SEEFOR SOUTH-EAST EUROPEAN FORESTRY

OPEN ACCESS
ISSN 1847-6481
eISSN 1849-0891

ORIGINAL SCIENTIFIC PAPER

DOI: https://doi.org/10.15177/seefor.25-09

Comparative Evaluation of Selected Properties of Stem and Branch Wood of *Terminalia superba*

Francis Kofi Bih[1,*]

(1) Akenten Appiah Menka University of Skills Training and Entrepreneurial Development, Faculty of Technical Education, Department of Wood Science and Technology, P.O Box 1277, GH-Kumasi, Ghana

*** Correspondence:** e-mail: fkbih@aamusted.edu.gh

Citation: Bih FK, 2025. Comparative Evaluation of Selected Properties of Stem and Branch Wood of *Terminalia superba*. *South-east Eur for* 16(1): 63-72. https://doi.org/10.15177/seefor.25-09.

Received: 21 Jan 2025, **Revised:** 13 Apr 2025, **Accepted:** 25 Apr 2025, **Published online:** 16 Jun 2025

ABSTRACT

Logging residue is a growing national concern in Ghana, yet it has not received adequate attention. Efficient utilization of both stems and branches can promote sustainable use of limited timber resources while minimizing waste. This study investigated the physical, mechanical, and durability properties of stem and branch wood of *Terminalia superba* to evaluate its potential as a structural raw material. The results revealed significant variations among stem heartwood, stem sapwood, and branch wood. Branch wood exhibited the highest moisture content (88.81%) but the lowest oven-dry density (575.39 kg·m^{-3}), while stem heartwood had the highest density (683.56 kg·m^{-3}) and lowest moisture content (72.68%). Water absorption progressively increased from stem heartwood (56.96%) to branch wood (70.48%). Mechanical properties were superior in stem heartwood, with the highest modulus of elasticity (11,061.09 MPa), modulus of rupture (101.30 MPa), and compression strength (68.82 MPa), whereas branch wood showed the weakest performance. Durability tests revealed stem heartwood as the most resistant to mass loss (22.70%), followed by stem sapwood (34.35%) and branch wood (48.23%). These findings demonstrate the suitability of stem heartwood for high-performance applications requiring strength and durability, while branch wood is more appropriate for less demanding uses. This study underscores the importance of targeted utilization of *Terminalia superba* components for sustainable and efficient resource management.

Keywords: stem wood; branch wood; heartwood; sapwood; durability; dimensional stability; in-ground field test

INTRODUCTION

The furniture industry in Ghana, like in many regions in sub-Saharan Africa, relies heavily on timber as a primary raw material (Dadzie et al. 2014). However, over recent decades, the availability of timber from primary sources has sharply declined due to deforestation, unsustainable logging, and forest degradation (Kyere-Boateng and Marek 2021). This depletion of forest resources has resulted in significant raw material shortages, compelling Ghana's furniture sector to explore alternative wood sources to sustain production (Neitzel et al. 2022).

One promising alternative is branch wood from *Terminalia superba* Engl. & Diels (locally known as "Ofram"), a fast-growing hardwood species abundant in Ghana's semi-deciduous zones, such as Tuobodom. Traditionally, the main stem of *T. superba* has been the focus of commercial harvesting due to its superior physical and mechanical properties (Nugawela et al. 2020). However, growing timber shortages have shifted attention to branch wood, a previously underutilized resource often left as logging residue or discarded as waste (Larbi et al. 2018).

Branch wood, derived from tree branches, has shown promise in preliminary studies. Okai (2002) demonstrated that branch wood of *Terminalia ivorensis* A. Chev. and *Anigeria robusta* A. Chev. possessed comparable density, modulus of elasticity (MoE), modulus of rupture (MoR), and compressive strength to their respective stem wood. Similarly, Zakaria et al. (2024) found that branch wood of *Diospyros mespiliformis* Hochst ex A. Rich exhibited acceptable mechanical properties for light to medium furniture applications. Despite these findings, questions remain regarding the suitability of *T. superba* branch wood for widespread industrial use, particularly concerning its strength, durability, and workability compared to stem wood.

The semi-deciduous forest zone of Ghana provides favorable ecological conditions for the growth of *T. superba*, supporting its rapid growth and adaptability (Forestry Commission Ghana 2019). However, increasing anthropogenic pressures, including illegal logging and agricultural expansion, have significantly depleted timber volumes (Yeboah et al. 2021). Consequently, large-diameter logs, traditionally preferred by the furniture industry, are increasingly scarce. Branch wood utilization offers a sustainable alternative, aligning with the principles of sustainable forest management and circular economy practices. By reducing waste and maximizing the use of harvested trees, branch wood utilization can alleviate logging pressures on primary forests, support biodiversity conservation, and contribute to climate change mitigation efforts (Leturcq 2014).

Despite its environmental and economic potential, branch wood faces challenges due to its higher juvenile wood content, which may affect mechanical strength and dimensional stability (Opoku-Asare and Adu-Poku 2022). Variability in grain orientation, moisture content, and density further complicates its processing and performance in furniture manufacturing. Research addressing these properties is essential to standardize processing techniques and ensure consistent quality in products derived from branch wood.

