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Evaluation of Strength Properties of *Laguncularia racemosa* (White Mangroves) from the Central and Western Regions of Ghana for Efficient Use

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

For a better use of wood as an engineering material, knowledge of its strength properties is important. In building projects, strength properties of wood and wood-based components are crucial. The research was to investigate some mechanical properties of white mangrove (*Laguncularia racemosa*) in two coastal regions of Ghana, Western and Central regions, to optimise their use. The results showed that, the mean modulus of rupture values of trees from the Central region was between 52.82 and 63.21 Nmm^{-2} while the mean modulus of rupture values of trees from the Western region was between 51.23 and 56.84 Nmm^{-2}. The mean modulus of elasticity

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values of trees from Central region was in the range of 6827.24 and 7711.07 Nmm^{-2} with that from Western in the range of 5852.73 and 7157.55 Nmm^{-2}. The compressive strength parallel to the grain of trees from the central region ranged from 27.05 to 30.73 Nmm^{-2} with that from Western ranged from 24.57 and 28.33 Nmm^{-2}. The study concluded that, *Laguncularia racemosa* exhibited low strength properties and is therefore not recommended for structural applications where strength is required.

Keywords: Strength properties; modulus of elasticity; modulus of rupture; compressive strength; white mangrove.

1. INTRODUCTION

It has been reported that up to 84 plant species have been identified as mangroves [1]. A review of scientific literature reveals that experts continue to discuss and differ over the classification status of many mangroves. Mangroves have a limited ability for vegetative propagation; hence seedlings are required for forest propagation [2]. Some species (*C. racemosa*) may regenerate from stumps but it is not the same as propagation. Vivipary is very distinct reproductive mechanisms shown by mangroves [2,3].

For any material to be used, a better understanding of its properties is required [4]. emphasises the significance of knowing the wood properties of timber species before promoting them on the market. According to analyses conducted by [5,6], these properties show excellent unity and interrelationships.

The mechanical properties of a substance are characteristics to its responses to externally applied forces. Density and moisture affect the mechanical properties of wood, such as elasticity and strength [7]. [8] reported that the mechanical properties are often measured as modulus of rupture (MOR) in static bending, maximum stress in compressive strength parallel to grain (CS), modulus of elasticity (MOE), shear strength parallel to grain and compressive stress perpendicular to grain. The chemical composition of wood affects its properties and, therefore, the usability for various applications [9].

To maximize forest benefits, there is the need to understand not only the fundamentals of tree development, but also the macroscopic and microscopic characteristics that define wood [10]. In building projects, strength properties of wood and wood-based components are crucial. When the bending strength of a beam is unknown; deflection caused by holding a load may result in severe distortion, and can lead to the beam's failure in service life. MOE is also crucial since it influences how much the floor joists will bend or deflect under load. There are mangrove trees located along the coast of Ghana. In order to use mangrove as a construction material, it is necessary to know its strength properties. The objectives of the study were to determine the MOE, MOR and (CS) of *Laguncularia racemosa (L. racemosa)* from the Central and Western regions of Ghana for efficient use.

2. MATERIALS AND METHODS

2.1 Materials

Three mature *L. racemosa* trees measuring 14 to 16 metres in height and 30 centimetres in diameter were picked from Abakam and Anloga located in the Central and Western regions of Ghana respectively. The bole of *L. racemosa* was divided into three portions, each measuring 3.3 metres, above the breast height of 1.3 meters: the base, the middle, and the top. They were tagged and sent to the workshop for further processing.

2.2 Preparation of Test Specimen

Quarter-sawn billets were taken from pieces of air-dried *L. racemosa.* Then, defect-free billets were used to obtain the desired sample sizes for the different tests. Twenty specimens were taken from the base, middle, and top respectively of *L. racemose* for MOR, MOE and CS tests. Three sets of samples were prepared for the MOR, MOE and CS tests and each set contained 60 replicates. Each sample size for the CS test was 20 X 20 X 60 mm and 20 X 20 X 300 mm (radial X tangential X longitudinal) for the MOR and MOE.

