermore, the MC levels recorded for *Z. gilletii* are comparable to those of some well-known commercial timber species (WKS), supporting its potential for wider utilization. (Fig. 2). This study thus provides valuable baseline data on the moisture content characteristics of *Z. gilletii*, aiding in its future promotion and application in the timber industry from the post hoc analysis (Table 2).

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 revealed that the average density at 12% moisture content (MC) varied along the tree height for both *Z. gilletii* and *cylindricum* (Fig. 3). In both axial and radial directions, Tree 3 of *Z. gilletii* exhibited the highest density compared to Trees 1 and 2, whereas for *E. cylindricum*, Tree 1 had the highest density relative to its other trees (Fig. 3). Overall, *Z. gilletii* demonstrated higher density values than *E. cylindricum* (Fig. 4). The descending order of mean density for *Z. gilletii* was Tree 3 > Tree 2 > Tree 1, while for *E. cylindricum*, it was Tree 1 > Tree 2 > Tree 3 (Fig. 3). Statistical analysis indicated a significant difference ($p < 0.05$) in density between and within the axial and radial directions for both species (Tables 1 & 2). Density, defined as the mass of wood substance per unit volume at a given moisture content (Ohemeng et al., 2023), is strongly correlated with wood physical and mechanical properties (Frodeson et al. 2019). In this study, *Z. gilletii* exhibited densities ranging from 712.1 to 819.5 kg/m³, indicating a medium-heavy to heavy density classification according to ATIBT (1990) and TEDB (1994) standards. This aligns with findings that, higher density generally corresponds to greater wood strength (Lemmens et al. 2012; Appiah-Kubi et al., 2012). The variation in density within *Z. gilletii* along the tree height concurs with previous research highlighting inconsistent density variation along tree stems (King et al. 2006). The relatively high density of *Z. gilletii* suggests it is well-suited for applications requiring resistance to bending stress, such as construction, compared to lower density woods (Hamdan et al. 2020). The observed variations in wood density within these species could be attributed to anatomical factors including cell size, wall thickness, earlywood-to-latewood ratio, ray cell number, and vessel element size (Antwi-Boasiako 2010). Additionally, chemical deposits within and between cells, juvenile wood presence, environmental conditions, site factors, climate, geographic location, age, and silvicultural practices may also influence density variation (Ofori et al. 2009; Frodeson et al. 2019; Ohemeng et al., 2023).

Modulus of Rupture (MOR) of Z. gilletii and E. cylindricum

The mean MOR values for *Z. gilletii* ranged from 105.97 to 117.54 N/mm², while *E. cylindricum* recorded lower mean values between 98.59 and 105.13 N/mm². Among the trees studied, Tree 3 of *Z. gilletii* exhibited the highest MOR in both axial and radial directions compared to Trees 1 and 2 (Table 5). Conversely, Tree 2 of *E. cylindricum* showed the highest MOR relative to its counterparts (Fig. 5). The descending order of mean MOR for *Z. gilletii* was Tree 3 > Tree 2 > Tree 1, while for *E. cylindricum*, it was Tree 2 > Tree 1 > Tree 3 (Fig. 5). The overall average MOR for the three *Z. gilletii* trees was 112.81 N/mm², surpassing the *E. cylindricum* average of 101.03 N/mm² (Fig. 6).

Comparatively, Appiah-Kubi et al. (2019) reported significantly lower MOR values for other lesser-known species (LKS), such as *Albizia ferruginea* (29.2 N/mm²) and *Canarium schweinfurthii* (25.2 N/mm²). While some LKS like *Sterculia rhinopetala* (63.2 N/mm²) showed moderate bending strength suitable for medium to heavy structures, *Z. gilletii* demonstrated exceptionally high bending strength, making it a strong substitute for heavy structural applications including timber buildings, bridges, decking, floors, docks, and roofing (Appiah-Kubi et al. 2019) (Table 3). ANOVA results indicated a very high significant difference ($p < 0.05$) in MOR and MOE between axial and radial directions for both species (Tables 3 & 4). MOR is recognized as a key indicator of wood strength and its use (Nocetti et al. 2013). A noted decline in mean MOR from the bottom to the top sections of *Z. gilletii* trees in this study may be attributed to the presence of juvenile wood along the stem height (Ohemeng et al. 2022; Piipanen et al. 2020). Additionally, wood from bottom sections of trees tends to have higher density matured wood, which positively influences its strength characteristics (Poorter et al. 2010). Based on the MOR results, *Z. gilletii* is suitable for furniture and structural use where high strength is required (Chen et al. 2020; Mi et al. 2020).

Table 3
ANOVA of MOR and MOE for *Z. gilletii* and *E. cylindricum* trees

Source	df	MOE			MOR		
		F – value	P - value	Var. (%)	F – value	P – value	Var. (%)
Specie Type (ST)	1	1106	0.000	.618	519.922	.000	.432
Tree Type (TT)	2	37.328	0.000	.098	72.427	.000	.175
Axial Section (AS)	2	398.542	0.000	.538	704.028	.000	.673
Radial Section (RS)	1	996.740	0.000	.593	1.019E3	.000	.598
ST * TT	2	.581	0.559	.002	51.224	.000	.130
ST * AS	2	95.245	0.000	.218	51.892	.000	.132
ST * RS	1	185.711	0.000	.214	64.180	.000	.086
TT * AS	4	60.730	0.000	.262	47.177	.000	.216
TT * RS	2	6.062	0.002	.017	107.892	.000	.240
AS * RS	2	1.003	0.367	.003	83.347	.000	.196
ST * TT * AS	4	26.823	0.000	.136	12.714	.000	.069
ST* TT * RS	2	.458	0.633	.001	42.562	.000	.111
ST * AS * RS	2	.951	0.387	.003	7.788	.000	.022
TT * AS * RS	4	22.447	0.000	.116	22.578	.000	.117
ST * TT * AS * RS	4	34.574	0.000	.168	11.400	.000	.063

Table 4
Post-hoc analysis of MOE and MOR for *Z. gilletii* and *E. cylindricum*

Tree types	Tree axial sections	*Z. gilletii*		*E. cylindricum*	
		MOE	MOR	MOE	MOR
Tree 1	Top	8474.10 ± 754.27a	86.08 ± 4.52a	8292.90 ± 492.89a	84.15 ± 2.58a
	Middle	12400 ± 1892.98b	111.17 ± 2.76b	9616.70 ± 705.95c	99.86 ± 5.66b
	Bottom	11106 ± 745.02c	120.67 ± 6.53c	9593 ± 921.86c	114.06 ± 4.30c
Tree 2	Top	9707 ± 538.70a	104.40 ± 7.79d	8362.20 ± 598.03a	100.83 ± 3.98d
	Middle	10774 ± 891.04b	116.33 ± 3.31e	9494.30 ± 774.15c	109.34 ± 3.36e
	Bottom	11411 ± 614.30c	123.99 ± 2.69f	9419.30 ± 712.58c	105.21 ± 4.09f
Tree 3	Top	9263.80 ± 494.06a	98.49 ± 3.27g	8809.80 ± 558.97a	90.89 ± 2.54g
	Middle	10834 ± 534.98b	121.88 ± 3.89h	8422.80 ± 690.73b	95.39 ± 3.51h
	Bottom	10713 ± 469.92c	132.25 ± 3.99z	8736.10 ± 572.65c	109.50 ± 3.36z

Modulus of Elasticity (MOE)

