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PHYSICAL AND MECHANICAL CHARACTERISATION OF YELLOW-FRUITED WEST AFRICAN TALL COCO WOOD FOR SUSTAINABLE FURNITURE APPLICATIONS IN GHANA

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Abstract:

This study investigates the physical and mechanical properties of 20-year-old Yellow-Fruited West African Tall (YFWT) coco wood for sustainable furniture applications in Ghana. Stems were sampled from plantations in the Central Region, Ghana, and processed into specimens from bottom, middle, and top log sections across inner and outer zones.

Moisture content increased from outer to inner zones and from bottom to top, while density, compressive strength, shear strength, modulus of elasticity (MOE), and radial hardness decreased along the same gradients. Tangential hardness and modulus of rupture (MOR) showed minimal variation.

Statistical analysis confirmed significant axial and radial differences, with lower stem zones exhibiting superior density, stiffness, and strength, making them suitable for load-bearing applications, while upper zones are appropriate for light or decorative furniture components.

These findings highlight coco wood as a sustainable alternative to conventional hardwoods, promoting eco-friendly furniture production and reducing pressure on natural forests in Ghana.

Key words: *coco wood; density; mechanical properties; moisture content; sustainability.*

INTRODUCTION

The coconut palm (*Cocos nucifera*) is a vital perennial crop in tropical regions, valued for its food, fiber, oil, and raw materials across multiple industries (Chan and Elevitch 2006, Henrietta et al. 2022). Beyond these uses, its stem-commonly referred to as coco wood-offers a promising alternative timber resource, particularly where deforestation and declining hardwood supplies constrain sustainable furniture production (Foale et al. 2020, Fortier 2021).

In Ghana, the main coconut varieties include West Africa Tall (WAT), Ghana Yellow Dwarf, and Brazil Green Dwarf (Wamucii 2020). Among these, the Yellow-Fruited West African Tall is widely cultivated in the Central and Western Regions. Senile palms, as well as those affected by Cape St. Paul Wilt disease, are often felled, yet their stems remain underutilized despite their potential for furniture and construction. Unlike conventional hardwoods, coco wood is monocotyledonous and composed of fibrous vascular bundles rather than annual growth rings. This unique anatomy leads to pronounced variability in density, strength, and durability along both radial and longitudinal stem axes (Fathi 2014, Coconut Knowledge Center 2017, Rüggeberg et al. 2009). Such structural distinctions strongly influence its physical properties-moisture content, shrinkage, and dimensional stability-as well as its mechanical properties, including compressive strength, shear resistance, and stiffness.

Globally, processed coco wood has found applications in furniture, paneling, and interior construction (Rana et al. 2015, Smardzewski 2015). In Asia-Pacific countries such as the Philippines, India, and Indonesia, it is actively promoted as an eco-friendly hardwood substitute (Arancon 2009, Wresearch 2023, Singh and Singh 2024). However, research in Africa remains limited, particularly on the Yellow-Fruited West African Tall variety, restricting its adoption in the Ghanaian furniture sector.

This study therefore evaluates the physical properties (moisture content, density, shrinkage, swelling) and mechanical properties (compressive strength, shear strength, hardness, modulus of elasticity, and modulus of rupture) of Yellow-Fruited West African Tall coco wood. Specifically, the findings aim to provide evidence-based insights into its suitability for furniture applications, support the sustainable utilization of senile and diseased palms, and contribute to diversifying Ghana’s timber resources.

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MATERIALS AND METHODS

Study Area

The study employed 20-year-old Yellow-Fruited West African Tall (YFWT) coco wood obtained from plantations in the Abura Asebu Kwamankese (AAK) District, Central Region, Ghana. The district spans roughly 380km², located between latitudes 5°05′N and 5°25′N, and longitudes 1°05′W and 1°20′W, within an ecological transition zone shifting from coastal savanna to tropical rainforest (GDS 2024).

