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Influence of CCA-B Preservative Treatment and Surface Finishing on the Mechanical Characteristics of Heartwood and Sapwood of Petersianthus Macrocarpus (Essia)

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Abstract
The sustainable utilization of lesser-used species (LUS) as alternatives to overexploited traditional timbers for furniture and structural applications is increasingly advocated in Ghana's forestry sector [1,2]. This study evaluated the mechanical performance of Chromated Copper Arsenate Type B (CCA-B) pressure-treated and surface-finished heartwood and sapwood of Petersianthus macrocarpus (Essia) and Ceiba pentandra (Onyina) as the control wood species. Preservative (CCA-B) treatment and surface finishes (varnish, shellac and lacquer) were applied to enhance strength and service performance the LUS for indoor and semi-exposed conditions. A total of 80 treated and non-treated samples were prepared and tested in accordance with BS 373 (1957) at 12% moisture content. Results showed that mean compression parallel to grain values ranged from 50.84 – 52.27 N/mm² for heartwood, 44.80 – 51.67 N/mm² for sapwood and 13.83 – 19.30 N/mm² for control samples. The modulus of rupture (MOR) and modulus of elasticity (MOE) ranged from 106.01 – 113.42 N/mm²; 17,965.6 – 19,380.2 N/mm² (heartwood), 90.99 – 97.18 N/mm²; 16,012 – 20,660.4 N/mm² (sapwood), and 34.61 – 38.99 N/mm² 5,138 – 7,597.2 N/mm² (control) respectively. Sapwood treated solely with CCA-B or surface finishes exhibited compression values of 23.00 – 45.03 N/mm², MOR of 75.21 – 81.70 N/mm² and MOE 16,269 - 18,892 N/mm². The findings indicate that CCA-B treatment and surface finishing significantly (p<0.05%) improved the strength properties of P. macrocarpus, supporting its suitability as a viable LUS for furniture and structural applications in Ghana [3,4].

Keywords: Traditional, Hardwood, Impregnated, Control, Lesser-Used Species, Pressure-Treated

1. Introduction

Wood remains one of the most versatile structural materials because of its favourable strength-to-weight ratio, aesthetic appeal and renewability. However, when used in ground contact or exposed conditions, it is susceptible to biodeterioration by fungi, termites and other wood-destroying organisms [5]. In Ghana, a limited number of naturally durable commercial timber species (CUS), notably *Entandrophragma cylindricum* (Sapele), *Enthandrophragma angolense* (Edinam), *Khaya ivorensis* (Mahogany), *Terminalia superba* (Ofram), *Tectona grandis* (Teak) and Milicia excelsa (Odum) are preferred for furniture, bridges and outdoor structures due to their known inherent mechanical properties [6,7]. The promotion of the abundantly LUS including *P. macrocarpus* could result in high demand/supply timber, less pressure, costs reduction, forest sustainability and survival of timber industries within Ghana [2,8].

Consequently, a desiring attention has shifted toward researching into the prospects of lesser-utilised species (LUS) such as *Albizia ferruginea*, *Cola gigantea, Sterculia rhinopetala, Antiaris toxicaria* and *Petersianthus macrocarpus* (Essia), which remain underexploited, mainly because of the perceived low strength and non-durability of their properties [7,9]. Studies in Ghana have demonstrated that preservative treatment can significantly enhance the durability and service life of non-durable timbers, thereby expanding their structural applications [4,10]. Therefore, continued studies on treatment of the abundant LUS is required to expand the timber supply to furniture industries and sustainability of the forests.

Pressure impregnation with Chromated Copper Arsenate Type B (CCA-B) remains effective against fungal and insect attack, though its environmental and health implications necessitate controlled use and compliance with international standards and its usage instruction [11,12]. Surface finishing further improves dimensional stability, aesthetics and coating performance of treated wood [5]. However, information on the enhancement of some mechanical properties of preservative treated and surface-finished LUS remains scanty.

P. macrocarpus was selected for the test because, it is classified among Ghana's lesser-utilised timber species (LUS) which remain underexploited despite their availability in the high forest zone [7,8,13]. Promoting the utilization of such species has been identified as a key strategy for reducing pressure on overharvested commercial timbers and enhancing sustainable forest management in Ghana [2,6]. *Ceiba pentandra* (Onyina), a fast-growing but low-density and non-durable species widely used for temporary applications such as formwork was also selected as the control due to its well-documented treatability and low strength properties [6,14].

Hence, this study delved in to ascertain some mechanical properties including compression parallel to grain, MOR and MOE of a CCA-B pressure-treated and surface-finished *P. macrocarpus* wood for its utilisation for furniture and structural applications in Ghana.

2. Materials and Methods

2.1. Materials and Preparation of Test Samples

Logs of both species, *P. macrocarpus* and *C. pentandra* (control) were obtained from Logs and Lumber Limited (LLL), a timber industry that deals with export of timber and timber products in Ashanti region, Kumasi - Ghana. The company owns and operates within forest concessions situated approximately between longitude 2°3′ W and latitude 6°7′ N in the moist evergreen forest zone at Sui near Sefwi-Akontombra (Figure 1) in the Western Region of Ghana where the two trees were obtained, sawn into logs and transported to [6,14]. The moist evergreen forest is characterised by high annual rainfall and relative humidity, conditions that influence wood density, anatomical structure and preservative treatability [2,5]. The logs were further converted into defect-free boards (200 x 300 x 2440 mm), and subsequently prepared into test samples sizes in accordance with BS 373: 1957 and BS EN 330:2014 (Table 1). Figure 2 shows heartwood (A) and sapwood (B) of *P. macrocarpus* and *C. pentandra* (C) samples stacked after machining to air-dry for two weeks.