The Modulus of Elasticity (MOE) for *Z. gilletii* and *E. cylindricum* followed the order, Tree 1 > Tree 2 > Tree 3 for both species (Fig. 5 & Table 6). The average MOE for the three *Z. gilletii* trees was 10,520.32 N/mm², while *E. cylindricum* showed a lower average of 8,971.9 N/mm² (Fig. 5 & Table 6). *Z. gilletii* exhibited higher MOE values in both axial and radial directions compared to *E. cylindricum* (Fig. 5), indicating that *Z. gilletii* strength is comparable to some well-known commercial wood species (WKS), making it a potential alternative for furniture manufacturing. ANOVA analysis confirmed a significant difference ($p < 0.05$) between the MOE of *Z. gilletii* and *E. cylindricum* (Tables 3 & 4). The MOE values for *Z. gilletii* decreased from the top to the bottom of the tree but remained stiffer in the middle and lower sections (Nocetti et al., 2013). When compared to other local utility species (LUS) studied by Appiah-Kubi et al. (2012), such as *Albizia ferruginea* [12,619 N/mm²], Blighia sapida [13,274 N/mm²], *Sterculia rhinopetala* [15,552 N/mm²], and *Canarium schweinfurthii* [9,209 N/mm²]. *Z. gilletii* MOE (10,270.27–10,660 N/mm²) is moderately high, while *E. cylindricum* (8,656.23–9,167.53 N/mm²) is closest to *Canarium schweinfurthii* value (Fig. 7). This suggests *Z. gilletii* is suitable for heavy structural applications. Variations in MOE are likely influenced by genetic factors, density, fiber length, and environmental conditions like temperature and humidity (Ayarkwa, 2009).

Compression parallel to grain

In terms of compressive strength parallel to the grain, Tree 2 of *Z. gilletii* exhibited the highest values

compared to its Tree 1 and Tree 3, while Tree 3 of *E. cylindricum* showed the highest strength relative to its other trees (Fig. 9). The order of compressive strength for *Z. gilletii* was Tree 2 > Tree 1 > Tree 3, whereas for *E. cylindricum* it was Tree 3 > Tree 1 > Tree 2 (Table 9). The mean compressive strength across the three *Z. gilletii* trees was 85.54 N/mm², surpassing the mean of 79.62 N/mm² recorded for *E. cylindricum* (Fig. 10). These results indicate that *Z. gilletii* has a higher compressive strength compared to *E. cylindricum*. Its strength is comparable to some commonly used timber species in furniture production, suggesting its potential as a suitable alternative to enhance timber resources. A significant difference ($p < 0.05$) was found between axial and radial directions for both species (Tables 5 & 6). Mean values and post-hoc analysis for compressive strength of both species (Table 6). According Anoop et al. (2012) less endowered timber species requires a study for promotion and utilisation. Within individual trees of both species, compressive strength generally decreased from the bottom to the top sections. This variation may be linked to differences in wood chemical composition, maturity of wood cells, and ecological growing conditions

Table 5

ANOVA for compressive strength and shear parallel to the grain of *Z. gilletii* and *E. cylindricum*

Source	Df	Com//g			Shear//g		
		F -value	P – value	Var. (%)	F – value	P– value	Var. (%)
Specie Type (ST)	1	60.009	.000	081	217.744	.000	.241
Tree Type (TT)	2	3.401	.034	.010	21.858	.000	.060
Axial Section (AS)	2	3.554	.029	.010	45.906	.000	.118
Radial Section (RS)	1	199.296	.000	.226	353.965	.000	.341
ST * TT	2	6.710	.001	.019	2.625	.073	.008
ST * AS	2	3.051	.048	.009	17.215	.000	.048
ST * RS	1	.073	.787	.000	26.670	.000	.038
TT * AS	4	2.401	.049	.014	4.193	.002	.024
TT * RS	2	4.570	.011	.013	1.200	.302	.003
AS * RS	2	.231	.793	.001	.889	.412	.003
ST * TT * AS	4	2.802	.025	.016	1.147	.333	.007
ST* TT * RS	2	.876	.417	.003	1.557	.211	.005
ST * AS * RS	2	.936	.393	.003	3.941	.020	.011
TT * AS * RS	4	.702	.591	.004	.067	.99	.000
ST * TT * AS * RS	4	2.097	.080	.012	.221	.927	.001

Note: Com//g = Compression parallel to grain; Shear//g = Shear parallel to grain.

Table 6
Post-hoc analysis of compressive and shear strength of *Z. gilletii* and *E. cylindricum* species.

Tree Types	Tree Axial Sections	*Z. gilletii*		*E. cylindricum*	
		Com//g	Shear//g	Com//g	Shear//g
Tree 1	Top	84.74 ± 9.79a	22.65 ± 5.89b	78.32 ± 10.91a	20.18 ± 5.09b
	Middle	84.27 ± 10.77a	24.42 ± 5.15a	76.98 ± 10.83a	20.55 ± 4.92b
	Bottom	81.04 ± 10.73b	28.07 ± 6.79a	82.55 ± 11.91b	22.96 ± 4.52b
Tree 2	Top	86.53 ± 11.04a	18.99 ± 4.49c	74.96 ± 9.91a	17.93 ± 4.43c
	Middle	87.45 ± 12.64a	23.51 ± 4.23b	81.34 ± 10.79a	17.77 ± 4.32c
	Bottom	89.39 ± 9.20b	25.90 ± 5.68a	80.95 ± 10.41b	20.62 ± 4.29b
Tree 3	Top	84.42 ± 10.31a	22.82 ± 5.16b	79.79 ± 9.03a	20.56 ± 4.83b
	Middle	80.57 ± 6.78b	25.93 ± 4.70a	80.06 ± 11.19a	18.96 ± 4.75c
	Bottom	85.48 ± 9.15c	26.62 ± 5.82a	81.68 ± 9.37b	19.78 ± 3.20c

Shear parallel to grain

For shear strength parallel to the grain, Tree 1 of both *Z. gilletii* and *E. cylindricum* recorded the highest values compared to their respective Trees 2 and 3 in both axial and radial directions (Fig. 11). Specifically, for *Z. gilletii*, the shear strength order was Tree 1 > Tree 3 > Tree 2, while for *E. cylindricum* it was Tree 3 > Tree 1 > Tree 2 (Fig. 11). The mean shear strength for *Z. gilletii* was 24.32 N/mm^2, surpassing *E. cylindricum* mean of 19.92 N/mm^2 (Fig. 12). Overall, *Z. gilletii* exhibited higher average shear strength than *E. cylindricum* (Fig. 12). A significant

difference ($p < 0.05$) was observed between axial and radial directions for both species, supported by mean values and post-hoc analysis (Tables 5 & 6). Shear strength is critical for timber's structural performance, especially in joinery. Variation in shear strength was noted within both species along the tree height, with the bottom portion showing the highest values, followed by the middle and top portions (Tables 5 & 6). These differences likely result from morphological variability, heterogeneous wood structure, density, and climatic influences typical of tropical species.