Additionally, economic feasibility remains a critical consideration. Initial investments in adapting existing processing technologies and raising awareness among stakeholders – such as sawmill operators, furniture manufacturers, and policymakers – are necessary for successful adoption (Ameyaw et al. 2019). Stakeholder engagement and policy support will play vital roles in promoting branch wood as a viable alternative resource in Ghana's furniture industry (Ofori et al. 2022).

This study aims to explore the potential of branch wood from *Terminalia superba* as an alternative raw material for Ghana's furniture industry. It will examine the physical and mechanical properties of branch wood, assess its suitability for furniture production, and analyze the economic and environmental implications of its utilization. By addressing these areas, the research seeks to contribute to sustainable resource management and enhance the resilience of Ghana's furniture sector in the face of declining timber resources.

MATERIALS AND METHODS

Material Preparation

The stem and branch wood of *T. superba* trees were purposively harvested from natural forest stands in the Bono East Region of Ghana, located at 01°55'37"W longitude and 07°35'05"N latitude. Five straight stem and branch logs were selected from each tree, with diameters ranging from 35 to 58 cm and lengths between 130 and 190 cm. Branch logs were taken from the first branches of the trees to ensure a representative range of branch wood diameters. To minimize the presence of knots, branches were cut approximately 350 mm away from the joint.

The harvested materials underwent precise processing, and an experimental investigation was conducted to assess their properties. Wood specimens were prepared at the sample preparation workshop of the Council for Scientific and Industrial Research in Kumasi. To determine the physical characteristics at 12% moisture content, two sectional discs, each approximately 5 cm thick, were cut from the ends of the stems and branch sections. The remaining billets were processed into lumber using the quarter-sawing method, then conditioned and tested at the Forestry Research Institute of Ghana in Fumesua.

Determination of Physical Properties

Physical characteristics, including oven-dry density, water absorption, and moisture content (MC), were evaluated in accordance with British Standard BS 373. Sectional discs were extracted from the radial sections (heartwood and sapwood) of each tree, using clear, defect-free samples from both stem and branch wood. To determine these physical properties, a total of 300 cubes, each measuring 20 mm · 20 mm · 20 mm, were meticulously prepared. The sampling process involved 30 cubes from each section (heartwood and sapwood) per tree, across five trees and two tree sections (stem wood and branch wood), resulting in the total sample count of 450 (30 samples · 2 sections (heartwood and sapwood) · 5 trees + (30 · 5 branch wood)).

After specimen preparation, the initial weight of each sample was recorded using an ELE International digital electronic scale with a precision of 0.001 g (Figure 1a). The samples were then conditioned to 12% MC and subsequently oven-dried at 103±2°C. After drying, the specimens were cooled in desiccators to prevent moisture reabsorption and reweighed using the electronic balance. This process was repeated until the weights stabilized, indicating constant mass.

The following formulae were applied to calculate the physical characteristics of the stem and branch wood:

Determination of Moisture Content (MC)

$$\text{Moisture Content (\%)} = \frac{\text{Initial weight - Oven dry weight}}{\text{Oven dry weight}} \quad (1)$$

Determination of Oven-dry Density

$$\text{Denisty} = \frac{\text{Mass (kg)}}{\text{Volume of wood (m}^3\text{)}} \quad (2)$$

where volume of wood at 12% moisture content.

Water Absorption

The initial weight of each specimen was recorded before they were horizontally submerged in a container filled with clean distilled water maintained at 26°C for seven days (Figure 1b). After the immersion period, the specimens were removed, and any excess surface water was gently wiped off. Subsequently, the specimens were placed in an oven for conditioning until they reached a moisture content of 12%.

The water absorption properties of the stem and branch wood specimens were determined using the standard equation specified for this purpose (Equation 3).

$$\text{Water Absorbtion (\%)} = \frac{\text{Satured weight - Oven dry weight}}{\text{Oven dry weight}} \quad (3)$$

(a) **(b)**

Figure 1. **(a)** Specimens from stem and branch wood soaked in distilled water; **(b)** Specimen on an ELE International digital electronic scale for determination of initial and final weights.

Mechanical Properties Determination

In accordance with British Standard BS 373, specimens were prepared for the evaluation of mechanical properties, including modulus of elasticity (MoE), modulus of rupture (MoR), compression parallel to grain, shear parallel to grain, hardness, and density at 12% moisture content (MC). The specimens were carefully marked and sawn to ensure precise separation of heartwood and sapwood sections from each billet. Samples were collected from both the stem and branch parts of the trees.

After air-drying the specimens to an appropriate moisture level, they were conditioned to achieve 12% MC and subsequently stored in a controlled laboratory environment for testing. Mechanical property assessments were conducted using an Instron testing machine, as specified by BS 373.

Bending Test (Modulus of Elasticity and Modulus of Rupture)

Static bending tests to determine the modulus of elasticity (MoE) and modulus of rupture (MoR) were conducted using a three-point bending (central loading) system on an Instron Universal Testing Machine. In compliance with BS 373 (1957), test samples were prepared with dimensions of 20 mm · 20 mm · 300 mm. The machine applied the load automatically at a constant rate of 6.5 mm·min^{-1}, recording the applied force and corresponding deflection at 0.1 N intervals.