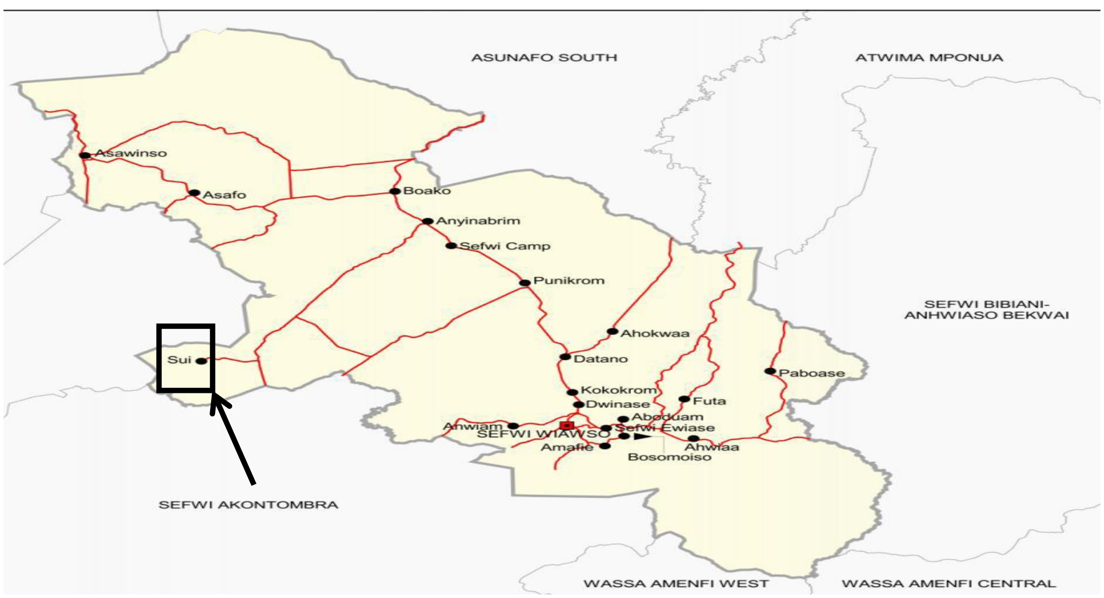

Figure 1: District Map of Sefwi-Wiawso
***Source:** Ghana Statistical Service. GIS, (2010)

Description	Samples Section	*P. macrocarpus* (Heartwood and Sapwood)	*C. pentandra*
Compression parallel to grain	60 x 20 x 20	60	30
MOR and MOE	300 x 20 x 20	60	30
* Longitudinal x radial x tangential (mm x mm x mm)			

Table 1: Dimensions of Samples for the Various Tests

Figure 2: *P. Macrocarpus Hardwood* (A) and Sapwood (B) and C. *Pentandra Samples* (C)

3. Methods

3.1. Determination of Mechanical Properties of Heartwood, Sapwood, and *Ceiba Pentandra*

All mechanical tests in this study were carried out at the Furniture and Testing Laboratory at the Council for Scientific and Industrial Research (CSIR) of the Forestry Research Institute of Ghana (FORIG). All samples (300 x 20 x 20 cm) were conditioned at room temperature and relative humidity of 65 ± 1 °C, [15-19]. Testing was performed using an Instron 4482 universal testing machine (UTM), Conditioning to this moisture content is critical, as wood's mechanical behaviour (MOR, MOE and compression strength) is highly sensitive to moisture variation within its surroundings [2,5,7]. Static bending tests were conducted on of 30 samples (heartwood and sapwood) samples of *P. macrocarpus* and *C. pentandra* each was used in this study. *C. Pentandra* samples were not categories into heartwood and sapwood due to the indistinct nature of section of this timber species. The samples tested using a three-point load system on the Instron 4482 in accordance with BS 373:1957 (Figure 3). Each sample was placed on trunnion roller bearings over a clear span of 28 cm to allow horizontal deflection (Figure 4). A continuous crosshead load of 5.6 N/mm² was applied at midspan until sample fractures (Figure 5). The MOR and MOE values was captured in an attached computer to the Instron 4482 and recorded.

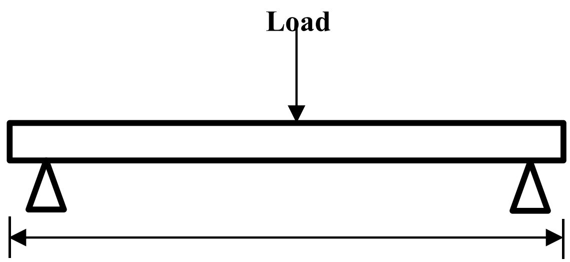

Figure 3: Schematic Diagram of Sample on

Figure 4: Sample Under Load on UTM

Figure 5: Sample Indicates Failure Upon

However, in the absence of Instron 4482 to conduct static bending on samples, the MOR and MOE can be computed using equation 1 for MOR and equation 2 for MOE respectively.