2.3 MOE, MOR and CS Test

MOE measures how easily a material is bent or stretched whilst MOR is the equivalent stress in extreme fibres of the specimen at the point of failure. The compressive strength also known as the maximum crushing strength is the maximum stress sustained by a compression parallel to grain of specimen with ratio of length to least dimension less than 11. The British Standard Methods of Testing Small Clear Specimens of Lumber, [11] was used to determine MOE, MOR and CS. The MOE MOR and CS were determined at the Council for Science and Industrial Research (CSIR) in Kumasi, Ghana.

3. RESULTS

3.1 Modulus of Rupture

Specimen taken from trees located from Western Region had the greatest values at the base as 61.09 and 52.60 Nmm^{-2} for heartwood and sapwood, respectively, and had the lowest values at the top as 56.80 and 45.66 Nmm^{-2} for heartwood and sapwood, respectively as shown in Fig. 1.

In general, the MOR of heartwood was greater than that of sapwood in both regions. The base had the greatest mean MOR of 63.21 and 56.84 Nmm^{-2} for trees from the Central Region (TCR) and trees from the Western Region (TWR) respectively, while the top had the least 52.82 and 51.23 Nmm^{-2} for TCR and TWR, respectively. TCR showed much greater MOR values than TWR as indicated in Fig. 2.

Table 1 shows Analysis of Variance (ANOVA) for MOR of *L. racemosa* for TCR and TWR of Ghana. Significant difference ($p > 0.05$) was observed in the average MOR of the individual tree sections from both areas. According to Tukey's multiple comparison test, there was no difference in MOR across the different parts of the stem's sapwood and heartwood for TCR and TWR.

3.2 Modulus of Elasticity

The mean modulus of elasticity (MOE) of specimens from TCR was highest at the base as 8407.78), and 7014.36 Nmm^{-2} for heartwood and sapwood respectively, and lowest at the top as 7138.24 and 6516.24 Nmm^{-2} for heartwood and sapwood respectively as indicated in Fig. 3.

Fig. 3 indicates that specimens from the Western area had the greatest MOE at the base heartwood (7577.2 Nmm^{-2}) and base sapwood (6737.9 Nmm^{-2}) and the lowest MOE at the top heartwood (6212.85 Nmm^{-2}) and top sapwood (5492.6 Nmm^{-2}). Along the stem, the heartwood showed substantially greater MOE values. The base resulted in 7711.07 and 7157.55 Nmm^{-2} for TCR and TWR respectively, middle, 7142.09 and 6100.25 Nmm^{-2}, for TCR and TWR respectively and top, 6827.24 and 5852.73 Nmm^{-2} for TCR and TWR respectively. In general, TCR stems exhibited a higher MOE than TWR as indicated in Fig. 4.

Table 2 shows ANOVA for MOE of *L. racemosa* from CR and WR of Ghana. At ($p > 0.05$), there was variation in the mean MOE between the different tree sections (Table 2).

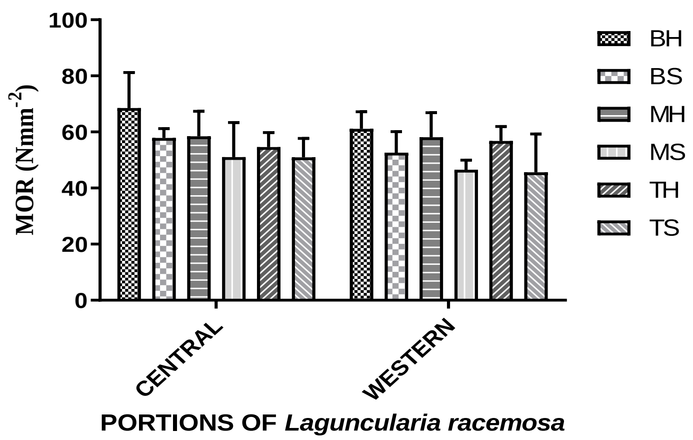

Fig. 1. Mean MOR of *L. racemosa* (axial and radial sections) from Central and Western Regions of Ghana