The loading rate was maintained until specimen failure, with the maximum load at failure and the proportional limit of the maximum load recorded by the machine's computerized system. The total test duration was 90±30 seconds, and results were reported in megapascals (MPa).

The modulus of elasticity (E) was calculated using the following formula:

$$E = \frac{P \cdot L^3}{4 \cdot b \cdot d^3 \cdot y} \tag{4}$$

where E is modulus of elasticity (MPa), P is load at proportional limit (N), L is span of the test specimen (mm), b is width of the specimen (mm), d is depth (thickness) of the specimen (mm), and y is deflection at mid-span corresponding to load P (mm).

The measured MoE values were evaluated against the classification criteria established by Bolza and Keating (1972), as detailed in Table 1.

Table 1. Bolza and Keating's (1972) classification of wood Modulus of Elasticity (MoE).

Values	Grades (N·mm^{-2})
Very High	>19,000
High	14,000–19,000
Medium	9,000–14,000
Low	<9,000

The modulus of rupture is the maximum load that a wood sample can sustain before cracking. The MoR was calculated using the same test methodology as that outlined for MoE.

The modulus of rupture (R) was calculated as:

$$R = \frac{3 \cdot P \cdot L}{2 \cdot b \cdot d^2} \tag{5}$$

where R is modulus of rupture ($N \cdot mm^{-2}$), P is maximum load applied at the midpoint of the sample (N), L is distance between supports (mm), b is breadth of the test piece (mm), and d is depth of the test sample (mm).

MoR values were compared to the benchmark categories defined by Bolza and Keating (1972), as presented in Table 2.

Table 2: Bolza and Keating's (1972) classification of wood Modulus of Rupture (MoR).

Values	Grades ($N \cdot mm^{-2}$)
S2	>134
S3	114–134
S4	93.7–114

Compression Parallel to Grain

Compressive strength parallel to grain was evaluated using a longitudinal grain technique, following the guidelines of BS 373 (1957). Test samples measuring 20 mm · 20 mm · 60 mm were prepared in accordance with the standard. Each sample was carefully inspected to ensure it was rectangular, smooth, parallel, and aligned normally to the grain axis, ensuring accurate and reliable test results.

A ball-contact plunger applied a crosshead load to each test specimen at a rate of 0.01 $mm \cdot s^{-1}$. The Instron Universal Testing Machine automatically recorded the maximum load (Pmax) as the specimen was loaded to failure. The compressive strength was calculated by dividing the maximum force recorded during the test by the cross-sectional area of the sample.

The compressive strength parallel to the grain was determined using the following formula:

$$C = \frac{P}{A} \tag{6}$$

where C is maximum compressive load ($N \cdot mm^{-2}$), P is maximum load (N), and A is cross sectional area of the sample (mm^2).

Determination of Natural Durability

Stem and branch wood specimens measuring 500 mm · 50 mm · 25 mm were prepared and oven-dried at a temperature of 103±2°C, following the guidelines of EN 252 (2014). Drying continued until there was no significant change (≤0.01 g) between two successive weighing. Each specimen was appropriately labeled for easy identification and conditioned to a moisture content (MC) of approximately 10–12%. The initial weights of the specimens were measured and recorded using an ELE International electronic balance.

Using a completely randomized design (Tascioglu et al. 2012), the replicates were buried in soil with a spacing of 50 cm between the specimens. One-third of each specimen's length (approximately 50 mm · 60 mm) was embedded in the soil. Monthly inspections were conducted to monitor deteriorating features and to ensure that the specimens remained undisturbed by stray animals.

After six months, the specimens were retrieved, and any debris adhering to the stakes was carefully removed. To evaluate degradation caused by soil organisms, the percentage mass loss was calculated. The specimens were oven-dried until a constant weight was achieved, and their final weight was recorded.

The percentage mass loss (%) was determined using the following formula:

$$\text{Mass loss} = \frac{M1\text{-}M2}{M1} \cdot 100 \tag{7}$$

where M1 is weight of specimens before the field test (kg), and M2 is post-exposure weight (kg).

Percentage mass losses of samples were determined as an indication of durability using the process of mass loss rating. The extent of damage caused by the biodegradable organisms to the wood was rated according to the scale proposed by EN 252 (1989) (Table 3).

Table 3. Natural durability rating based on percentage mass loss against degradation.

Durability Class	Mass Loss (%)
Very durable	0–10
Durable	11–20
Moderately durable	21–30
Non-durable	>31

Source: (EN 252, 1989).

Description of Experimental Area

The decay resistance of the specimens was assessed at the durability test site of the Department of Wood Science and Technology, located at the Faculty of Renewable Natural Resources (FRNR) Demonstration Farm, Kwame Nkrumah University of Science and Technology (KNUST). The site's vegetation formations, as described by Benneh et al. (1990), include coastal savannah, coastal strand, mangrove, evergreen forest, semi-deciduous forest, and savannah. The area features a wet sub-equatorial climate with moderate temperature and humidity, creating conditions conducive to wood decay.