Three trees were purposively selected based on uniformity in diameter, fruit-bearing status, and absence of disease. Each tree averaged 30m in height and 45cm in diameter. Following felling, stems were divided into bottom, middle, and top log sections, each 8 ft long. The logs were then flat-sawn into planks of 2 in × 6 in × 8 ft, encompassing both inner and outer zones. These planks were processed into specimens for subsequent physical and mechanical testing.

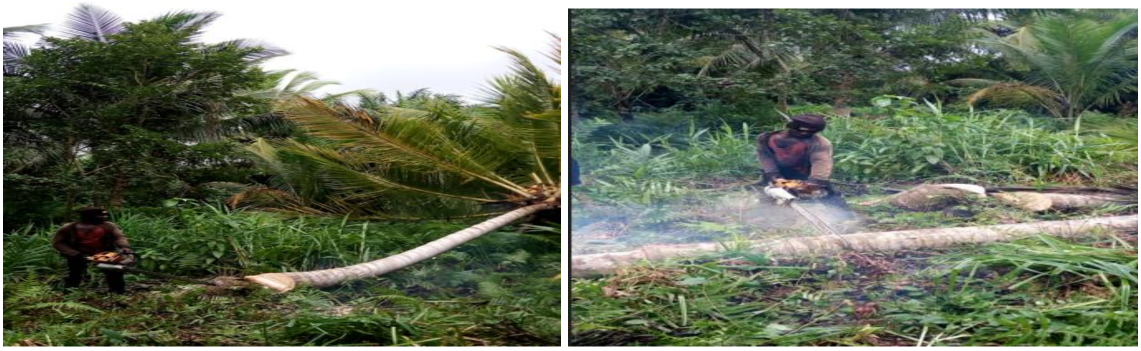
a b

Fig. 1.
Felling and division of coconut stems into log sections.


a b

Fig. 2.
Conversion of the coconut stem sections into planks. This stem was converted from the outer zone to the inner zone.


a b c d e

Fig. 3.
Specimen for physical and mechanical properties: a. density, moisture content, and dimensional stability, b. hardness, c. bending, d. shearing, e. compressive strength.

Conditioning of Specimens

All specimens were conditioned at 20±2°C and 65±2% relative humidity to achieve equilibrium moisture content before testing.

Experimental Design

The tests were designed to compare property variations across the bottom, middle, and top sections of the coco wood stem. Each property was assessed using 150 specimens per test type (Table 1).

Table 1

Description of test specimens of Yellow-Fruited West African Tall Coco Wood

Tests conducted	Properties evaluated	Specimen geometry (mm)	No. Of specimens
Physical	Moisture content	20 × 20 × 20	150
	Density	20 × 20 × 20	150
	Vol. swelling/shrinkage	20 × 20 × 100	150
Mechanical	Static bending	20 × 20 × 300	150
	Compression (ǁ grain)	20 × 20 × 60	150
	Shear (ǁ grain)	50 × 50 × 50	150
	Hardness	50 × 50 × 150	150

Physical Properties determination

Moisture content, density, and volumetric swelling/shrinkage were determined according to BS 373:1957 and ASTM D1037-06a standards.

Moisture Content

Specimens (20×20×20mm) were oven-dried at **103±2°C** until constant weight. Moisture content (%) was calculated as:

$$MC = \left(\frac{\mathrm{Mw-Md}}{\mathrm{Md}}\right) x\ 100\ (\%) \tag{1}$$

where:
MC – moisture content, in percent (%);
Mw – wet weight of specimen, in grams (g);
Md– oven-dry weight of specimen, in grams (g).

Density

Specimens were weighed (accuracy ±0.001g) and measured (accuracy ±0.001mm). Density was expressed as oven-dry mass divided by volume, and standardized to **12% MC** using:

$$\rho = \frac{Md\times 1000}{V} \tag{2}$$

where:
ρ – density, in kilograms per cubic metre (kg/m^3)
Md– oven-dry mass of specimen, in kilograms (kg);
V – volume of specimen, in cubic metres (m^3).