BH = Heartwood of Base, BS = Sapwood of Base, MH = Heartwood of Middle, MS = Sapwood of Middle, TH = Heartwood of Top, TS = Sapwood of Top

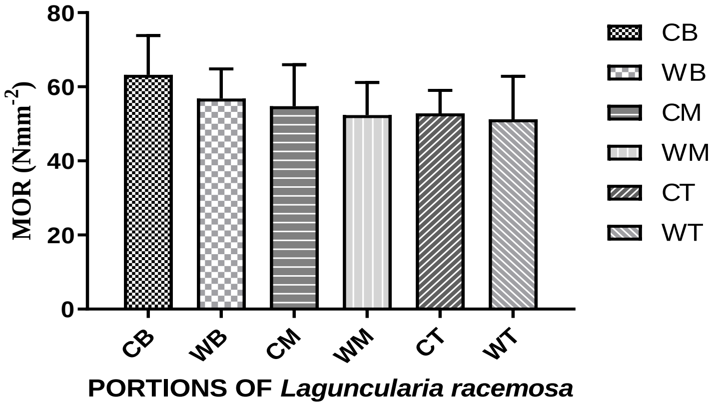

Fig. 2. Mean of MOR along the Stem (heartwood and sapwood portions) of *L. racemosa*
CB = Central Base, CM = Central Middle, CT = Central Top, WB = Western Base, WM = Western Middle, WT = Western Top

Table 1. ANOVA for MOR of *L. racemosa* from CR and WR of Ghana

Source of Variation	% of total variation	P value	P value summary	Significant	
Interaction	2.550	0.1143	Ns	No	
Regions	2.830	0.0018	**	Yes	
Stem Location	29.92	<0.0001	****	Yes	
ANOVA table	**SS**	**DF**	**MS**	**F(DFn, DF)**	**P value**
Interaction	648.5	5	129.7	F (5, 228) = 1.797	P=0.1143
Regions	719.6	1	719.6	F (1, 228) = 9.973	P=0.0018
Stem Location	7610	5	1522	F (5, 228) = 21.09	P<0.0001
Residual	16451	228	72.15		
Alpha = 0.05					

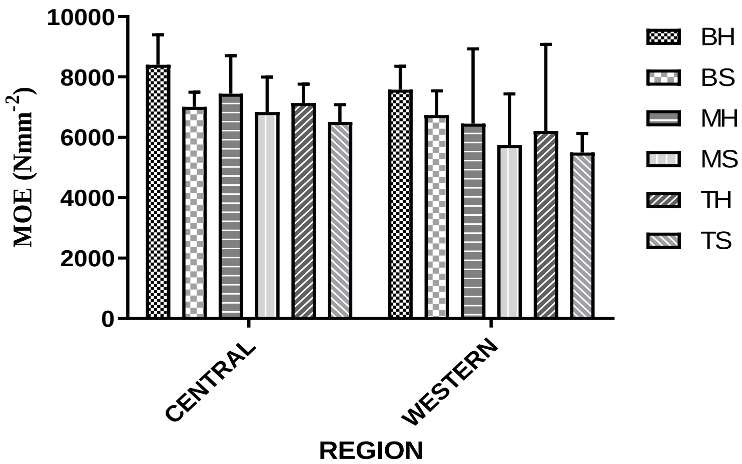

Fig. 3. Mean MOE of *L. racemosa* (axial and radial sections) from CR and WR of Ghana.
BH = Heartwood of Base, BS = Sapwood of Base, MH = Heartwood of Middle, MS = Sapwood of Middle, TH = Heartwood of Top, TS = Sapwood of Top