The site is characterized by numerous termite mounds and a high decay hazard index. Common insects present in the test field include subterranean termites, such as *Anobium* spp., *Ancistrotermes* spp., and *Nasutitermes latifrons* (Usher 1975).

Ravenshorst et al. (2013) emphasized the preference for field tests over laboratory tests, as the former accounts for the combined effects of various biotic and abiotic factors that contribute to wood deterioration. This comprehensive approach provides a more realistic evaluation of decay resistance under natural environmental conditions.

Figure 2. (a) Specimens from stem and branch wood packed in an oven after six months of field exposure; **(b)** branch specimens mounted at the field; **(c)** stem specimens mounted at the field; **(d)** stem specimens packed after field exposure.

Statistical Analysis

Data obtained from the laboratory experiments were analyzed using the SPSS 22.0 statistical package, with a significance level set at $p<0.05$. Comparisons were made between the tree parts and sections to evaluate differences in the observed variations.

RESULTS AND DISCUSSION

Moisture Content

Moisture content significantly affects product quality, operational costs, and processing efficiency (Corleto et al. 2024). In this study, the average green moisture content of stem heartwood was measured at 72.68%, while stem sapwood was recorded at 80.22%. Branch wood exhibited the highest moisture content, 88.81% on average. The results show a proportional increase in moisture content between the stem and branch sections of the tree.

Although the amount of bound water, potentially linked to dimensional stability, was unknown, the higher moisture content in branch wood suggests greater susceptibility to dimensional changes during drying, likely due to its anatomical structure facilitating water retention. In contrast, the lower moisture content of stem wood enhances its dimensional stability, reducing the risk of shrinkage and warping, making it more suitable for applications requiring consistent performance.

Statistical analysis using ANOVA (Table 4) indicated a significant difference in moisture content between stem and branch wood ($F=113.3$, $p=<.001$**), highlighting distinct moisture-retention capacities, potentially influenced by anatomical and physiological differences. The radial position within the tree (heartwood vs. sapwood) also significantly affected moisture content ($F=113.3$, $p=<.001$**), with a 7.54% variation.

Heartwood exhibited lower moisture content compared to sapwood, likely due to its dense nature and packed with extractives that reduces porosity and moisture retention. In contrast, sapwood's higher moisture content is attributed to its larger proportion of living parenchyma cells, which store water and nutrients. These findings are consistent with Zobel and van Buijtenen (2012), who reported higher moisture content in branch wood relative to stem wood due to a greater proportion of sapwood and thinner cell walls in branches.

Density

The oven-dry density of *T. superba* tree parts (stem and branch wood) reveal significant variation between the two sections. The average density of stem wood was 652.58 $kg\cdot m^{-3}$, while branch wood recorded a lower density of 575.39 $kg\cdot m^{-3}$. These findings align with those by Terrasse et al. (2021) and Zhao et al. (2018), but contradict the results reported by Suansa and Al-Mefarrej (2020).

The observed density variation between stem and branch wood can be attributed to the maturation of the stem, reflecting differences in growth patterns. Stem wood's higher density suggests superior mechanical properties, including greater strength and durability, compared to the lower density and strength of branch wood. This observation aligns with Zhao et al. (2018), who reported an average stem wood density of 0.59 $g\cdot cm^{-3}$ compared to 0.50 $g\cdot cm^{-3}$ for branch wood.

Comparative analysis between tree sections, as shown in ANOVA Table 4, reveals a statistically significant disparity in density ($F=65.08$, $p=<.001$**) with a variation of 77.19 $kg\cdot m^{-3}$. The higher basic density of stem wood is likely due to its role as a primary structural support, requiring thicker cell walls and increased density. These findings are consistent with Nygård et al. (2004), who observed similar trends, attributing the higher density of stem wood to the differing mechanical demands and growth dynamics compared to branch wood.

Overall, the stem wood of *T. superba*, particularly the heartwood, exhibits higher density and superior mechanical properties compared to branch wood, emphasizing its suitability for applications requiring greater structural integrity.

Water Absorption

Wood products in use often encounter liquid water through various mechanisms, resulting in rapid changes in moisture content. This is contrast to the slower changes caused by water vapor absorption. When wood absorbs water beyond its fiber saturation point, the air within its cell lumina is displaced by water, continuing until the wood reaches its maximum moisture content (Glass and Zelinka 2010).

This study observed that the timber species exhibited an initial rapid rate of moisture absorption, which subsequently slowed during the relaxation phase. A decline in water absorption levels was noted between the two tree sections (stem and branch wood). Specifically, the sapwood of stem samples recorded a water absorption level of 63.24%, while the heartwood portions exhibited a lower absorption level of 56.96%. Branch wood specimens displayed the highest water absorption level at 70.48%.

Despite higher absorption rate in branch wood, the interaction between tree part (stem vs. branch wood) and tree section (heartwood vs. sapwood) was not statistically significant, as shown in Table 4. Greater water absorption in branch wood can be attributed to the presence of capillaries, which enable rapid equilibrium with the hydration medium through capillary action. Larger cell cavities in branch wood permit unrestricted water flow, while smaller cavities are influenced by trapped air bubbles, which regulate the internal water gradient.