$R = 3PL/2bd^2$…………………………..(1)

Where: R = modulus of rupture (N/mm²), P = maximum load applied (N); L = span of the beam (mm), b = breadth of sample (mm), d^2 = depth of sample (mm).

$E = \frac{P'L^2}{4\Delta A^2}$……………………………(2)

Where: E = Young's modulus of elasticity (N/mm²), P' = load at limit of proportionality (N), L = span of sample (mm), Δ' = deflection at midspan at limit of proportionality (mm), A = cross-sectional area normal to load (mm²). The accuracy of measurement was ±0.01 N/mm² for position, ±0.1% for duration, and ±0.5% for loading [20-22].

3.2. Compression Strength Parallel to Grain of Heartwood, Sapwood and *C. Pentandra*

A total of 30 samples comprising of heartwood and sapwood of *P. macrocarpus*, and *Ceiba pentandra* samples each were tested for compression parallel to grain [15]. Sample dimensions (60 x 20 x 20 mm) were measured using a precision calliper before testing. Compression tests were performed on an Instron 4482 universal testing machine, with a continuous load applied at 5.6 N/mm² until rupture [23,24]. The maximum load (P. max) and deflection were recorded automatically, with positional accuracy ±0.01 mm, speed ±0.1%, and load ±0.5%. In the absence of Instron, equation 3 can be used to compute values of compression parallel to grain.

$C=K/H$……………………………..(3)

Where: C = compression stress at maximum load (kN/cm²), K = maximum load applied at mid-point of sample (kN), H = cross-sectional area of sample (cm²). Diagrammatic illustrations of the compression setup and sample placement are shown in figures 6 and samples under load on Instron 4482 (Figure 7).

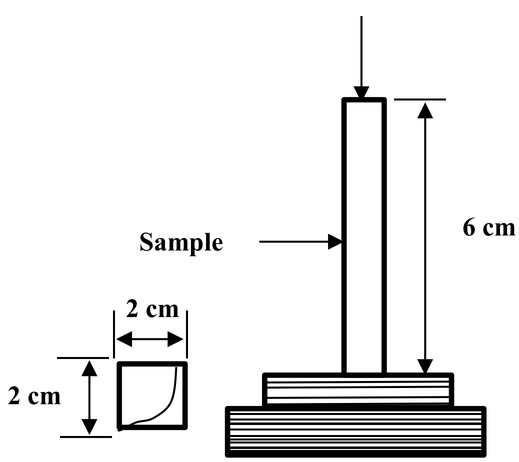

Figure 6: Schematic Diagram of Sample

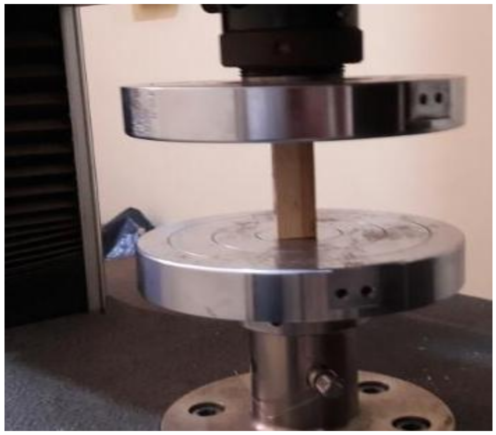

Figure 7: Schematic Diagram of Sample Under Load on Instron 4482 for Compression Parallel to Grain Tests

4. Results

4.1. Modulus of Rupture of *P. MACROCARPUs* Heartwood, Sapwood, and *C. Pentandra*

The mean modulus of rupture (MOR) values for all samples at 12% moisture content across different treatment schedules ranged from 34.61 to 113.42 N/mm² (Figure 8). Among *P. macrocarpus* heartwood samples, MOR mean values decreased in the following order: heartwood treated with preservative and shellac (PMHS) 113.42 N/mm² > heartwood with preservative and varnish (PMHV) 112.34 N/mm² > heartwood with preservative and lacquer (PMHL) 109.20 N/mm² > non-treated heartwood (PMH) 106.01 N/mm². For sapwood, MOR mean values followed the descending order as sapwood treated with preservative and varnish (PMSV) 97.18 N/mm² > sapwood with preservative and shellac (PMSS) 96.18 N/mm² > non-treated sapwood (PMS) 93.42 N/mm² > sapwood with preservative and lacquer (PMSL) 90.99 N/mm² (Figure 8). Sapwood samples treated with only surface finishes or preservative showed further reduced MOR mean values as follows, varnish (OV) 81.70 N/mm² > lacquer (OL) 81.78 N/mm² > shellac (OS) 80.49 N/mm² > only preservative (45.04 N/mm²). This demonstrates that surface finishes or preservative alone provided limited reinforcement against bending stresses for structural [2,7]. Those of *Ceiba pentandra* (control) samples recorded the lowest MOR mean values across all treatments. The ascending order was, varnish only (CPV) 34.61 N/mm² < non-treated (CP) 35.42 N/mm² < CCA-B + shellac < (CPS) 37.17 N/mm² < CCA-B + lacquer (CPL) 38.99 N/mm² (Figure. 8). Statistical analysis revealed no significant differences within groups of heartwood, sapwood, and *C. pentandra* treatment ($p > 0.05$) (Table 2). Overall, the heartwood consistently exhibited the highest bending strength, followed by sapwood with *C. pentandra* showing the lowest mean MOR. Figure 9 illustrates the mean MOR values along with standard error bars for each treatment group. These results align with recent Ghanaian studies emphasizing that preservative and surface finish treatments enhance mechanical performance, particularly making *P. macrocarpus* a promising LUS for furniture and structural applications [2,4,25].

