Original Research Article

EVALUATION OF STRENGTH PROPERTIES OF WHITE MANGROVES (*Laguncularia racemosa*) FROM THE CENTRAL AND WESTERN REGIONS OF GHANA

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 districts of Ghana, Western and Central regions, to optimise their use. The results showed that, the mean modulus of rapture (MOR) values of trees from the Central region was between 52.82 and 63.21 Nmm^2 while the mean modulus of rapture (MOR) values of trees from the Western region was 51.23 and 56.84 Nmm^2. The mean modulus of elasticity (MOE) 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 compression parallel to the grain (CPG) of trees from the central region ranged from 27.05 to 30.73 N/mm^2 with ~~and~~ that from Western ranged from 24.57 and 28.33 N/mm^2. The study concluded that~~In general,~~ *Laguncularia racemosa* exhibited somewhat superior mechanical qualities. The study therefore recommende that Laguncularia *racemosa* ~~It~~ has the potential for structural applications.

Keywords: Strength Properties, Modulus of Elasticity, Modulus of Rupture, Compression Strength, White Mangrove.

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 (*Agerminants* and *C. racemosa*) may regenerate from stumps but it is not the same as propagation. Hydrochorg and vivipary are two 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 are modulus of rupture (MOR) in static bending, maximum stress in compression parallel to grain, 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 maximize the use of 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 CPG of *Laguncularia racemosa (L. racemosa)* from the Central region (CR) and Western region (WR) of Ghana for efficient use.

Materials and methods

Materials

Three mature *L. racemosa* trees measuring 14 to 16 meters in height and 30 cemtimetres in diameter were picked from Abakam and Anloga located in the Central ~~R~~ and Western ~~R~~ 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.

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 of *L. racemose* for each mechanical properties test. Test for CPG tests 60 samples in total were use each measuring 20 X 20 X 60 mm were used. Test for MOE and MOR tests 120 samples in total were use each measuring 20 X 20 X 60 mm were used.

CPG Test

For CPG tests 60 samples in total each measuring 20 X 20 X 60 mm were used. Two groups of 20 samples each were taken from the base, middle and top of the stem.

MOE, MOR

For MOE, MOR tests 120 samples in total measuring 20 X 20 X 300 mm were used. Twenty samples each were taken from the base, middle and top of the stem.

MOE, MOR and CPG Test

British Standard Methods of Testing Small Clear Specimens of Lumber, [11] was used to determine MOE, MOR CPG using small clear wood samples. The MOE MOR and CPG were determined at the Council for Science and Industrial Research (CSIR) in Kumasi, Ghana.

Results and Discussions

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 Figure 1.

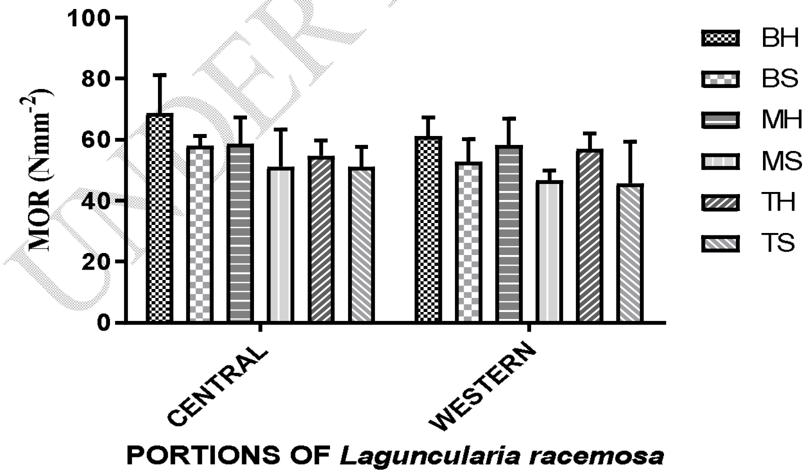

Fig. 1: Mean MOR of *L. racemosa* (axial and radial sections) from Central and Western Regions of Ghana.

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

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 trees (TCR) and trees from (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 Figure 2.