These findings align with previous studies suggesting that branch wood has active cells and a more open structure, facilitating greater water retention. In contrast, stem wood comprises a higher proportion of mature wood densely packed with extractives, which reduce porosity and limit moisture absorption. These structural differences explain the lower water absorption in stem wood compared to branch wood (Tete Okoh 2014).

Mechanical Properties

Table 5 summarizes the analysis of variance (ANOVA) for the mechanical properties of *T. superba* wood. The results indicate no significant interaction between tree sections but reveal statistically significant differences based on tree parts.

Modulus of Elasticity (MoE)

The study revealed that MoE values decrease progressively from the stem portion to the branch wood portion of the trees, with average strengths of 11,061.09 MPa for stem heartwood, 10,500.60 MPa for stem sapwood, and 10,110.79 MPa for branch wood, as illustrated in Figure 3.

ANOVA results in Table 5 showed no statistically significant difference between the radial sections (heartwood and sapwood of the stem). However, the difference between the tree section (stem vs. branch) and tree part (heartwood vs. sapwood) was statistically significant at a 95% confidence level ($p<0.05$).

Table 4. ANOVA for physical properties of stem and branch wood of *Terminalia superba*.

		Moisture Content			Basic Density			Water Absorption		
Source	df	F-value	P-value	Var. (%)	F-value	P-value	Var. (%)	F-value	P-value	Var. (%)
Tree Part (TP)	1	113.3	<.001**	24.7	65.08	<.001**	36.6	135.61	<.001**	24.4
Tree Section (TS)	1	113.3	<.001**	19.6	65.08	<.001**	27.6	135.61	<.001**	14.4
TP · TS	1	1.3	0.651ns	0.3	1.467	0.229ns	1.9	6.024	0.515ns	3

Note: ** = significant at p<0.05, ns=not significant.

The insignificant variation in MoE values between the radial sections of the stem is likely due to similarities in density and anatomical structure (Zakaria et al. 2024). These findings corroborate prior research, which posits that axial variations in the mechanical properties of certain timber species decrease significantly along the bole height, from the base to the upper portions (Chulet et al. 2010).

Based on the Timber Export Development Board Ghana (1994) and the classification by Bolza and Keating (1972), the strength of *T. superba* can be categorized according to MoE values at 12% moisture content as in Table 1.

The classification indicates that the stem and branch wood strength of *T. superba* trees, with MoE values ranging from 10,110.79 MPa to 11,061.09 MPa, fall within the "Medium" strength category. This suggests that the wood is well-suited for applications such as furniture production and construction works.

Modulus of Rupture (MoR)

The study revealed a slight decline in the modulus of rupture (MoR) values from the base of the tree to the branches. At 12% moisture content, the heartwood portion of the stem recorded the highest mean static bending strength (MoR) at 101.30 MPa, while the branch portion exhibited the lowest mean MoR at 93.97 MPa. The results suggest that the heartwood's resistance to static bending is higher than that of sapwood in the stem at the same moisture content. However, the branch wood consistently demonstrated the lowest MoR values, revealing a statistically significant difference as shown in Table 5.

When compared to commercially known timber species, *Aningeria altissima* exhibits MoR values between 93.00 and 130.00 N·mm^{-2}, *Terminalia ivorensis* records 83.00 N·mm^{-2}, and *Antiaris toxicaria* achieves 59.00 N·mm^{-2}. This comparison indicates that the branch wood of *T. superba* has sufficient strength to perform well in applications traditionally suited for stem wood. The results align closely with other findings on *T. superba,* supporting the assertion by Tampori et al. (2024) that strength qualities improve as moisture content decreases.

When assessing the sectional differences in heartwood MoR, the mean variations among the trees were significant. Based on Bolza and Keating's (1972) wood strength classification (Table 2), both the stem and branch wood of *Terminalia superba* fall under the "S4" category, making them suitable for furniture production.

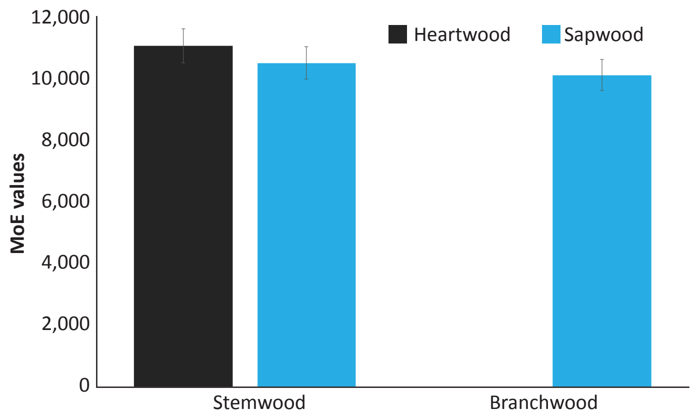

Figure 3. Average modulus of elasticity (MoE) values of stem and branch wood of *Terminalia superba* from semi deciduous zone of Ghana.