Volumetric Swelling & Shrinkage

Specimens (20×20×100mm) were submerged in water at 26°C for 24 hours, then reconditioned to 12% MC. Dimensional changes were computed as:

$$S = \left(\frac{\mathrm{Ds-Dd}}{\mathrm{Dd}}\right) \times 100\ (\%) \tag{3}$$

where:
S – swelling, in percent (%);
Ds – dimension in swollen state, in millimetres (mm);
Dd– dimension in dry state, in millimetres (mm).

$$\mathrm{VS} = \frac{\mathrm{Vg-Vd}}{\mathrm{Vg}} \times 100\ (\%) \tag{4}$$

where:
VS – volumetric shrinkage, in percent (%);
Vg– green (fresh) volume, in cubic metres (m^3);
Vd– oven-dry volume, in cubic metres (m^3).

Fig. 4.
Determination of the physical properties of coco wood: a. samples used in density tests; b. weighing the sample to determine the moisture content; c. measuring dimensional stability.

Mechanical Properties determination

Mechanical strength tests were conducted according to BS 373:1957 using a Hegewald & Peschke (Inspekt 50kN) Universal Testing Machine (UTM). All tests were performed at a controlled loading rate, and specimen dimensions were prepared following standard requirements.

Compressive Strength (parallel to grain)

Specimens (20×20×60mm) were tested at a loading rate of 0.6mm/min until failure. Deformations were recorded with an accuracy of 0.002mm. The compressive stress was calculated using:

$$\sigma cpl = \frac{\mathrm{Wmax}}{A} \qquad (5)$$

where:
σcpl = compressive strength parallel to the grain (MPa);
Wmax = maximum load at failure (N);
A = cross-sectional area of specimen (mm²).

Janka Hardness

A steel ball (11.3mm diameter) was pressed into specimens (50×50×150mm) until half its diameter was embedded. A 50kN load cell with a depth gauge was used to measure the resistance.

Static Bending

Specimens (20×20×300mm) were subjected to three-point bending at a loading rate of 6.5mm/min. The modulus of elasticity (MOE) and modulus of rupture (MOR) were calculated using the following formulas:

$$MOE = \frac{PL^3}{4bd^3\Delta} \qquad (6)$$

where:
P' = load at proportional limit (N);
L = span length of specimen (mm);
b = breadth (mm);
d = depth (mm);
Δ= deflection at proportional limit (mm).

$$MOR = \frac{3PmaxL}{2\mathrm{bh}^3} \qquad (7)$$

where:
Pmax = maximum load at failure (N);
L= span length of specimen (mm);
b= breadth (mm);
h= depth (mm).

Shear Strength (parallel to grain)

Specimens (50×50×50mm) were loaded at a rate of 0.06mm/min until shear failure occurred. The shearing strength was calculated using the formula:

$$\tau = \frac{3V}{2bd} \qquad (8)$$

where:
τ = shear strength parallel to grain (MPa);
V = maximum shear load (N);
b = breadth of specimen (mm);
d = depth of specimen (mm).

Fig. 5.
Mechanical property testing of coco wood: a. Shearing; b. hardness; c. compression; d. bending.

Data Analysis

Data were analyzed using Statistica software. Descriptive statistics were generated, and repeated measures ANOVA was applied to compare properties across tree sections (bottom, middle, top). Statistical significance was determined at $p < 0.05$ with 95% confidence intervals.