CONCULSION

This study reveals that *Z. gilletii* exhibits moisture content, density, and mechanical properties specifically, modulus of rupture (MOR) and modulus of elasticity (MOE), that are comparable to or exceed those of the widely used *E. cylindricum*. These findings highlight *Z. gilletii* as a promising alternative timber species for furniture manufacturing, construction, and structural applications. Introducing *Z. gilletii* into commercial use not only offers a viable substitute to traditional hardwoods but also contributes to sustainable forest management by promoting species diversification and reducing pressure on overexploited timber resources

The **novelty (newness)** of the research topic lies in several key aspects:

1. Underexplored Timber Species:
   Z. gilletii is not widely studied or commercially used compared to well-known species like *E. cylindricum*. Evaluating its properties fills a knowledge gap about an underutilized species.
2. Comparative Analysis:
   Directly comparing *Z. gilletii* with an established hardwood species (*E. cylindricum*) in terms of physical and mechanical properties provides new, practical data that can guide industry decisions on timber selection.
3. Application Focus:
   The study emphasizes real-world applications such as furniture and construction, offering insights into the feasibility of using *Z. gilletii* in these sectors which hasn't been extensively documented before.
4. Sustainability Angle:
   By identifying an alternative timber that matches or exceeds the qualities of commonly used wood, this research promotes species diversification. This contributes to sustainable forest management, addressing environmental concerns linked to overharvesting traditional timber species. So, the newness comes from investigating and validating an alternative, lesser-known timber species with potential commercial and environmental benefits, backed by comparative strength data that support its practical use.

Declarations

Author Contribution

Contribution of AuthorsState what each other’s did in the work,DDD, KA Samples collection and preparation, testing of samples, wrote the main manuscript text, prepared figuresEAK, MAM, Data analysis, prepared figures All authors reviewed the manuscript.

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Figures

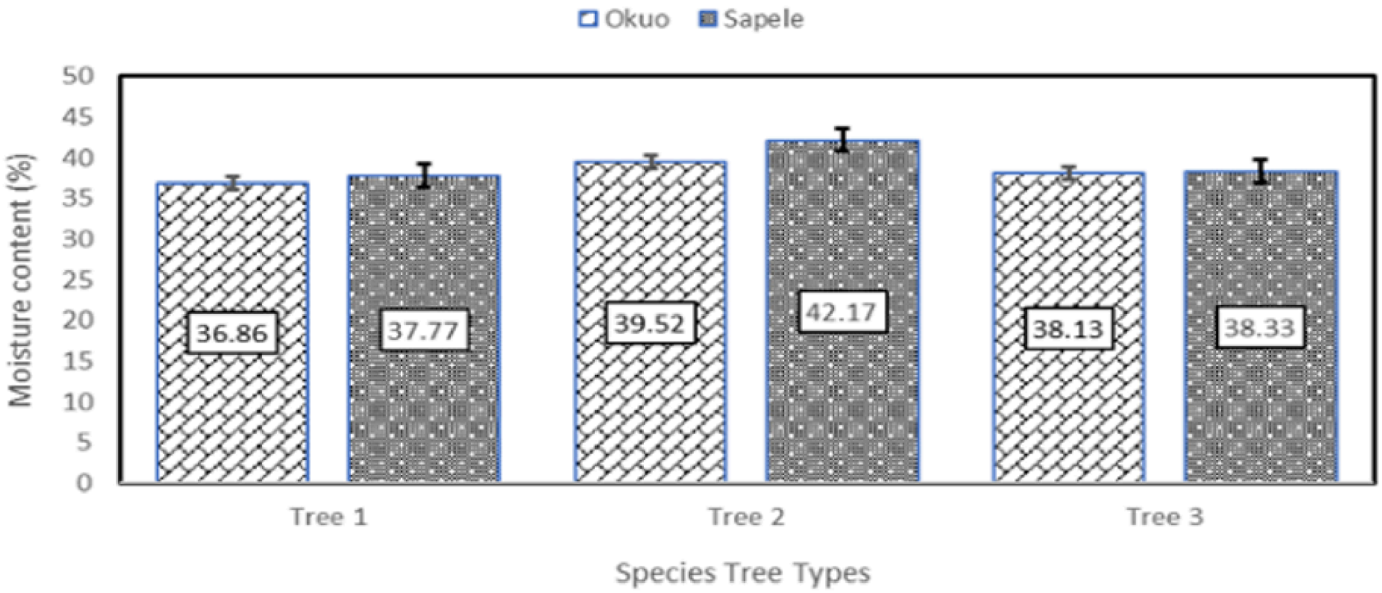

Figure 1

Mean moisture content between and among tree types (Bar – Standard Error)

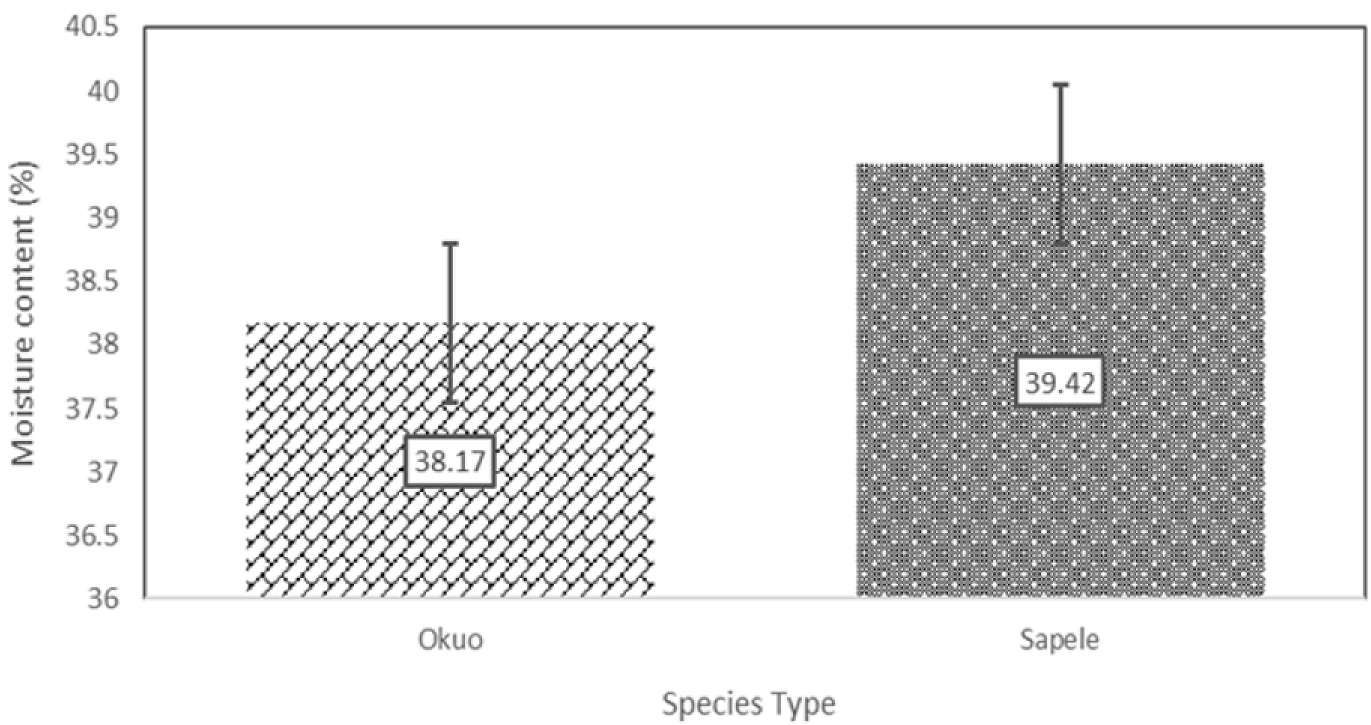

Figure 2

Overall mean moisture content between trees.