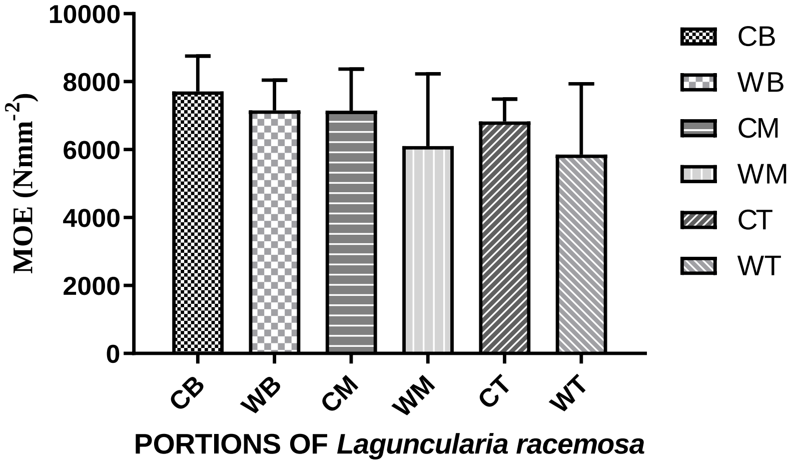

Fig. 4. Mean of MOE along the Stem (heartwood and sapwood portions) of
L. racemose. CB = Central Base, CM = Central Middle and CT = Central Top, WB = Western Base, WM = Western Middle, WT = Western Top

Table 2. ANOVA for MOE of *L. racemosa* from CR and WR of Ghana

Source of Variation	**% of total variation**	**P - value**	**P value summary**	**Significant**	
Interaction	0.7497	0.8128	Ns	No	
Regions	7.431	<0.0001	****	Yes	
Stem Location	15.91	<0.0001	****	Yes	
ANOVA table	**SS**	**DF**	**MS**	**F (DFn, DFd)**	**P value**
Interaction	4441988	5	888398	F (5, 228) = 0.4503	P=0.8128
Regions	44028097	1	44028097	F (1, 228) = 22.32	P<0.0001
Stem Location	94289626	5	18857925	F (5, 228) = 9.560	P<0.0001
Residual	449771819	228	1972683		

Alpha = 0.05

Furthermore, Tukey's multiple comparison tests revealed no significant difference in MOE between the centre and top for both locations.

3.3 Compressive Force Parallel to the Grain

Fig. 5 illustrates the mean compression strength parallel to grain (CS) of the sections of *L. racemosa* stem.

For the sapwood, the base region recorded the greatest mean values of 30.58 and 26.34 Nmm^{-2} for the TCR and TWR respectively, while the top portion recorded the lowest average values of 27.03 and 20.50 Nmm^{-2} for the TCR and TWR, respectively. Similarly, the heartwood had the greatest CS at the base as 30.88 and 30.33 Nmm^{-2} for TCR and TWR respectively and the lowest CS at the top as 27.08 and 28.65 Nmm^{-2} for TCR and TWR respectively. The mean CS of heartwood was greater than that of sapwood.

Fig. 6 illustrates the total mean CS along the *L. racemosa* stem.

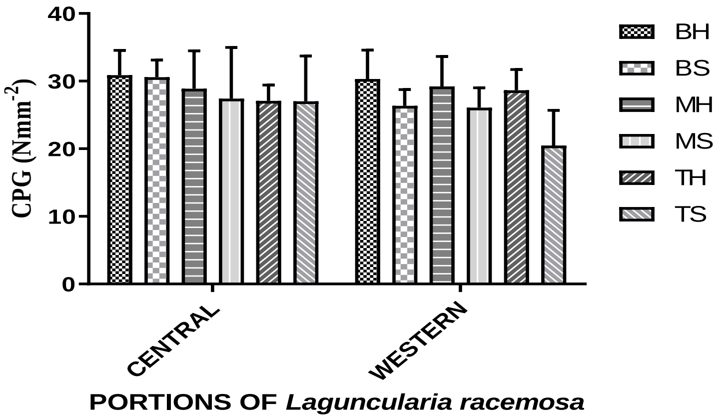

Fig. 5. Mean CS of *L. racemosa* (axial and radial sections) from CR and WR of Ghana.
Source: *Authors' laboratory work (2020).*
BH = Heartwood of Base, BS = Sapwood of Base,
MH = Heartwood of Middle, MS = Sapwood of Middle, TH = Heartwood of Top, TS = sapwood of top