RESULTS AND DISCUSSION

Table 2

Physical Properties of Yellow Coco Wood-Inner and Outer Zones

Section	Zone	Tree 1	Tree 2	Tree 3
Moisture Content (%)				
Bottom	Inner	96.8 ± 34.5	103.2 ± 36.1	101.5 ± 35.7
Bottom	Outer	100.4 ± 39.2	105.8 ± 40.7	103.7 ± 39.5
Middle	Inner	106.9 ± 16.2	104.2 ± 18.1	107.3 ± 17.5
Middle	Outer	108.3 ± 15.6	103.7 ± 17.9	105.8 ± 17.1
Top	Inner	184.2 ± 18.7	187.6 ± 17.5	185.8 ± 18.1
Top	Outer	186.5 ± 18.2	188.3 ± 17.1	187.1 ± 17.8
Density (kg/m³)				
Bottom	Inner	472.1 ± 81.2	476.8 ± 80.6	474.9 ± 80.9
Bottom	Outer	478.6 ± 82.5	482.3 ± 79.8	480.2 ± 80.7
Middle	Inner	439.2 ± 51.3	443.6 ± 50.9	441.7 ± 51.0
Middle	Outer	441.6 ± 52.0	446.2 ± 49.7	443.4 ± 50.8
Top	Inner	318.1 ± 20.2	321.2 ± 19.4	319.7 ± 19.8
Top	Outer	320.4 ± 20.0	322.5 ± 19.3	321.1 ± 19.6
Volumetric Shrinkage (%)				
Bottom	Inner	12.4 ± 1.2	11.9 ± 1.5	12.1 ± 1.3
Bottom	Outer	12.7 ± 1.1	12.3 ± 1.2	12.5 ± 1.3
Middle	Inner	11.6 ± 1.4	11.8 ± 1.3	12.0 ± 1.2
Middle	Outer	11.8 ± 1.5	12.1 ± 1.4	11.9 ± 1.3
Top	Inner	10.2 ± 1.1	10.5 ± 1.3	10.3 ± 1.2
Top	Outer	10.4 ± 1.2	10.6 ± 1.1	10.5 ± 1.3
Swelling Coefficient (%)				
Bottom	Inner	0.29 ± 0.03	0.28 ± 0.04	0.27 ± 0.03
Bottom	Outer	0.31 ± 0.04	0.30 ± 0.03	0.29 ± 0.04
Middle	Inner	0.27 ± 0.03	0.26 ± 0.02	0.27 ± 0.03
Middle	Outer	0.28 ± 0.03	0.27 ± 0.03	0.26 ± 0.02
Top	Inner	0.23 ± 0.02	0.24 ± 0.03	0.23 ± 0.02
Top	Outer	0.24 ± 0.03	0.25 ± 0.02	0.24 ± 0.02

Moisture Content and Density

Moisture content is a critical factor influencing wood strength, dimensional stability, and durability. In Yellow-Fruited West African Tall coco wood, MC generally increased from the outer to inner zones and from the bottom to the top of the stem. For example, Tree 1 recorded values ranging from 96.8% (bottom inner) to

186.5% (top outer), with Trees 2 and 3 showing similar patterns. These findings align with reports on Malaysian coco wood, where inner zones consistently exhibited higher MC than outer zones (Khairul 2022). Broader reviews also confirm that MC increases toward the top and inner regions of the stem (Fathi et al. 2023). A repeated-measures ANOVA revealed no significant differences in outer-zone MC among trees, $F(2,6) = 0.09$, $p = 918$, with a small effect size ($\eta^2_p = 0.04$), suggesting relatively uniform moisture distribution across samples.

Density

Density exhibited a marked axial decline, decreasing from 472.1-476.8kg·m^{-3} in bottom inner zones to 318.1-321.2kg/m^3 in top inner zones, with similar trends observed in the outer zones. A repeated-measures ANOVA confirmed significant outer-zone differences, $F\ (2,4) = 64.15$, $p = 001$, with a very large effect size ($\eta^2_p = 0.97$), underscoring the strong practical relevance of axial variation. These results agree with Hamza et al. (2001), who reported decreasing density from butt to top but increasing density radially from inner to outer zones in coco stems.

Volumetric Shrinkage and Swelling

Volumetric shrinkage decreased progressively from bottom to top, ranging from 12.4–10.2% in inner zones and 12.7–10.4% in outer zones. ANOVA revealed no significant differences among trees, $F(2,4) = 0.03$, $p = .97$, indicating that although shrinkage decreases axially, variations are not statistically meaningful. Comparable results were reported by Ogunjobi et al. (2018), where volumetric shrinkage decreased from base to top (8.54% vs. 9.25%) and showed radial differences (mean 9.82% from inner to outer zones), suggesting similar patterns of shrinkage across species.