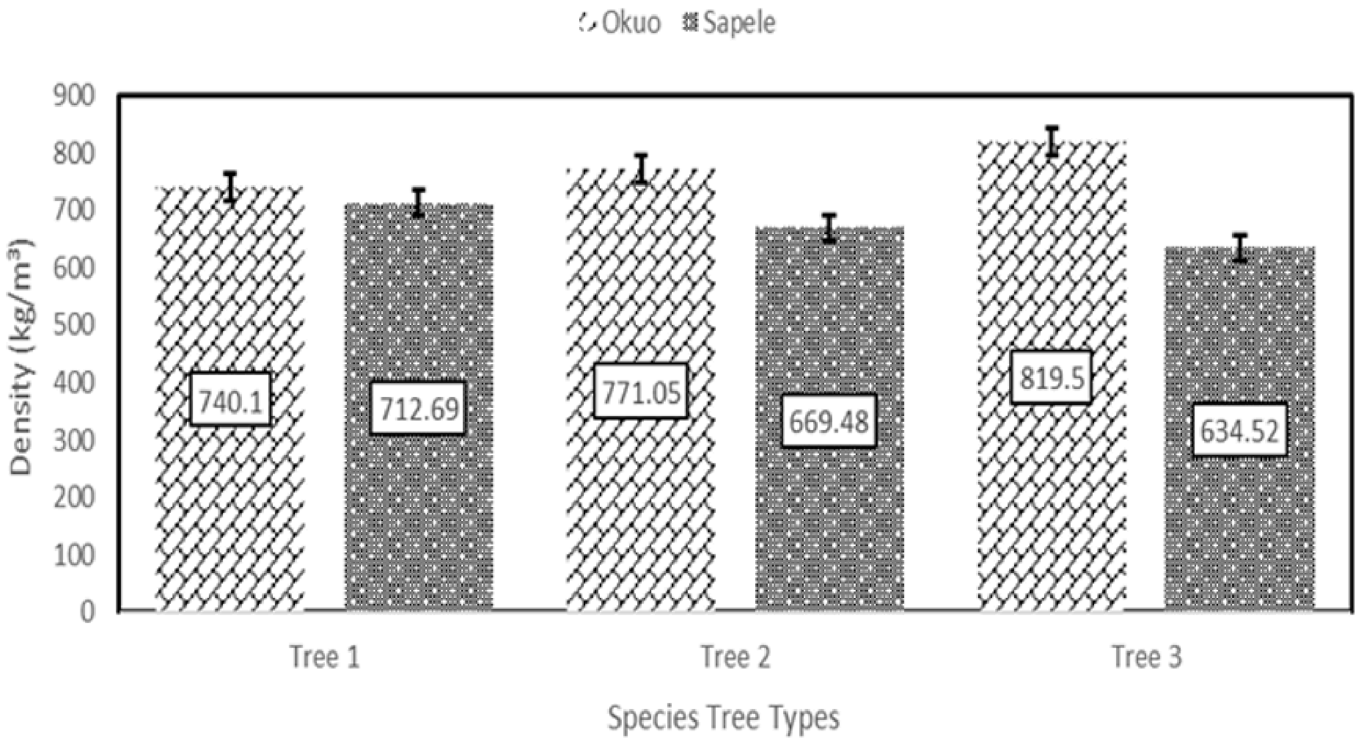

Figure 3

Axial and radial mean density within and among tree types

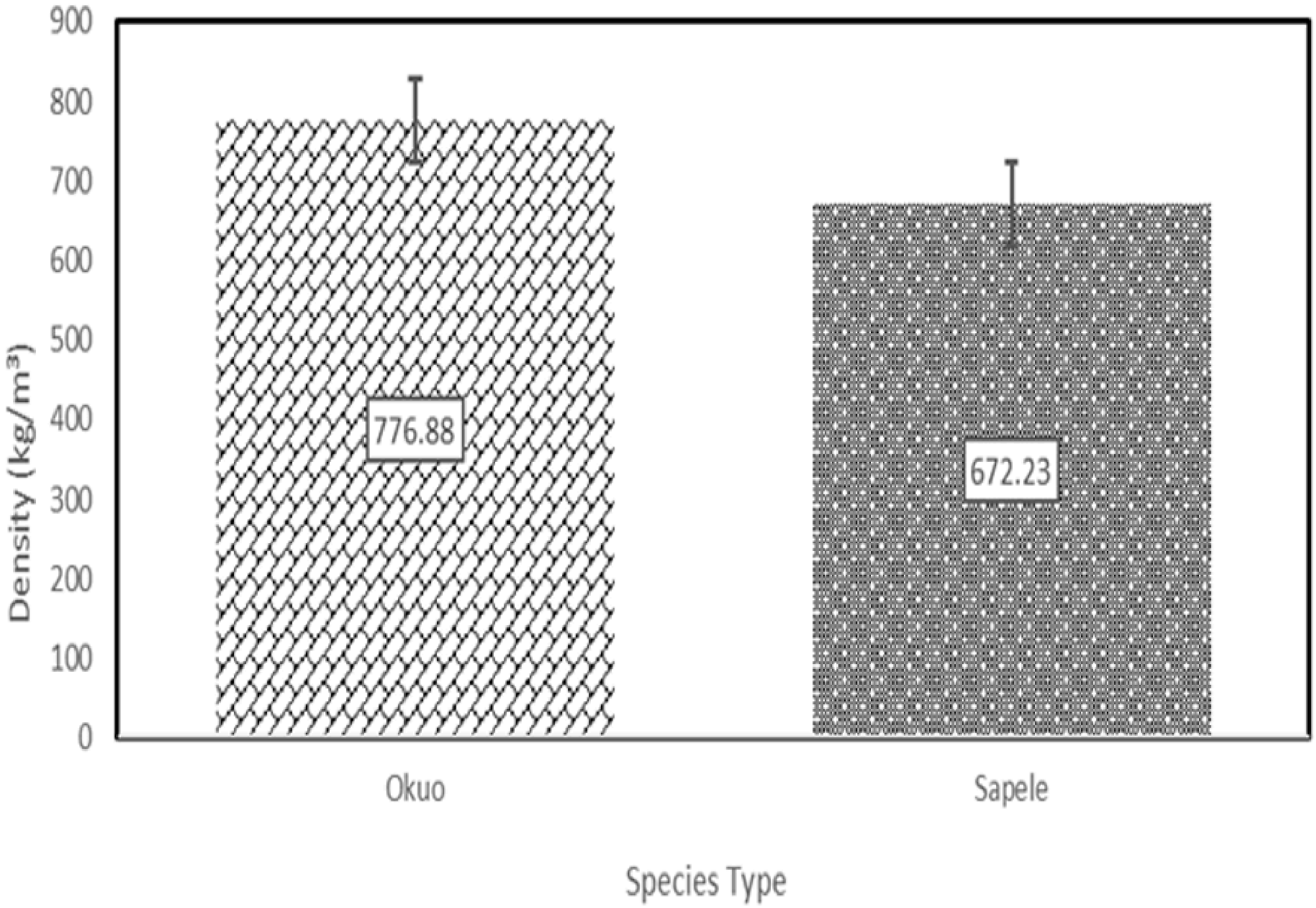

Figure 4

Overall mean density between trees.