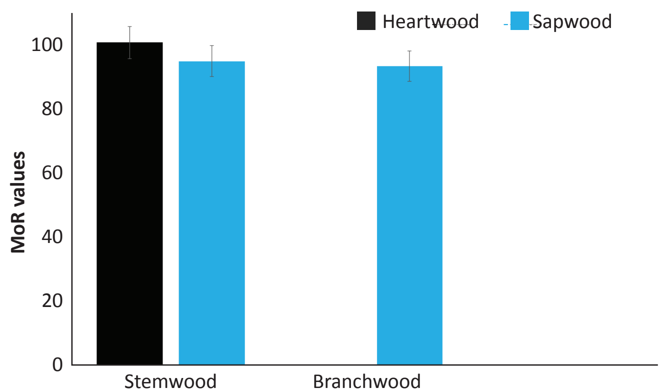

Figure 4. Average modulus of rupture (MoR) values of stem and branch wood of *Terminalia superba* from semi deciduous zone of Ghana.

Compression Parallel to Grain

The compressive strength of *Terminalia superba* for both stem and branch wood is comparable to other timber species, such as *Pericopsis elata* (63–71 N·mm^{-2}) and *Pterocarpus angolensis* (50–57 N·mm^{-2}), which are commonly used for furniture legs and deck posts requiring high compressive strength (Unger et al. 2001). Gindl and Teischinger (2002) noted that 84% of the variation in axial compressive strength in Norway spruce could be explained by density-induced differences in shear strength across tree sections. A similar observation was reported by Unsal and Ayrilmis (2005) for *Eucalyptus camaldulensis* Dehn.

The higher compressive strength observed in the stem section of *T. superba* compared to the branch section can be partly attributed to its higher density. Meier (2014) emphasized that high-density timbers, such as *Quercus alba* and *Sequoia sempervirens* D. Don Endl., which have compressive strengths of 51.3 N·mm^{-2} and 39.2 N·mm^{-2}, respectively, are suitable for structural applications. Similarly, *T. superba* demonstrates potential as a viable alternative for use in the furniture and construction industries due to its impressive compressive strength.

Decay Resistance of Stem and Branch Wood of *Terminalia superba*

This study evaluated the variations in decay resistance between the stem and branch wood of *Terminalia superba*. The results revealed a declining trend in durability from the stem to the branch. The branch wood exhibited an overall mass loss of 48.23%, classifying it as "non-durable" according to the decay susceptibility index. In contrast, the stem wood recorded a lower mass loss of 28.53%, placing it in the "moderately durable" category.

Radially, heartwood demonstrated greater resistance to decay compared to sapwood. Ibrahim et al. (2020) and Mensah et al. (2022) attributed the lower performance of sapwood to its lower concentration of extractives and higher starch content, which supports tree growth but increases susceptibility to decay. Statistical analysis presented in Table 6 ($p<0.005$) revealed a significant difference in decay resistance between the radial sections (heartwood and sapwood) and between the tree parts (stem and branch wood), while the interaction between the two factors also indicated a statistically significant difference.

In decay-prone environments, heartwood from species in the "resistant" category typically provides satisfactory performance for above-ground applications, while species classified as "very resistant" perform well in ground contact. These findings align with prior studies by Jamala et al. (2013) and Osman and Tarig (2013), which reported that the durability of wood species is influenced by factors such as density, moisture content, and the presence of extractives when in service.

Although the branch wood of *T. superba* falls within the non-durable class, eco-friendly preservation techniques, such as thermal modification, could enhance its durability and maximize its performance in service.

CONCLUSIONS

This study highlighted significant differences in the physical, mechanical, and durability properties between the stem heartwood, stem sapwood, and branch wood of *Terminalia superba*. The branch wood exhibited the highest moisture content (88.81%), followed by stem sapwood (80.22%) and stem heartwood (72.68%). Nevertheless, oven-dry density was highest in stem heartwood (683.56 kg·m^{-3}), followed by stem sapwood (621.59 kg·m^{-3}) and branch wood (575.39 kg·m^{-3}). Water absorption levels progressively increased from stem heartwood (56.96%) to branch wood (70.48%).

Mechanically, stem heartwood demonstrated superior strength with the highest values for modulus of elasticity

Table 5. Mechanical properties of stem and branch wood of *Terminalia superba.*

Tree part	Tree section	Mechanical properties (MPa)		
		MoE	MoR	Compression parallel to grain
Stem	Heartwood	11,061.09 ± 142^{a}	101.30 ± 3.0^{a}	68.82 ± 1.0^{a}
	Sapwood	10,500.60 ± 214^{a}	98.54 ± 2.0^{a}	66.13 ± 1.3^{a}
Branch	Branch wood	10,110.79 ± 128^{b}	93.97 ± 3.6^{b}	53.99 ± 1.1^{b}

MoE = Modulus of elasticity and MoR=Modulus of Rupture. Means in the same column with the same superscripts are not significantly different at $p<0.05$.

Table 6. Durability properties of stem and branch wood of *Terminalia superba*.

Tree Part/ Tree Section	Type III Sum of Squares	df	Mean Squares	F	p	η^2
Tree Part	60.44	1	30.22	21.79	.002*	0.88
Tree Section	60.44	1	50.14	21.79	.011*	0.88
Tree Part X Tree Section	60.44	1	38.43	21.79	.005*	0.88

*Significance at alpha=0.05.