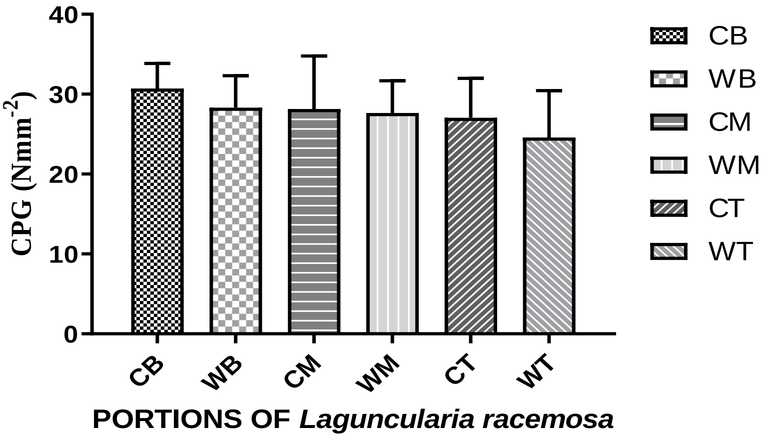

Fig. 6. Mean of CS along the stem (heartwood and sapwood portions) of *L. racemosa*
CB = Central Base, CM = Central Middle, CT = Central Top, WB = Western Base, WM = Western Middle, WT = Western Top

Table 3. ANOVA for CPG of *L. racemosa* from CR and WR of Ghana

Source of Variation	**% of total variation**	**P value**	**P-value summary**	**Significant**	
Interaction	7.136	0.0007	***	Yes	
Regions	2.991	0.0025	**	Yes	
Stem Location	16.88	<0.0001	****	Yes	
ANOVA table	**SS**	**DF**	**MS**	**F (DFn, DFd)**	**P value**
Interaction	460.2	5	92.05	F (5, 228) = 4.458	P=0.0007
Regions	192.9	1	192.9	F (1, 228) = 9.342	P=0.0025
Stem Location	1089	5	217.8	F (5, 228) = 10.55	P<0.0001
Residual	4707	228	20.65		

Alpha = 0.05

TCR showed the highest and lowest mean values at the base as 30.73 Nmm^{-2} and top as 27.05 Nmm^{-2} sections respectively, whereas TWR showed the highest and lowest mean values at the base (28.33 Nmm-2) and top (24.57 Nmm^{-2}) respectively. In general, TCR had a higher CS than TWR.

Table 3 shows ANOVA for CPG of *L. racemosa* from CR and WR of Ghana.

The difference in mean CS throughout the stem followed a similar pattern and was statistically significant ($p > 0.05$). Tukey's multiple comparison tests showed that there was no significant difference in the mean CS for any of the CR tree sections.

4. DISCUSSION

4.1 Test of Static Bending (MOR)

Wood's MOR is determined by the force necessary to produce its failure [12]; the greater the force required, the greater the MOR. The findings indicated that MOR decreased throughout the sapwood and heartwood from bottom to top for both areas as indicated in Fig. 1. The total mean MOR values (Fig. 2) illustrate that the base section had a higher mean value for both areas; 63.21 Nmm^{-2} and 56.21 Nmm^{-2} for TCR and TWR respectively, while the top portion had the lowest mean value; 52.82 Nmm^{-2} and 51.23 Nmm^{-2} for TCR and TWR respectively. According to [7], the variation in MOR of wood may be linked to the thin cell walls, low cellulose content, and crystallinity of the wood. Wood strength properties, such as MOR, may also be associated with density [13,14], wood species and location [13–16].