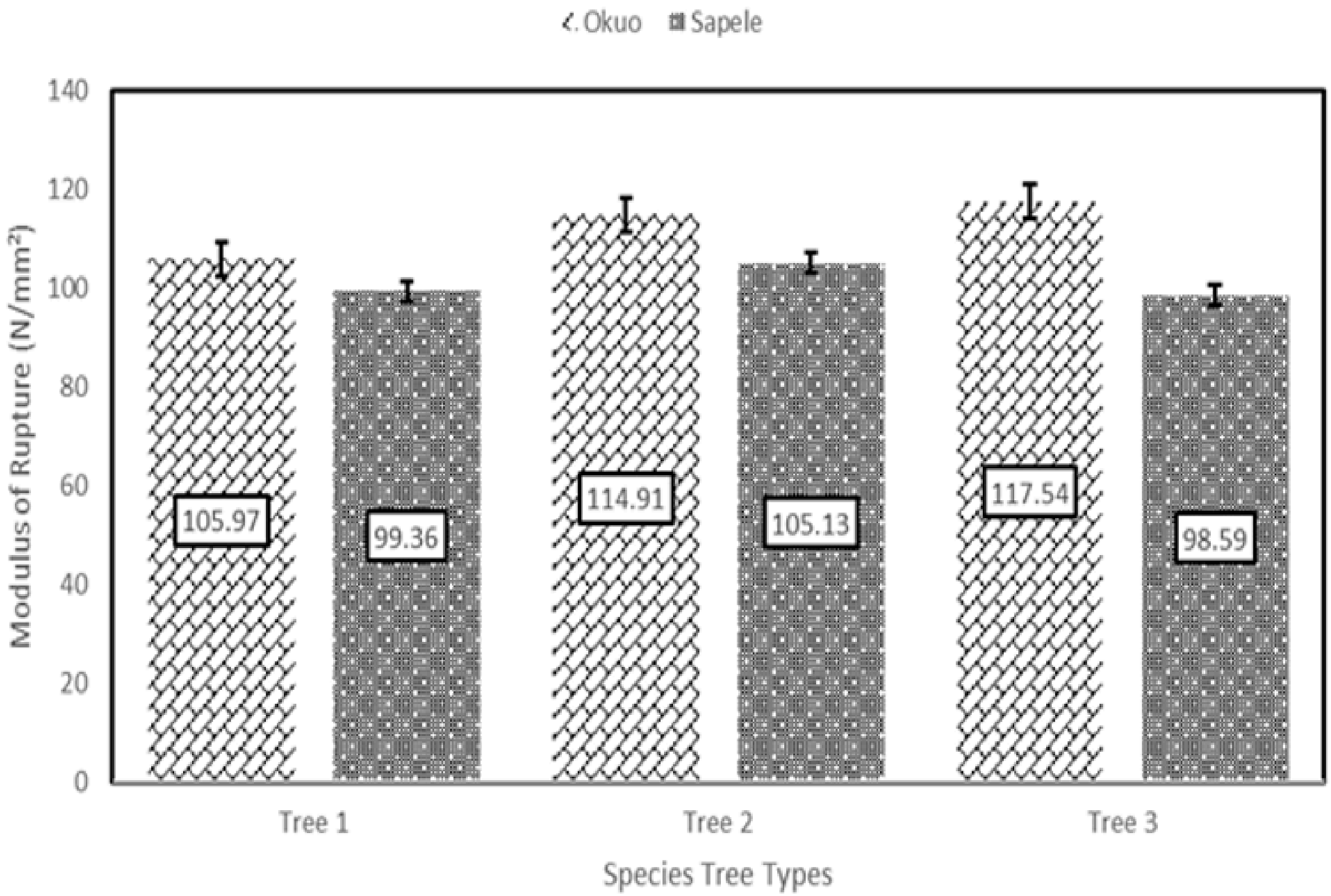

Figure 5

Mean of modulus of rupture of tree types

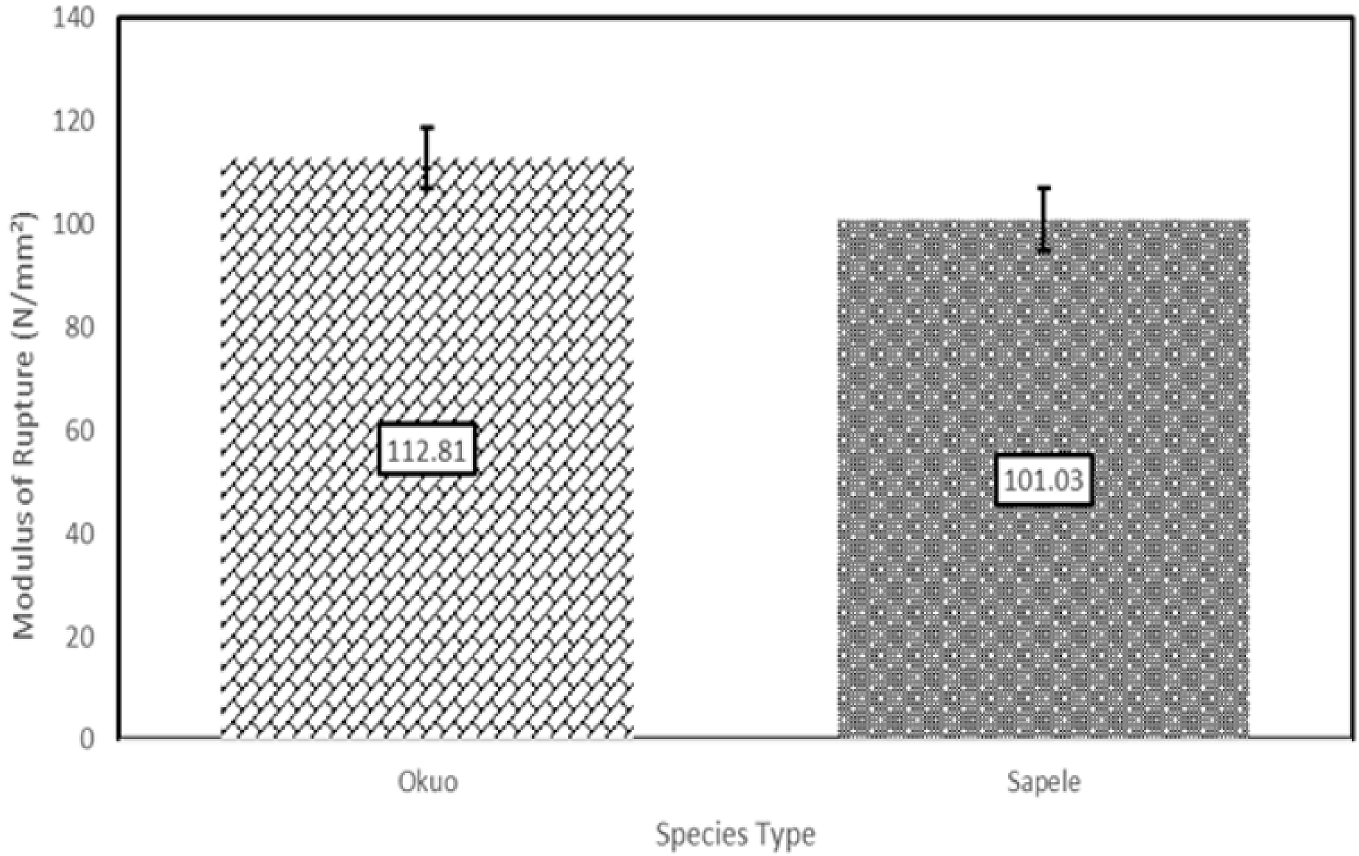

Figure 6

Total mean of modulus of rupture of tree species

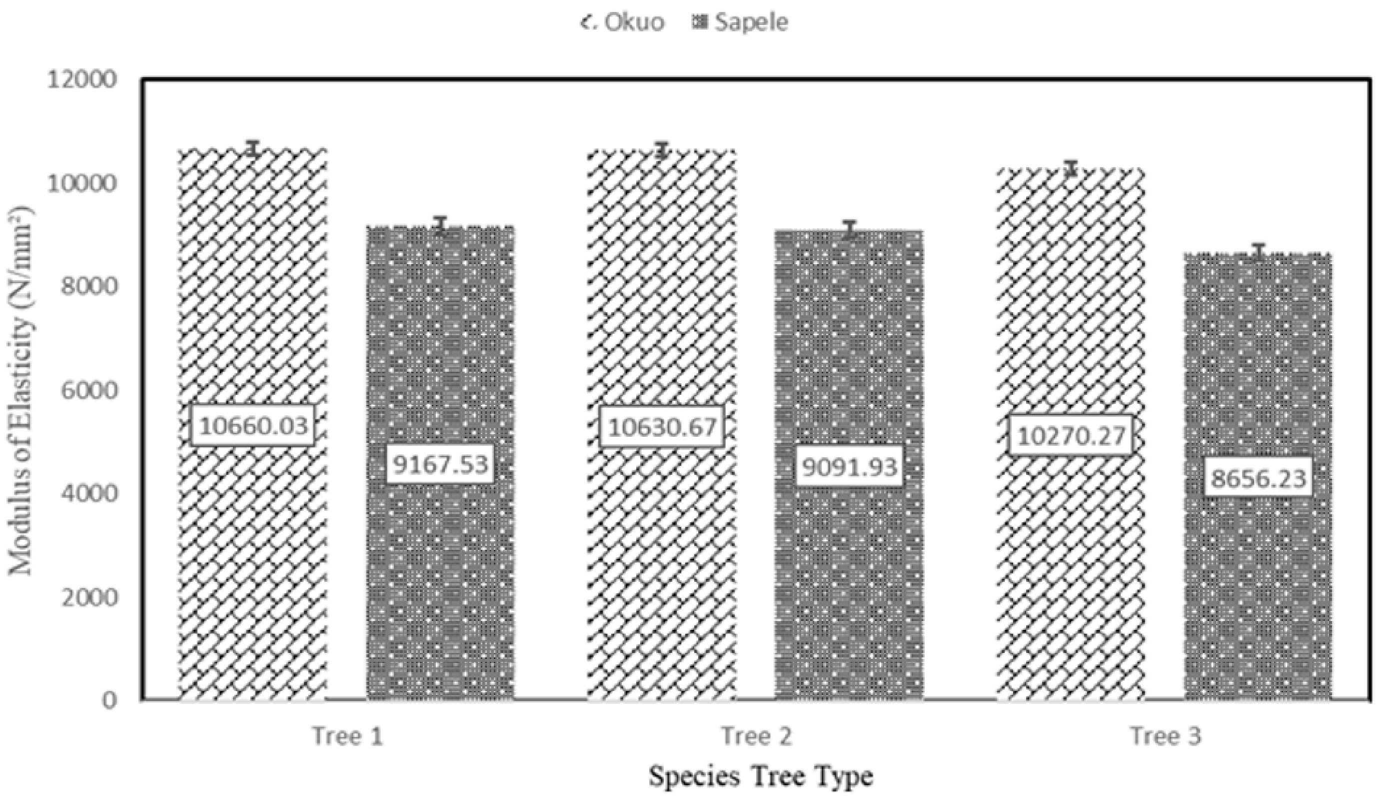

Figure 7