Moisture Content.						
Source of variation	**SS**	**Df**	**MS**	**F**	**P-values**	**F-crit**
Between Groups	21545.42	15	1436.36	0.77	0.7 *	1.79
Within Groups	14.8414.34	80	1855.18			
Total	169959.76	95				

Table 2: ANOVA for MOR (N/mm2) of P. Macrocarpus (Heartwood and Sapwood) and C. Pentandra Tree Species

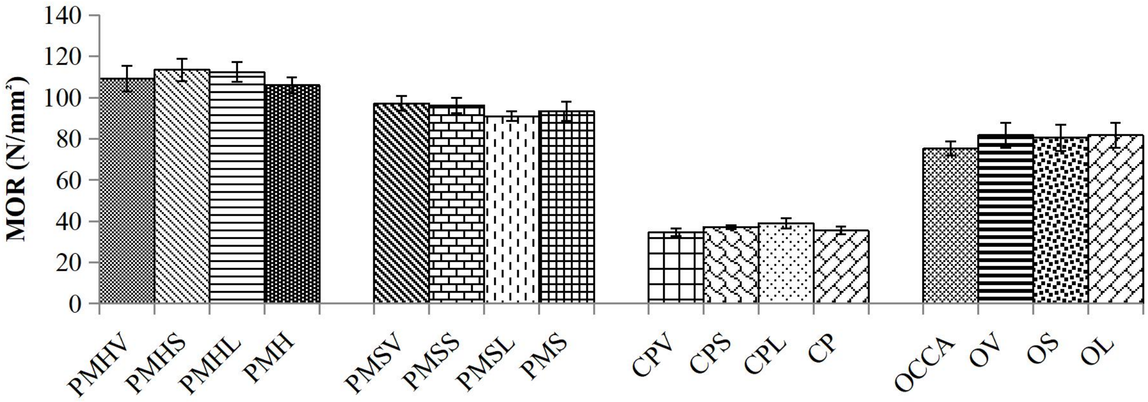

Figure 8: Mean MOR OF Treated and Non-Treated Heartwood, Sapwood and C. Pentandra

Legend: PMHV = heartwood treated and varnish, PMHS = heartwood treated and shellacked, PMHL = heartwood treated and lacquered, PMH = heartwood non-treated, PMSV = Sapwood treated and varnished, PMSS = Sapwood treated and shellacked, PMSL = Sapwood treated and lacquered, PMS = Sapwood non-treated, CPV = C. pentandra treated and varnished, CPS = C. pentandra treated and shellacked, CPL = C. pentandra treated and lacquered, CP = C. pentandra non-treated, OCCA = Sapwood only preservative treated, OV = Sapwood only varnish, OS = Sapwood only shellacked, OL = Sapwood only lacquer.

4.2. MOE of *P. Macrocarpus* Heartwood, Sapwood and *C. Pentandra*

The MOE values for all treated and non-treated heartwood, sapwood and *C. pentandra* at 12% moisture content ranged from 5,138 to 20,660.4 N/mm² (Figure 9). Overall, *P. macrocarpus* exhibited substantially higher stiffness compared to *C. pentandra* as follows; 17,965.6 N/mm² (PMHS) < 18,292 N/mm² (PMHV) < 18,415 N/mm² (PMHL) < 19,380.2 N/mm² (non-treated heartwood) (Figure 9). Interestingly, non-treated heartwood recorded the highest stiffness, suggesting that preservative and coating applications slightly reduced elasticity, possibly due to chemical modification of cell wall components or microstructural changes during treatment [4,23]. However, the variations are insignificant among the treated samples to those non-treated. Sapwood followed a comparable trend as Treated samples ranked as; 16,012.8 N/mm² (PMSS) < 16,328.4 N/mm² (PMSL) < 16,422 N/mm² (PMSV) < 20,660.4 N/mm² (non-treated) sapwood (Figure 9). In contrast, *C. pentandra* recorded significantly lower MOE mean values, decreasing as follows: 7,597.2 N/mm² (CPS) > 6,565.8 N/mm² (CPV) > 6,315 N/mm² (CPL) > 5,138 N/mm² (non-treated CP) (Figure 9). For sapwood treated exclusively with preservative or surface finishes, MOE mean values were ranked as 18,892 N/mm² (preservative only) > 17,639.2 N/mm² (shellac only) > 16,269 N/mm² (lacquer only) > 15,658.8 N/mm² (varnish only). Statistical analysis revealed no significant differences ($p < 0.05$) between treated and non-treated heartwood, sapwood, and *C. pentandra* samples (Table 3). Quantitatively, heartwood generally exhibited superior stiffness, followed by sapwood, while *C. pentandra* consistently showed the lowest MOE values. These findings agree with recent research indicating that wood density, extractive content, and treatment chemistry strongly influence elastic behaviour in tropical hardwoods [2,4,25].