Swelling also decreased slightly with tree height, ranging from 0.29-0.23% in inner zones and 0.31-0.24% in outer zones. Although not statistically significant ($F(2,4) = 3.25$, $p = 145$), the large effect size ($\eta^2_p = 0.62$) indicates practical relevance. Comparable observations have been made in other species, where swelling is strongly influenced by dimensional changes under varying humidity, reflecting its importance for evaluating wood stability (Sargent 2019).

Table 3

Mechanical Properties of Yellow-Fruited Coco Wood – Inner and Outer Zones

Property	Section	Tree 1 inner	Tree 1 outer	Tree 2 inner	Tree 2 outer	Tree 3 inner	Tree 3 outer
Compressive strength ∥ grain (MPa)	Bottom	18.2 ± 2.4	17.5 ± 2.6	17.8 ± 2.3	17.2 ± 2.5	18.5 ± 2.5	17.7 ± 2.7
	Middle	17.6 ± 2.5	17.0 ± 2.6	17.2 ± 2.4	16.6 ± 2.5	17.9 ± 2.6	17.1 ± 2.7
	Top	17.0 ± 2.3	16.5 ± 2.4	16.7 ± 2.2	16.2 ± 2.3	17.2 ± 2.4	16.8 ± 2.5
Shear strength ∥ grain (MPa)	Bottom	14.0 ± 1.5	13.6 ± 1.6	13.8 ± 1.4	13.4 ± 1.5	14.2 ± 1.6	13.7 ± 1.6
	Middle	13.6 ± 1.5	13.3 ± 1.5	13.4 ± 1.4	13.1 ± 1.5	13.8 ± 1.5	13.4 ± 1.5
	Top	13.2 ± 1.4	12.9 ± 1.4	13.0 ± 1.3	12.8 ± 1.4	13.3 ± 1.4	13.0 ± 1.4
Modulus of Elasticity (MOE) (MPa)	Bottom	4520 ± 560	4450 ± 570	4470 ± 550	4400 ± 560	4550 ± 580	4480 ± 590
	Middle	4450 ± 550	4380 ± 560	4400 ± 540	4335 ± 550	4480 ± 560	4410 ± 570
	Top	4380 ± 540	4320 ± 550	4330 ± 530	4270 ± 540	4420 ± 550	4350 ± 560
Modulus of Rupture (MOR) (MPa)	Bottom	18.0 ± 0.8	17.7 ± 0.8	17.7 ± 0.7	17.4 ± 0.8	18.2 ± 0.8	17.9 ± 0.8
	Middle	17.6 ± 0.8	17.3 ± 0.7	17.3 ± 0.7	17.0 ± 0.7	17.8 ± 0.8	17.5 ± 0.8
	Top	17.2 ± 0.7	16.9 ± 0.7	16.9 ± 0.6	16.6 ± 0.7	17.4 ± 0.7	17.1 ± 0.7
Hardness – Radial (MPa)	Bottom	11.4 ± 0.8	11.0 ± 0.7	11.2 ± 0.8	10.9 ± 0.7	11.5 ± 0.8	11.1 ± 0.7
	Middle	11.2 ± 0.8	10.9 ± 0.7	11.0 ± 0.7	10.8 ± 0.7	11.3 ± 0.8	11.0 ± 0.8
	Top	11.0 ± 0.7	10.7 ± 0.7	10.8 ± 0.7	10.5 ± 0.7	11.1 ± 0.7	10.8 ± 0.7
Hardness – Tangential (MPa)	Bottom	11.5 ± 1.0	11.1 ± 1.0	11.3 ± 0.9	11.0 ± 1.0	11.6 ± 1.0	11.2 ± 1.0
	Middle	11.3 ± 1.0	11.0 ± 0.9	11.1 ± 0.9	10.9 ± 0.9	11.4 ± 1.0	11.1 ± 1.0
	Top	11.1 ± 0.9	10.8 ± 0.9	10.9 ± 0.8	10.7 ± 0.9	11.2 ± 0.9	10.9 ± 0.9

Mechanical Properties

Compressive Strength

Compressive strength declined both radially (inner → outer) and axially (bottom → top), with Tree 1 ranging from 18.2MPa (bottom inner) to 16.5MPa (top outer). This pattern reflects a structural gradient where denser, mechanically stronger tissue is concentrated at the base and core. Similar trends have been reported in West African Tall coco wood (Rana et al. 2015), highlighting the importance of stem position in determining strength. ANOVA confirmed highly significant variation ($F = 78.4$, $p < 001$, $\eta^2_p = 0.98$), indicating that stem location is a major determinant of compressive performance, with implications for selecting basal wood in load-bearing furniture components.