Mean of Modulus of Elasticity of the tree type

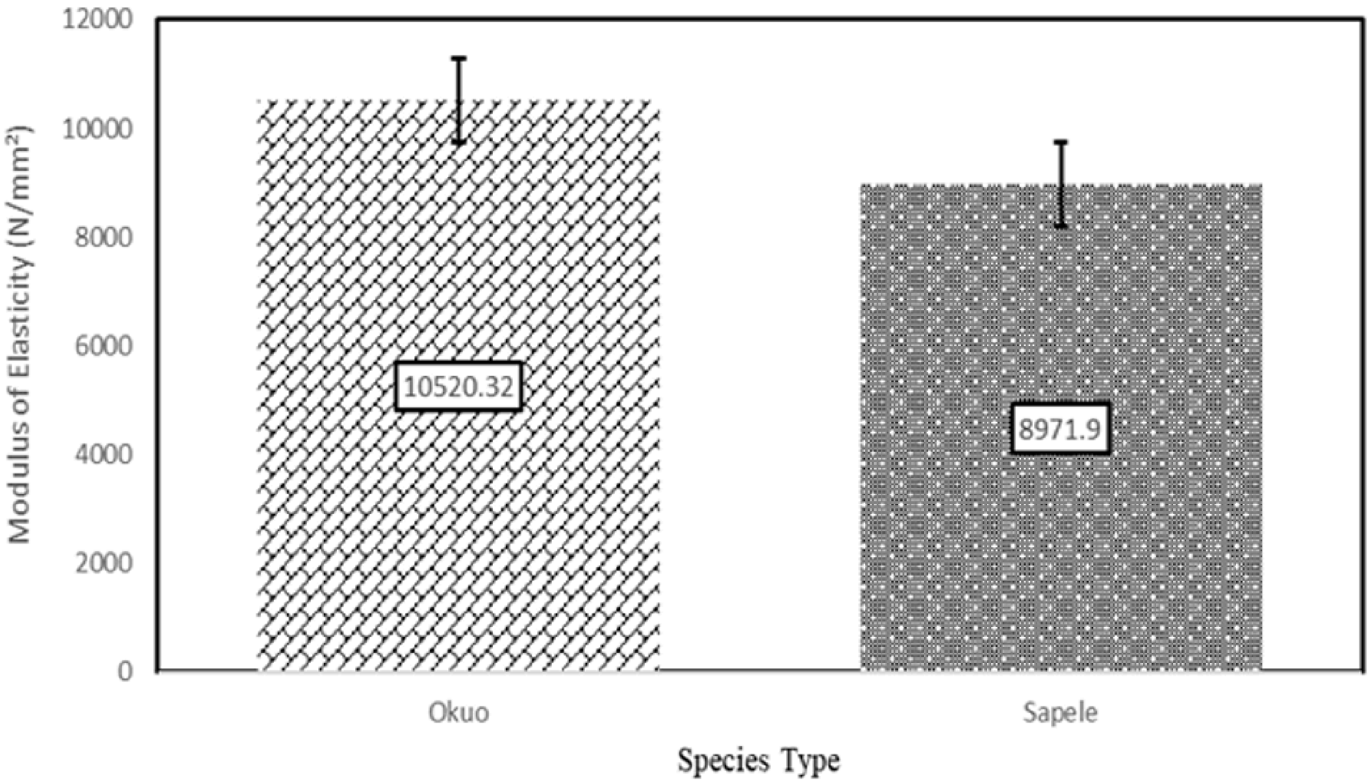

Figure 8

Total mean of Modulus of Elasticity of the species

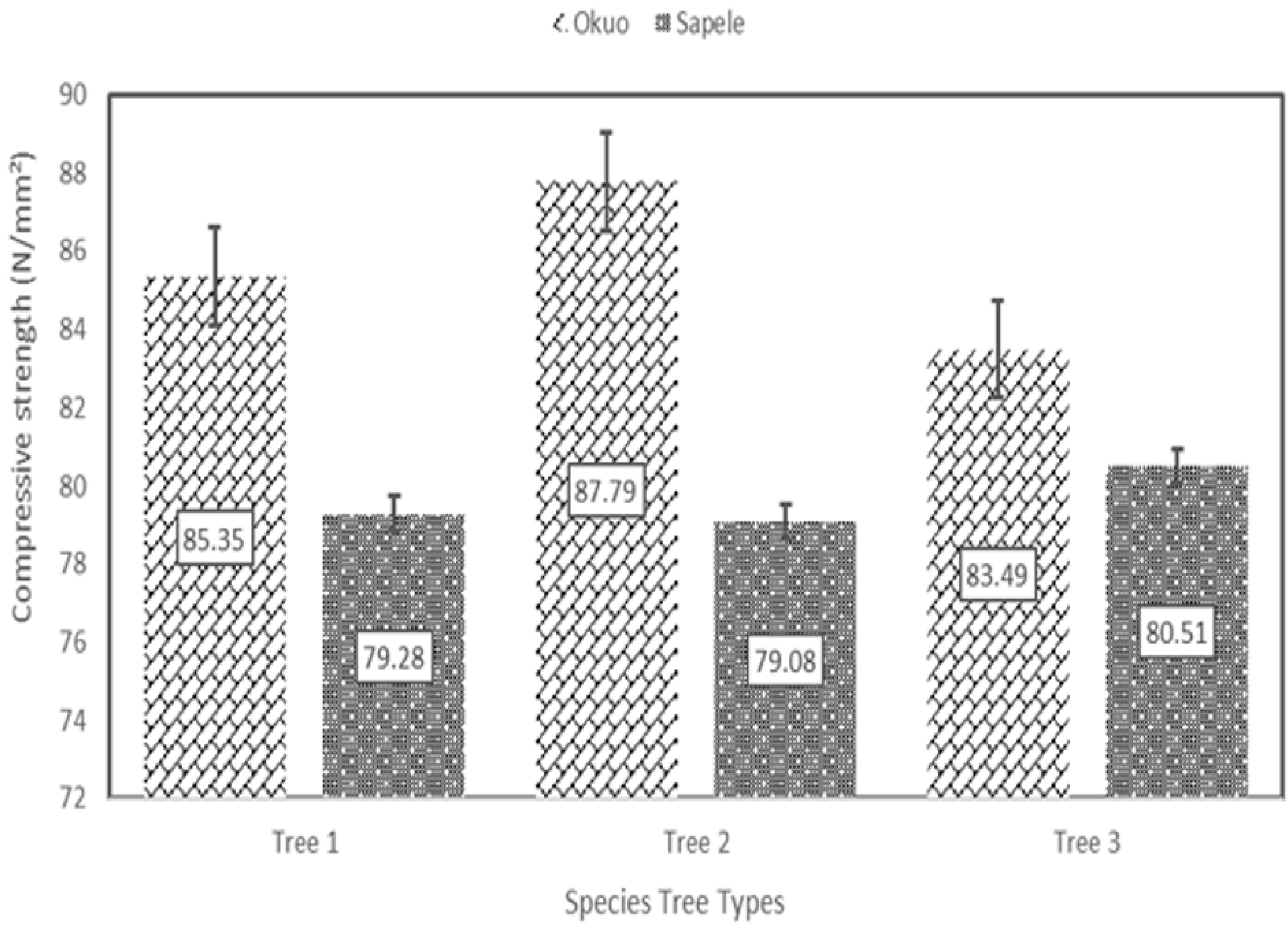

Figure 9

Mean of compressive strength for *Z. gilletii* and *E. cylindricum* wood.