(11,061.09 MPa), modulus of rupture (101.30 MPa), and compressive strength (68.82 MPa). Conversely, branch wood consistently recorded the lowest values, reflecting reduced mechanical performance compared to stem sections.

Durability testing revealed that stem heartwood had the lowest degradation rate (22.70%), followed by stem sapwood (34.35%) and branch wood (48.23%). These findings underscore the higher resistance of heartwood to decay compared to sapwood and branch wood. Despite its lower durability, the branch wood's performance can be significantly improved through eco-friendly preservation techniques, such as thermal modification.

The study reveals considerable variation in the physical and mechanical properties of *Terminalia superba* across different tree parts, notably affecting strength, dimensional stability and durability. The results indicate that, with appropriate treatment, branch wood can serve as a technically viable substitute for stem wood, promoting the sustainable and value-added utilization of *T. superba* in wood-based applications.

Funding

This research received no external funding.

Acknowledgments

I extend my heartfelt gratitude to the management and staff of the Council for Scientific and Industrial Research (CSIR) at the Forestry Research Institute of Ghana, Fumesua, for their invaluable support and resources. I am also deeply thankful to Issah Chakurah for his dedicated assistance during the data collection process.

Conflicts of Interest

Author declares no conflict of interest.

REFERENCES

Acheampong E, Adomako F, Larbi J, 2019. An overview of wood resource utilization in Ghana: Challenges and future prospects. *J For Res* 11(3): 45-52.

Acheampong JB, Effah B, Antwi K, Achana EW, 2022. Physical properties of Pamyra palm wood for sustainable utilization as a structural material. *Maderas-Cienc Tecnol* 24(8): 1-14. https://doi.org/10.4067/s0718-221x2022000100408.

Ameyaw JK, Gyamfi M, Agyare W, 2019. Economic assessment of alternative wood sources in Ghana's timber industry. *Afr J Econ Sustain Dev* 5(2): 28-39.

Benneh G, Agyepong GT, Allotey JA, 1990. Land degradation in Ghana. Commonw. Food Production and Rural Development Division, Commonwealth Secretariat, 183 p.

Bolza E, Keating WG, 1972. African timbers – the properties, uses, and characteristics of 700 species. *Div Build Res, CSIRO*, Melbourne.

BS 373:1957, 1957. Standard methods of testing small clear specimens of timber. 149-149.

Corleto R, Gaff M, Rezaei F, Sethy AK, Nemeth R, Valente F, Ditommaso G, Todaro L, 2024. Effect of moisture content levels on the quality of beech wood cut by CO_2 laser. *Int J Adv Manuf Tech* 134: 159-169. https://doi.org/10.1007/s00170-024-14015-7.

Dadzie PK, Amoah M, Tekpetey SL, 2014. Preliminary assessment of wealth creation in wood products' business in Ghana: The perspective of lumber and furniture production and implications for entrepreneurship. *International Journal of Business and Economics Research* 3(6): 243-249. https://doi.org/10.11648/j.ijber.20140306.15.

EN-252, 2014. Field test method for determining the relative protective effectiveness of a wood preservative in ground contact.

Forestry Commission Ghana, 2019. Forest resources report: Semi-deciduous forest zone. Available at: https://www.fcghana.org.

Gindl W, Teischinger A, 2002. Axial compression strength of Norway spruce related to structural variability and lignin content. *Compos Part A-Appl S* 33(12): 1623-1628. https://doi.org/10.1016/S1359-835X(02)00182-3.

Glass SV, Zelinka SL, 2010. Wood Handbook, Chapter 04: Moisture relations and physical properties of wood. Wood as an Engineering Matererial, General Techical Report FPL-GTR-190, pp. 1-19. Available at: http://www.treesearch.fs.fed.us/pubs/37428.

Ibrahim B, Ahmet T, Gamze G, 2020. The effect of sapwood and heartwood differences on mechanical properties of fast-growing tree species. *Drvna Ind* 71(3): 261-269. https://doi.org/10.5552/drvind.2020.1940.

Jamala GY, Olubunmi SO, Mada DA, Abraham P, 2013. Physical and mechanical properties of selected wood species in tropical rainforest ecosystem, Ondo State, Nigeria. *IOSR Journal of Agriculture and Veterinary Science* 5(3): 29-33. https://doi.org/10.9790/2380-0532933.

Kollmann FFP, Cote WA Jr, 1968. Principles of Wood Science and Technology: Solid Wood.

Kwaku A, Tobias C, Kwasi FM, 2022. Physical and mechanical properties of Holarrhena floribunda and Nesogordonia papaverifera branch wood in Ghana. *Afr J Plant Sci* 16(3): 29-33. https://doi.org/10.5897/ajps2022.2228.

Kyere-Boateng R, Marek MV, 2021. Analysis of the social-ecological causes of deforestation and forest degradation in Ghana: Application of the DPSIR framework. *Forests* 12(4): 409. https://doi.org/10.3390/f12040409.