Shear Strength

Shear strength also decreased along radial and axial directions; for example, Tree 1 dropped from 14.0MPa (bottom inner) to 12.9MPa (top outer). Rüggeberg et al. (2009) similarly emphasized that shear properties are influenced by fiber orientation and peripheral tissue distribution. ANOVA results ($F = 49.0$, $p = .002$, $\eta^2_p = 0.96$) highlight significant variability, suggesting that lower-stem wood provides better resistance to shear stresses in joinery applications, while upper zones may be better suited to non-structural parts.

Modulus of Elasticity (MOE) and Modulus of Rupture (MOR)

MOE, a key indicator of stiffness, decreased both radially and axially, with Tree 1 recording 4520MPa (bottom inner) versus 4320MPa (top outer). The highly significant ANOVA outcome ($F = 1687$, $p < .001$, $\eta^2_p = 1.00$) underscores the strong influence of stem location on stiffness. Comparable declines have been reported in Scots pine (Jelonek and Tomczak 2014) and tropical rainforest species (Mclean et al. 2011), where reduced fiber density and alignment toward the periphery and upper stem account for this pattern. These results reinforce the suitability of basal coco wood for structural furniture elements requiring high rigidity.

MOR decreased slightly with height and from core to periphery (Tree 1: 18.0MPa bottom inner vs. 16.9MPa top outer). Although ANOVA showed no significant differences ($F = 6.85 \times 10^{15}$, $p = 1.00$), this minor axial decline mirrors trends observed in tropical species (Matan and Buhnnum 2003, Adedipe 2004). The relative stability of MOR suggests that coco wood maintains adequate bending resistance across the stem, allowing even upper sections to be used for moderate structural applications.

Hardness

Radial hardness decreased from bottom to top (Tree 1: 11.4 → 10.7MPa), with significant variation ($F = 37.0$, $p = .003$, $\eta^2_p = 0.95$), while tangential hardness remained relatively uniform (11.5–10.9MPa, $p = 1.00$). Similar axial patterns have been observed in other species (Fu et al. 2021), where hardness is linked to density gradients. The relative uniformity of tangential hardness suggests coco wood provides consistent wear resistance across stem sections, making it suitable for surfaces subject to moderate abrasion.

CONCLUSION

This study demonstrated that 20-year-old Yellow-Fruited West African Tall coco wood exhibits pronounced radial and axial variations in its physical and mechanical properties. Moisture content increased from the outer to inner zones and from the bottom to the top, while density, compressive strength, shear strength, modulus of elasticity (MOE), modulus of rupture (MOR), and radial hardness generally decreased along the same directions. Tangential hardness, however, remained relatively stable across zones.

Despite these variations, all stem sections satisfied baseline requirements for furniture construction. The bottom and middle stem zones, characterized by higher density and stiffness, are most suitable for load-bearing furniture components, whereas the upper zones are more appropriate for lightweight or decorative parts. These findings confirm that Yellow-Fruited West African Tall coco wood is a sustainable and versatile raw material, offering both environmental and economic benefits by reducing reliance on traditional hardwoods and supporting local timber diversification.

RECOMMENDATIONS

1. Bottom and middle zones should be prioritized for structural furniture components, while upper sections should be directed toward decorative or non-load-bearing applications.
2. Proper drying and surface finishing are necessary to minimize moisture-related dimensional changes and enhance service durability.
3. Adoption of coco wood in the local furniture industry should be encouraged through training, technology transfer, and demonstration of value-added products.
4. Further studies on durability, preservative treatments, and long-term performance under varying environmental conditions are recommended to broaden industrial acceptance.

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