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	1679977198	15	111998480	44.84308	4.14*	1.825586
Within Groups	159844128	64	2497564.5			
Total	1839821326	79				

Table 3: ANOVA for MOE (N/mm2) for *P. Macrocarpus* (Heartwood and Sapwood) and *C. Pentandra* Samples at 12% MC

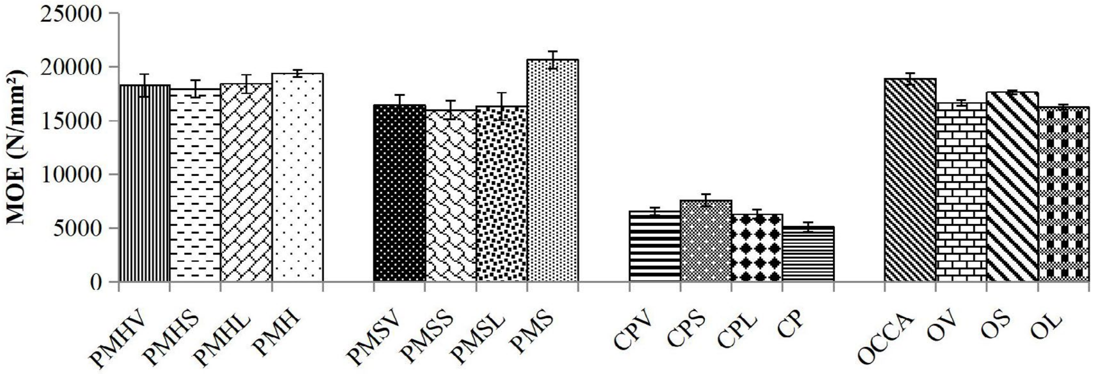

Figure 9: Treated and Non-Treated Heartwood, Sapwood and Control Samples

Legend: PMHV = heartwood treated and varnish, PMHS = heartwood treated and shellacked, PMHL = heartwood treated and lacquered, PMH = heartwood non-treated, PMSV = Sapwood treated and varnished, PMSS=Sapwood treated and shellacked, PMSL=Sapwood treated and lacquered, PMS = Sapwood non-treated, CPV = C. pentandra treated and varnished, CPS = C. pentandra treated and shellacked, CPL = C. pentandra treated and lacquered, CP = C. pentandra non-treated, OCCA = Sapwood only preservative treated (CCA-B), OV = Sapwood only varnish, OS = Sapwood only shellacked, OL = Sapwood only lacquer.

4.3. Compression Parallel to Grain of Heartwood, Sapwood, and *C. Pentandra*

The mean maximum crushing strength parallel to grain at 12% moisture content of all samples ranged from 13.83 to 52.27 N/mm² (Figure 10). Among *P. macrocarpus* heartwood samples treated with CCA-B and surface finishes, the compression strength in decreasing order were PMHL (51.94 N/mm²) > PMHV (51.41 N/mm²) > PMHS (50.84 N/mm²) (Figure 10). Similarly, *P. macrocarpus* sapwood samples treated with preservative and surface finishes mean compression parallel to grain values were PMHL (51.67 N/mm²) > PMHV (51.54 N/mm²) > only CP. CCA-B (45.04 N/mm²) > PMSS (44.80 N/mm²) (Figure 10). Sapwood treated only surface finishes had mean values in decreasing order as; OV (26.47 N/mm²) > OS (23.13 N/mm²) > OL (23.00 N/mm²). *C. pentandra*, used as a control, recorded the lowest mean compression strength values among all treated groups in decreased order as CCA-B + shellac (CPS) 19.30 N/mm² > CCA-B + varnish (OV) 19.00 N/mm² > CCA-B + lacquer (OL) 14.45 N/mm² (Figure 10). The non-treated samples revealed mean values as heartwood (PMH) 52.27 N/mm² > sapwood (PMS) 49.38 N/mm² > *C. pentandra* (CP) 13.83 N/mm². ANOVA analysis indicated no significant difference (p>0.05) between the treated groups (Table 4). However, *P. macrocarpus* heartwood and sapwood compression strength indicates a medium class which is recommended for superior furniture and structural applications.