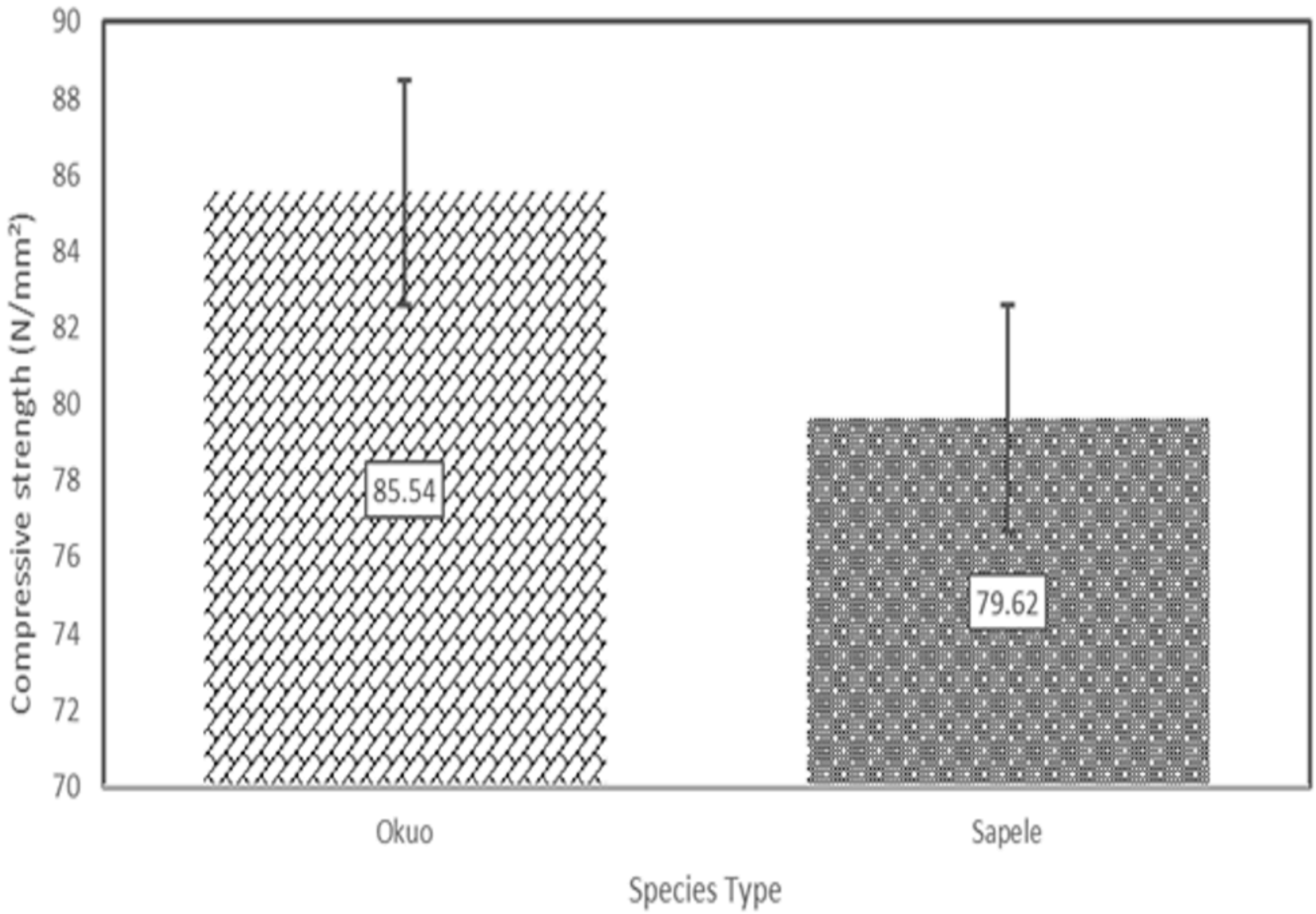

Figure 10

Overall compressive strength of *Z. gilletii* and *E. cylindricum* species

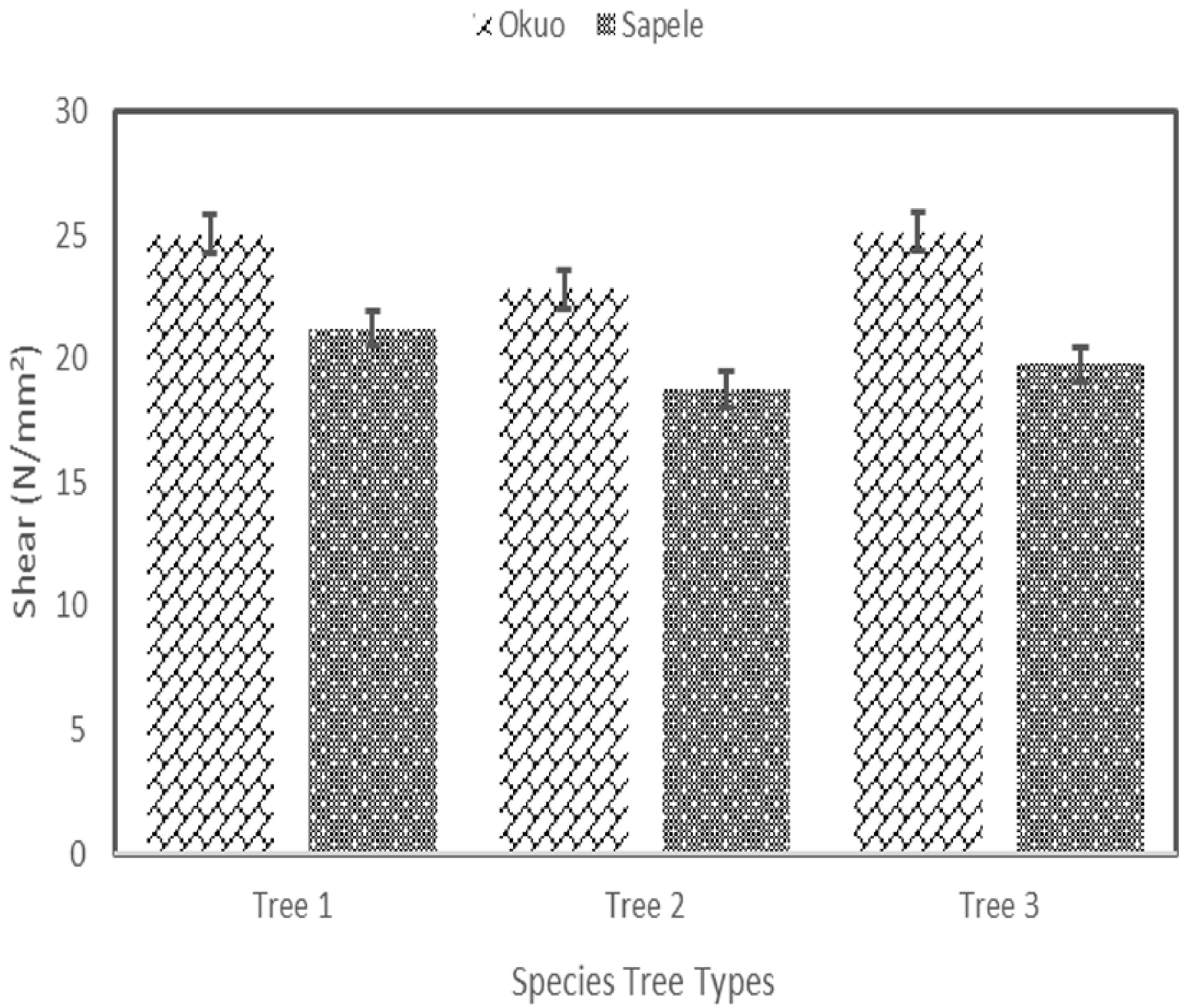