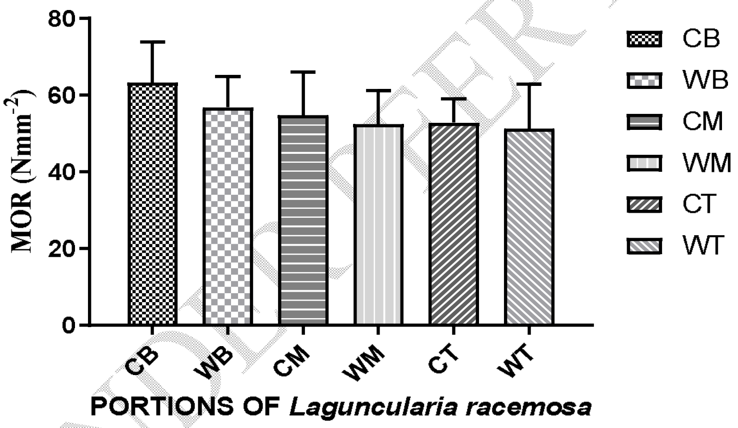

Fig. 2: Mean MOR along the Stem (heartwood and sapwood portions) of *L. racemosa.*

Source: Authors' laboratory work (2020).

CB = Central Base, CM = Central Middle, CT = Central Top, WB = Western Base, WM = Western Middle, WT = Western Top.

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.

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

Source of Variation	% of total variation	P value	Pvalue summary	Significant
Source of				
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, DFd)	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

Source: Authors' laboratory work (2020).

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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 Figure 3.

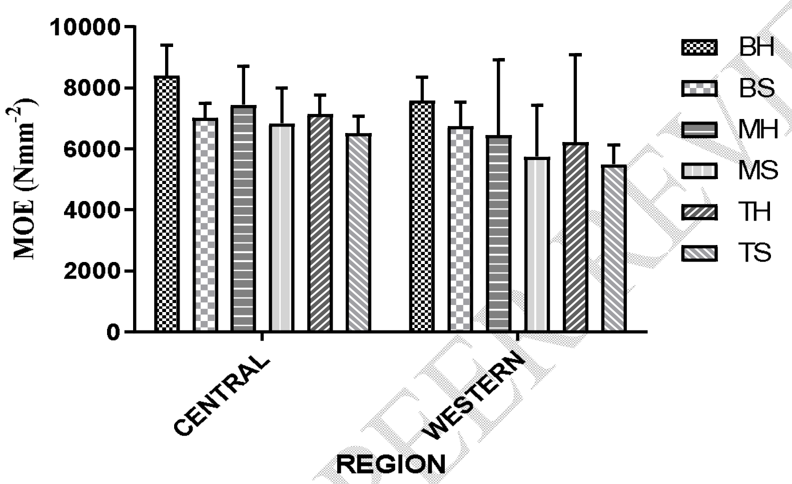

Fig. 3: Mean MOE of *L. racemosa* (axial and radial sections) from CR and WR of Ghana.

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

Figure 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 Figure 4.

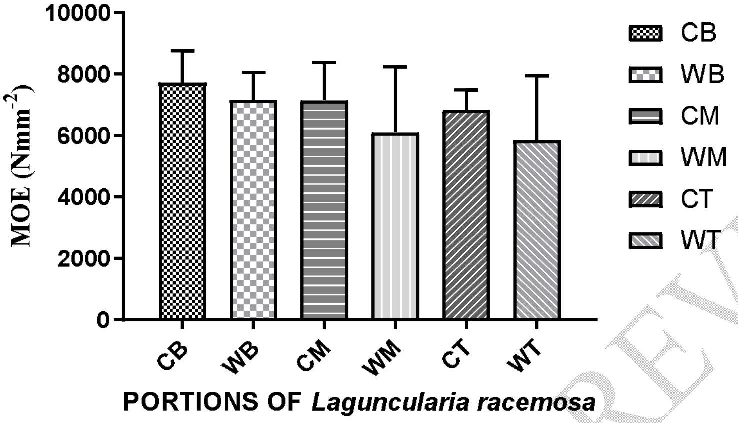

Fig. 4: Mean MOE along the Stem (heartwood and sapwood portions) of *L. racemose*. CB = Central Base, CM = Central Middle and CT = Central Top, WB = Western Base, WM = Western Middle, WT = Western Top.

Source: Authors' laboratory work (2020).

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).

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

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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

Source: Authors' laboratory work (2020).