Source of variation	SS	Df	MS	F	P-values	F-crit
Between Groups	18.707.56	15	1247.17	125.17	2.02*	1.83
Within Groups	637.70	64	9.96			
Total	19345.26	79				

Table 4: ANOVA for Compression Parallel to Grain (N/mm2) of *P. Macrocarpus* (Heartwood and Sapwood) and *C. Pentandra* Tree Species at 12% Moisture Content

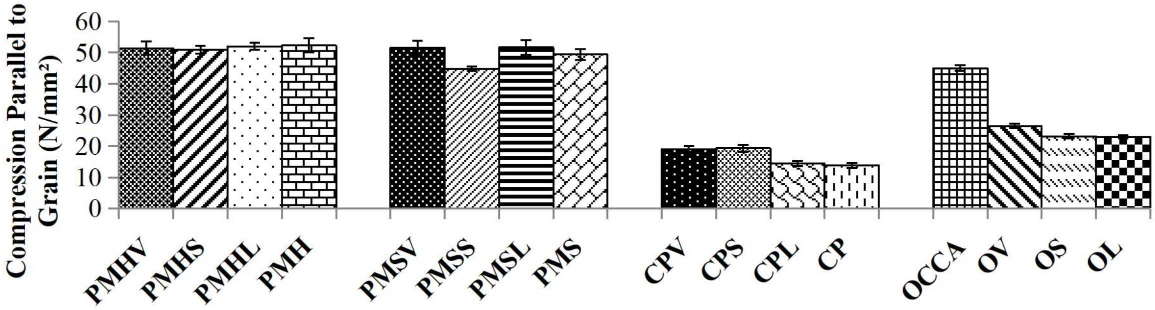

Figure 10: Compression Parallel to Grain of Treated and Non-Treated Heartwood, Sapwood and *C. Pentandra*

Legend: PMHV = heartwood treated and varnish, PMHS = heartwood treated and shellacked, PMHL = heartwood treated and lacquered, PMH = heartwood non-treated, PMSV = Sapwood treated and varnished, PMSS = Sapwood treated and shellacked, PMSL= Sapwood treated and lacquered, PMS = Sapwood non-treated, CPV = *C. pentandra* treated and varnished, CPS = *C. pentandra* treated and shellacked, CPL = *C. pentandra* treated and lacquered, CP = *C. pentandra* non-treated, OCCA = Sapwood only preservative treated (CCA-B), OV = Sapwood only varnish, OS = Sapwood only shellacked, OL = Sapwood only lacquer.

5. Discussion

5.1. MOR of *P. Macrocarpus* Heartwood, Sapwood and *Ceiba Pentandra*

The overall mean modulus of rupture (MOR) at 12% moisture content ranged from 34.61 to 113.42 N/mm² across heartwood, sapwood, and *C. pentandra* samples (Figure 11). Heartwood consistently recorded the highest bending strength values. In descending order, the mean MOR values were: 113.42 N/mm² (CCA-B + shellac) > 112.34 N/mm² (CCA-B + lacquer) > 109.20 N/mm² (CCA-B + varnish) > 106.01 N/mm² (non-treated heartwood). The superior MOR performance of heartwood can be attributed to its mature anatomical structure, including thicker fiber walls, reduced lumen diameter, and greater deposition of extractives, which collectively enhance resistance to bending failure [6,26]. Although the text previously associated heartwood strength with thin cell walls and low cellulose content, mechanical strength is generally correlated with higher density, greater cellulose crystallinity, and well-developed fiber structure [2,5]. The slight improvement observed in treated heartwood suggests that preservative–finish combinations may reduce micro-crack propagation and moisture-related weakening, thereby improving flexural performance [4,25]. The MOR values recorded for *P. macrocarpus* heartwood were comparable to those reported for Potrodom (*Erythrophleum suaveolens*) and Denya (*Cylicodiscus gabunensis*), species known for their strength and durability [27,28]. These similarities suggest that *P. macrocarpus* may serve as a potential substitute for these heavily exploited commercial species, supporting current efforts to promote lesser-utilized timbers in Ghana [2,7]. Sapwood exhibited moderately lower MOR values compared with heartwood. The treated sapwood ranked as follows: 97.18 N/mm² (CCA-B + varnish) > 96.18 N/mm² (CCA-B + shellac) > 93.42 N/mm² (non-treated) > 90.99 N/mm² (CCA-B + lacquer). The increase in MOR for preservative-treated sapwood relative to untreated samples indicates that CCA-B impregnation may contribute to enhanced rigidity through cell wall bulking and improved stress distribution [4,29]. The obtained sapwood values fall within the MOR range of *Muanga* timber (80–106 N/mm² at 12% MC) as reported, indicated a competitive structural performance [5]. Sapwood treated solely with preservative recorded a mean MOR of 75.21 N/mm², whereas sapwood treated only with surface finishes showed values of 81.70 N/mm² (varnish), 81.70 N/mm² (shellac), and 80.49 N/mm² (lacquer). The relatively modest improvement from surface finishes alone may be explained by their superficial application, which enhances surface hardness but does not significantly modify internal fiber bonding or structural integrity. In contrast, preservative impregnation penetrates deeper into the wood matrix, potentially influencing mechanical behavior [2,23]. *C. pentandra* recorded the lowest MOR values among all samples. Even when treated with preservative and finishes, its bending strength remained substantially lower than that of *P. macrocarpus*. This reduced performance is attributed to its low density, high proportion of parenchymatous tissues, and relatively weak sclerenchyma fiber network [5,28]. Such anatomical features limit its capacity to resist bending stresses, explaining its consistently low MOR values. According to the classification by Farmer (1972), MOR values at 12% MC are categorized as: Very low: < 50 N/mm², Low: 50–85 N/mm², Medium: 85–120 N/mm², High: 120–175 N/mm², Very-high > 175 N/mm² [13]. Based on this classification, treated and non-treated heartwood samples fall within the "medium" to upper-medium strength category (approaching high structural performance), while treated and non-treated sapwood samples fall within the "medium" category. Sapwood treated only with preservative or surface finishes generally falls within the "low" to lower-medium category. In contrast, all *C. pentandra* samples are classified as "very low." These ratings align with the established relationship between bending strength and wood density [2,13,29]. Overall, the MOR performance followed this ascending order; *C. pentandra* < sapwood (surface or preservative only) < treated sapwood < heartwood. Given its comparable bending strength to established commercial species such as Mahogany (*Khaya spp*.) and Teak (*Tectona grandis*), treated *P. macrocarpus* heartwood demonstrates strong potential as an alternative structural and furniture timber [2,5,7].