According to Farmer [17], the bending strength, MOR, of tiny clear specimens at 12% MC is evaluated as very low Nmm^{-2} if it falls below 50 Nmm^{-2}, low if it falls between 50 and 85 Nmm^{-2}, medium, if it falls between 85 and 120 Nmm^{-2}, high if it falls between 120 and 175 Nmm^{-2} and very high if it falls beyond 175 Nmm^{-2}. *Laguncularia racemosa* for the TCR has a low MOR strength (51.03 - 63.50 Nmm^{-2}). The base (59.62 Nmm^{-2}), middle (54.70 Nmm^{-2}), and top (46.11 Nmm^{-2}) parts of sections from the TWR are deemed to have medium bending strengths. However, the mean MOR for *L. racemosa* in this research is similar to that of *Pinus patula* (43.14 - 63.61 Nmm^{-2}) [16]. Nonetheless, it is lower than other well-known Ghanaian species, including Wawabima (87.1-249.8 Nmm^{-2}), Dahoma (73.1-039.0 Nmm^{-2}), and *Celtis mildbraedii* (74.5-181.9 Nmm^{-2}) [18]. Although *L. racemosa* may perform comparatively better under stress than certain species, it might not be a superior alternative compared to the vast majority of species. Consequently, for applications where MOR of *L. racemosa* is crucial, the heartwood from both zones might be evaluated.

4.2 Modulus Elasticity (MOE)

MOE is an important property influences its structural uses [19]. The MOE findings reveal a general pattern of base, middle and top for both areas (Fig. 3), with heartwood showing comparatively greater values for both regions. TCR generally had the greatest MOE in the stem (7711.07 – 6827.24 Nmm^{-2}) as compared to TWR (7157.55 – 5852.73 Nmm^{-2}) (Fig. 4). Multiple researchers have documented a downward trend in MOE from bottom to top [16,20]. Regarding wood mechanical properties, it is believed that the organisation of axial and ray parenchyma, fibres and vessels in hardwood species have a key effect in variations of MOE in wood and density affects mechanical properties [21,22]. There has been a study on the possibility of certain wood mechanical properties being dependent on density on a variety of hardwood species, including *Hevea brasiliensis* [23], *Eucalyptus globulus*, *E. nitens* and *E. regnans* [24], *Celtis mildbraeii* and *Maesopsis eminii* [25]. The MOE of wood is typically between 3,450 and 19,300 Nmm^{-2} [26,27] categorised species' strength based on the MOE at 12% moisture content as follows: 'Very High' (19,000 Nmm^{-2}), High' (14,000-19,000 Nmm^{-2}), 'Medium' (11,000-14,000 Nmm^{-2}), 'Low' (9,000-11,000 Nmm^{-2}), and 'Very Low' (below 9,000 Nmm^{-2}). The categorisation is low because there is no differences in stiffness among the tree's many parts. Engineers and structural designers estimate needed beam sizes based on their knowledge of the MOE [28]. Due to its poor MOE strength ratings, *L. racemosa* might not be advisable for use by structural works such as floor joist structures.

4.3 Compressive Strength Parallel to the Grain

Compressive Strength Parallel to the Grain (CS) measures the performance of wood under crushing loads (Gupta et al., 1996). CS of the sapwood decreased from the base to the top, while that of the heartwood was in the order base greater than middle greater than top for both areas as in Fig. 5, with average values of 28.93 – 28.20 Nmm^{-2} for TCR and 29.15 – 23.42 Nmm^{-2} for TWR as in Fig. 6. The compressive strength parallel to the grain of the sections decreased in the order of the butt to the middle and the top. The variations in CS in the sapwood is consistent with what [16,29] discovered in *Pinus patula* and *Pterygota Macrocarpa*, where there was a decreasing order from bottom to top. According to [17], Compression Parallel to the Grain is categorized as very low, low, medium, high, and very high when the strength values are under 20 Nmm^{-2}, 20-35 Nmm^{-2}, 35-55 Nmm^{-2}, 55-85 Nmm^{-2}, and above 85 Nmm^{-2}, respectively. This categorisation subsequently assigns low ratings to the top, middle, and butt parts. The measured values for *L. racemosa* were lower than those for dry *Pinus patula* (40.00 - 64.71 Nmm^{-2}) and *Pterygota Macrocarpa* (51.60 - 66.12 Nmm^{-2}) [16,29].

5. CONCLUSIONS

In both zones, strength properties of *L. racemosa* decreased from bottom to the top parts. The mechanical strength properties of *L. racemosa* were typically poor, but that of the heartwood was better than the sapwood. The strength properties of *L. racemosa* from Central and Western regions of Ghana are low and is not recommended to be used for construction where strength of the material is required.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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