Figure 11

Mean shear strength of *Z. gilletii* and *E. cylindricum* species.

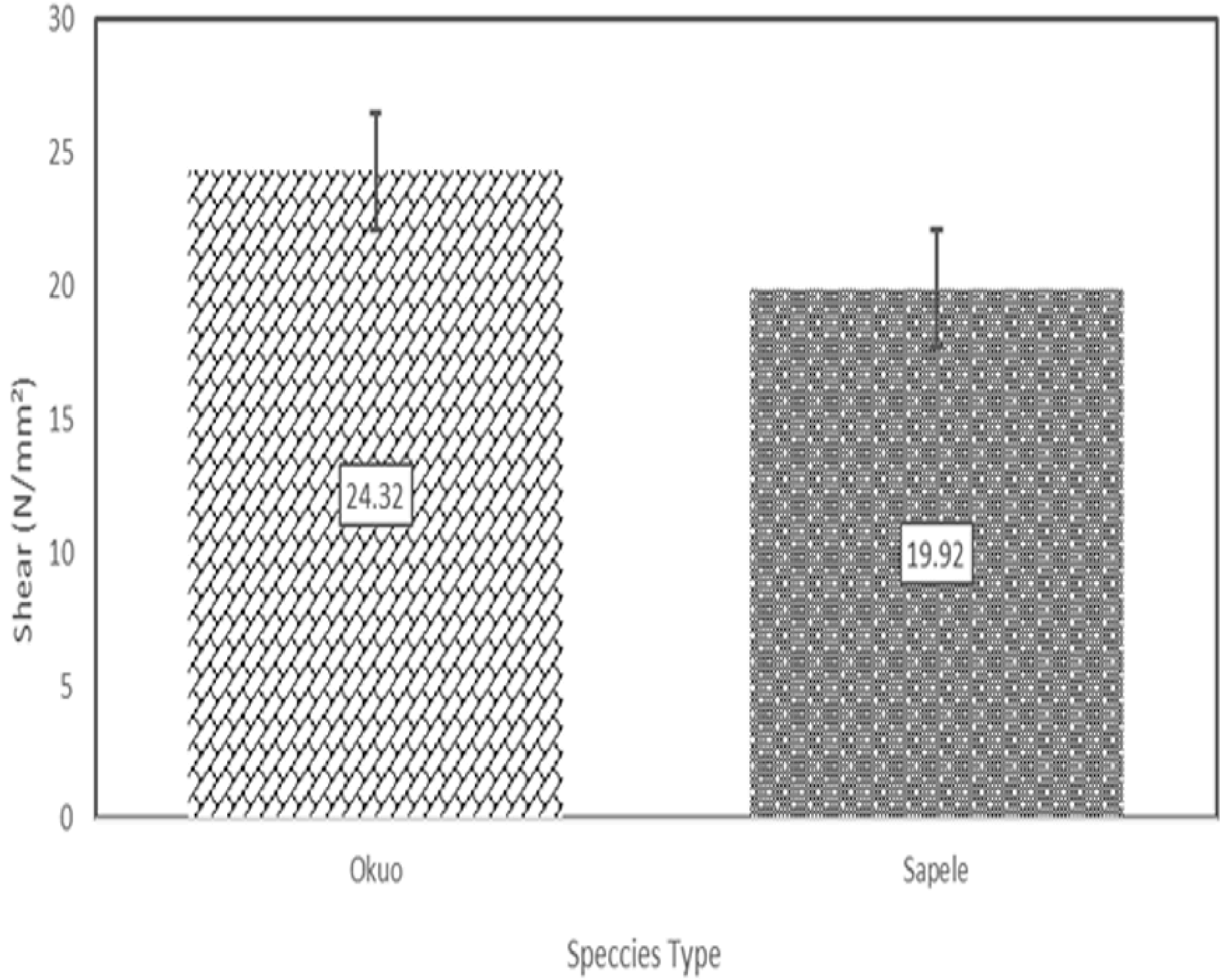

Figure 12

Total mean of Shear strength of the species