Promoting its utilization could reduce harvesting pressure on overexploited primary commercial species while maintaining structural performance standards.

5.2. MOE of Heartwood, Sapwood and *C. Pentandra*

The MOE mean values obtained for heartwood, sapwood and *C. pentandra* revealed marked variation among treatment types and wood categories. MOE, which expresses the stiffness of wood and its resistance to elastic deformation under load, remains a critical parameter in structural and serviceability assessments [13,30]. In structural design, MOE is indispensable in predicting deflection behavior of beams and other load-bearing members.

For heartwood treated with preservative and surface finishes, the mean MOE decreased in the following order: preservative + lacquer > preservative + varnish > preservative + shellac. This trend suggests that lacquer coatings may have contributed to slightly greater surface rigidity compared to varnish and shellac. Surface finishes can influence stiffness marginally by forming rigid films on the wood surface, although their contribution is generally secondary to intrinsic wood properties such as density and microstructure. In sapwood treated with preservative and surface finishes, MOE values followed a decreasing order of 16,422 N/mm² (varnished) > 16,328.4 N/mm² (lacquered) > 16,012.8 N/mm² (shellacked) (Figure 9).

However, sapwood treated with only surface finish recorded higher values overall, particularly shellac-treated samples (17,639.2 N/mm²), followed by varnish (16,658.8 N/mm²) and lacquer (16,269 N/mm²). Sapwood treated solely with preservative attained an even higher mean MOE of 18,892 N/mm². These findings suggest that preservative treatment alone may enhance apparent stiffness, potentially due to increased mass and cell wall impregnation, which can temporarily reduce cell wall flexibility. However, excessive chemical treatment or pressure impregnation may also induce microstructural changes that reduce elasticity in some cases.

For *C. pentandra*, samples treated with preservative and surface finishes exhibited comparatively low MOE values: 7,597.2 N/mm² (shellac) > 6,565.8 N/mm² (preservative + varnish) > 6,315 N/mm² (preservative + lacquer) (Figure 10). Non-treated samples showed a decreasing order of MOE as follows: 20,660.4 N/mm² (non-treated sapwood) > 19,380.2 N/mm² (non-treated heartwood) > 5,138 N/mm² (non-treated *C. pentandra*). The extremely low MOE of *C. pentandra* compared to heartwood and sapwood confirms its relatively poor stiffness characteristics. The reduced MOE of *C. pentandra* can be attributed to its anatomical structure, particularly its large vessel lumens and thin-walled fibres. Wood species with thick-walled fibres and smaller lumens tend to exhibit higher density, greater stiffness and improved resistance to bending stresses, as observed in heartwood and sapwood of *P. macrocarpus.*

In contrast, species with thin-walled fibres and larger lumens generally possess lower density and reduced stiffness [17]. Density remains one of the strongest predictors of MOE across hardwood species. Statistical analysis indicated significant differences ($p > 0.05$) between treated and non-treated heartwood, sapwood and C. pentandra. According to Farmer (1972), MOE serves as a reliable indicator of stiffness and structural performance [13].

The mean MOE values of heartwood and sapwood at 12% moisture content (MC) were consistent with the MOE strength classifications of TEDB (1994) and Upton & Attah (2003), which categorize wood as: Very low: < 9,000 N/mm², Low/Medium: 9,000–11,000 N/mm², Medium: 11,000–14,000 N/mm², High: 14,000–19,000 N/mm², Very high: ≥ 19,000 N/mm². Based on this classification, non-treated heartwood and sapwood at 12% MC were categorized as "very high", whereas heartwood and sapwood treated with both preservative and surface finish were classified as "high." This slight reduction in MOE following combined treatment may be associated with pressure treatment effects, which can alter cell wall structure and induce internal stresses [31,20]. The hardening effect of preservative chemicals may reduce flexibility, leading to earlier failure under bending loads compared to untreated samples, which retain greater elastic recovery capacity. Sapwood treated with only surface finish or only preservative remained within the "high" classification. In contrast, *C. pentandra* consistently fell within the "very low" MOE classification confirming its limited suitability for structural applications requiring high stiffness [31,20]. These results align with earlier findings by Addea-Mensah (1989), who reported an MOE of 13,790 N/mm² for *P. macrocarpus*, comparable to the heartwood MOE values obtained at 12% MC in this study [24].