Larbi JA, Boateng MA, Amponsah R, 2018. Characteristics of juvenile wood and its implications for industrial applications. *Wood Sci Technol* 52(1): 12-23.

Leturcq P, 2014. Wood preservation (carbon sequestration) or wood burning (fossil-fuel substitution), which is better for mitigating climate change? *Ann For Sci* 71(2): 117-124. https://doi.org/10.1007/s13595-013-0269-9.

Meier E, 2024. The wood database. Available at: http://www.wood-database.com/wood-articles/crushing-strength/.

Mensah P, Owusu FW, Seidu H, 2022. Natural durability of three selected Ghanaian lesser-used/known timber species using accelerated laboratory tests. *Eur Mod Stud J* 6(1).

Neitzel N, Hosseinpourpia R, Walther T, Adamopoulos S, 2022. Alternative materials from agro-industry for wood panel manufacturing-A review. *Materials* 15(13): 1-28. https://doi.org/10.3390/ma15134542.

Nugawela A, Appiah S, Brown H, 2020. Growth performance and utilization potential of Terminalia superba in Ghanaian forests. *Int J For Res* 14(2): 77-89.

Nygård R, Sawadogo L, Elfving B, 2004. Wood-fuel yields in short-rotation coppice growth in the north Sudan savanna in Burkina Faso. *Forest Ecol Manag* 189: 77-85. https://doi.org/10.1016/j.foreco.2003.07.030.

Ofori F, Amponsah J, Yeboah S, 2022. Policy frameworks for sustainable timber utilization in Ghana. *J Environ Policy Res* 18(3): 54-67.

Okai R, 2002. A study on the milling and strength properties of branchwood. *ITTO Trop For* Update 12(1): 24-25.

Okai R, 2013. Can logging residue be used to help meet timber demands for the downstream processing sector?

Opoku-Asare ES, Adu-Poku E, 2022. Mechanical properties of alternative wood resources: Branchwood as a sustainable option. *Wood Fiber Sci* 54(1): 102-110.

Osman TE, Tarig OK, 2013. Physical and mechanical properties of Cupressus lusitanica as a potential timber tree for Sudan. *J For Prod Ind* 2(1): 43-46.

Ravenshorst GJP, Gard WF, de Kuilen JWGV, 2013. The importance of characterization and sampling of tropical wood species with regard to strength and durability classification. *Heron* 53(2–3): 2.

Suansa NI, Al-MeFarrej HA, 2020. Branch wood properties and potential utilization of this variable resource. *BioResources* 15(1): 479-491.

Tampori EG, Bih FK, Antwi K, Chakurah I, 2024. Physical and mechanical properties of wood of plantation-grown *Albizia lebbeck* in the savannah ecological zone, Ghana. *Les/Wood* 73(1): 55-68. https://doi.org/10.26614/les-wood.2024.v73n01a05.

Tascioglu C, Yalcin M, Troya T, de Sivrikaya H, 2012. Termiticidal properties of some wood and bark extracts used as wood preservatives. *BioResources* 7: 2960-2969.

Terrasse F, Brancheriau L, Marchal R, Boutahar N, Lotte S, Guibal D, Pignolet L, Candelier K, 2021. Density, extractives, and decay resistance variabilities within branch wood from four agroforestry hardwood species. *iForest* 14(3): 212-220. https://doi.org/10.3832/ifor3693-014.

Tete Okoh E, 2014. Water absorption properties of some tropical timber species. *J Energy Nat Resour* 3(2): 20-24. https://doi.org/10.11648/j.jenr.20140302.12.

UNFCCC, 2023. Nationally determined contributions under the Paris Agreement, 22207.

Unger A, Schniewind A, Unger W, 2001. Conservation of wood artifacts: a handbook. Springer, Berlin, 578 p.

Unsal O, Ayrilmis N, 2005. Variations in compression strength and surface roughness of heat-treated Turkish river red gum (*Eucalyptus camaldulensis*) wood. *J Wood Sci* 51: 405-409. https://doi.org/10.1007/s10086-004-0655-x.

Usher MB, 1975. Studies on a wood-feeding termite community in Ghana, West Africa. *Biotropica* 7(4): 217-233. https://doi.org/10.2307/2989735.

Yeboah P, Agyare A, Owusu S, 2021. Anthropogenic pressures on Ghana's forest resources: Trends and implications for timber industries. *Land Use Policy* 101: 105108.

Zakaria J, Bih FK, Chakurah I, Antwi K, Korkor Tetteh CL, 2024. Physical and mechanical properties of the stem and branch wood of West African ebony (*Diospyros mespiliformis*). *Les/Wood* 73(2): 49-62. https://doi.org/10.26614/les-wood.2024.v73n02a05.

Zhao X, Guo P, Zhang Z, Wang X, Peng H, Wang M, 2018. Wood density and fiber dimensions of root, stem, and branch wood of *Populus ussuriensis* Kom. *BioResources* 13(3): 7026-7036. https://doi.org/10.15376/biores.13.3.7026-7036..

Zobel BJ, van Buijtenen JP, 2012. Wood variation: Its causes and control. Springer-Verlag, Berlin Heidelberg.