According to Shrivastava (1997), MOE is fundamental in determining the serviceability performance of beams under load [30]. The classification framework provided by Farmer (1972) further supports the conclusion that heartwood and sapwood exhibit high inherent stiffness despite treatment variations [13]. Overall, the decreasing order of MOE across all samples was: Heartwood > Sapwood > *C. pentandra* This ranking reinforces the influence of anatomical structure, density and treatment interactions on stiffness performance. From a utilization perspective, heartwood and sapwood of *P. macrocarpus* demonstrate superior structural potential, while C. pentandra may be more suitable for non-structural applications such as lightweight panels, packaging, or core materials where stiffness is not a primary requirement.

5.3. Compression Parallel to Grain of *P. Macrocarpus* Heartwood, Sapwood and *C. Pentandra*

The mean compression strength parallel to grain at 12% moisture content ranged from 13.83 to 52.27 N/mm² (Figure 10). Overall, *P. macrocarpus* heartwood, both treated and non-treated recorded the highest crushing strength values. In descending order, the values were: 52.26 N/mm² (non-treated heartwood) > 51.94 N/mm² (CCA-B + lacquer) > 51.41 N/mm² (CCA-B + varnish) > 50.84 N/mm² (CCA-B + shellac). Sapwood followed a similar but slightly lower trend: 51.67 N/mm² (CCA-B + lacquer) > 51.54 N/mm² (CCA-B + varnish) > 49.38 N/mm² (non-treated sapwood) > 44.80 N/mm² (CCA-B + shellac). The gradual reduction in strength from heartwood to sapwood reflects inherent anatomical differences, particularly variations in density, extractive content, and cell wall thickness [2,6,21]. The comparatively higher compression strength of heartwood may be attributed to its matured, occluded cell structure composed of physiologically inactive (dead) cells with greater deposition of extractives. These structural characteristics enhance resistance to crushing stresses [6,26]. Additionally, pressure treatment processes, especially those involving vacuum pressure cycles may contribute to improved mechanical performance by facilitating deeper preservative penetration and possible cell wall bulking effects, which can increase rigidity [4,29]. The chemical nature of CCA-B may also influence mechanical behavior by reinforcing the lignocellulosic matrix and limiting microstructural deformation under compressive loads [2,25]. Statistical analysis indicated no significant differences ($p > 0.05$) among treated and non-treated heartwood, sapwood, and *C. pentandra* samples (Figure 10). In contrast, *C. pentandra* consistently exhibited the lowest compression strength values. Treated samples ranked in descending order as: 19.30 N/mm² (CCA-B + shellac) > 19.00 N/mm² (CCA-B + varnish) > 14.45 N/mm² (CCA-B + lacquer) > 13.83 N/mm² (non-treated). The relatively poor crushing resistance of *C. pentandra* is consistent with its low density and highly porous anatomical structure, which limits its capacity to withstand high compressive stresses [4,8]. Sapwood treated exclusively with preservative (CCA-]B) recorded 45.03 N/mm², indicating that preservative impregnation alone enhanced compressive performance more effectively than surface coatings alone. Sapwood treated only with finishes showed markedly lower values: 26.47 N/mm² (varnish) > 23.13 N/mm² (shellac) > 23.02 N/mm² (lacquer), confirming that surface films without preservative protection contribute minimally to internal load-bearing capacity. According to the classification by Farmer (1972), compression strength parallel to grain is categorized as: Very low: < 20 N/mm², Low: 20–35 N/mm, Medium: 35–55 N/mm², High: 55–85 N/mm² Very high: > 85 N/mm² [4]. Based on this classification, all *C. pentandra* samples fall within the "very low" category. Sapwood treated only with surface finishes falls within the "low" category, while preservative-treated sapwood and all heartwood samples are classified as "medium." These results align with the established relationship between compression strength and wood density [2,13,29]. Overall, compression strength increased in ascending order as follows: C. pentandra < sapwood (surface finish only) < sapwood (CCA-B treated) < heartwood. Wood species rated as "medium" are considered suitable for both ground and above-ground construction under moderate loading conditions [13]. Therefore, the heartwood and sapwood of *P. macrocarpus*, particularly when treated with preservative and surface finish, demonstrate adequate mechanical performance for structural and furniture applications. Treated *C. pentandra* may be suitable for light-duty applications where minimal compressive stress is expected. The compression strength values obtained for P. macrocarpus at 12% moisture content are consistent with established findings for tropical hardwoods reported by Desch & Dinwoodie (1996) and corroborated by more recent studies on Ghanaian lesser-utilized species [2,25,26].

6. Conclusions

Wood mechanical properties are essential in selecting suitable species for furniture production and structural applications, as they inform users the ability stiffness, strength performance and durability. The study revealed that *P. macrocarpus*, an LUS demonstrated its mechanical properties comparable to many traditional hardwoods such as *T. grandis* (Teak), *M. excelsa* (Odum), *E. cylindricum* (Sapele), *T. Ivorensis* (Emire), *P. africanum* (Dahoma) and mahogany making it a viable alternative for structural and furniture applications. With the continued depletion of conventional hardwood species, promoting lesser-utilized species (LUS) including *P. macrocarpus* is necessary to ensure sustainable wood supply and create employment in the furniture industry. To enhance their adoption, consistent and accessible data on their properties, availability and end uses must be provided to industry stakeholders. This will support, inform decision-making and encourage wider utilization within the wood industry.

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