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

Compressive force parallel to the grain

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

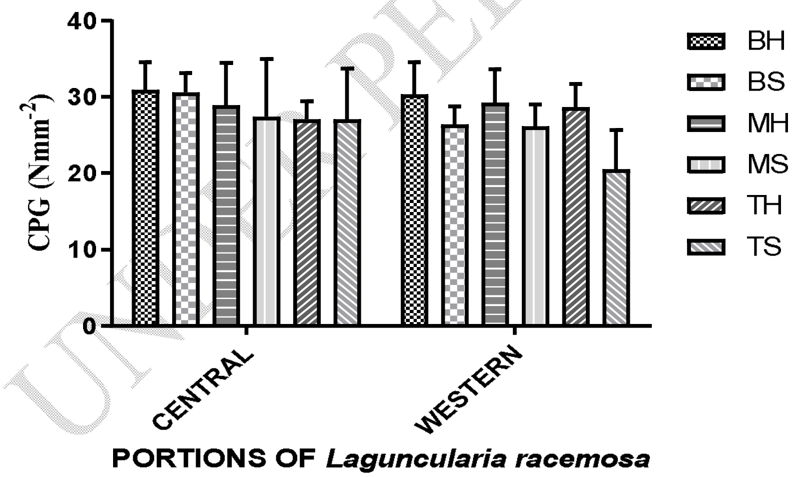

Fig. 5: Mean CPG of *L. racemosa* (axial and radial sections) from CR and WR of Ghana.

Source: Authors' laboratory work (2020).

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BH = Heartwood of Base, BS = Sapwood of Base,

MH = Heartwood of Middle, MS = Sapwood of Middle, TH = Heartwood of Top, TS = sapwood of top.

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 sapwood, the heartwood had the greatest CPG at the base as 30.88 and 30.33 Nmm^{-2} for TCR and TWR respectively and the lowest CPG at the top as 27.08 and 28.65 Nmm^{-2} for TCR and TWR respectively. The mean CPG of heartwood was greater than that of sapwood.

Figure 6 illustrates the total mean CPG along the *L. racemosa* stem.

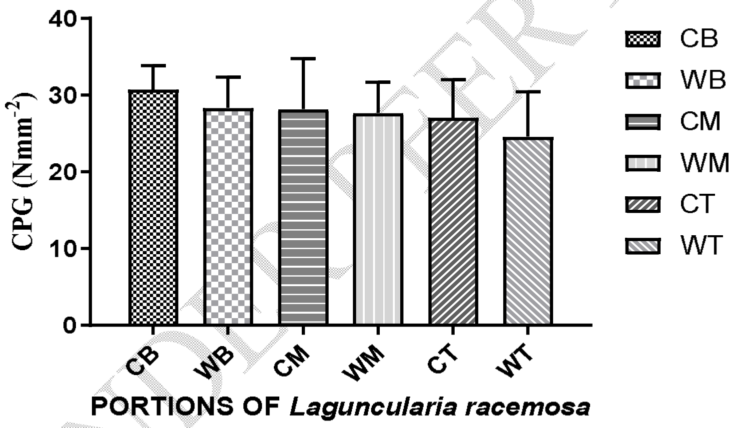

Fig. 6: Mean CPG along the stem (heartwood and sapwood portions) of

L. racemosa.

CB = Central Base, CM = Central Middle, CT = Central Top, WB = Western Base, WM = Western Middle, WT = Western Top.

Source: Authors' laboratory work (2020).

TCR showed the greatest 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 CPG than TWR.

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

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

Source of Variation	**% of total variation**	**P value**	**Pvalue 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

Source: Authors' laboratory work (2020).

The difference in mean CPG 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 CPG for any of the CR tree sections.

Discussion

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

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sapwood and heartwood from bottom to top for both areas as indicated in Figure 1. The total mean MOR values (Figure 2) illustrate that the base section had a bigger 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 if it falls below 50 Mpa, low if it falls between 50 and 85 Mpa, medium, if it falls between 85 and 120 Mpa, high if it falls between 120 and 175 Mpa, and very high if it falls beyond 175 Mpa. *Laguncularia. racemosa* for the TCR has a low MOR strength (51.03 - 63.50 Nmm^{-2}). The base (59.62 N/mm^{2}), middle (54.70 Nmm^{-2}), and top (46.11 Nmm^{-2}) parts of sections from the TWR are deemed to have medium shear 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.

Elasticity modulus (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 (Figure 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}) (Figure 4). Multiple researches have documented a downward trend in MOE from bottom to top [16, 20]. Regarding wood mechanical characteristics, it is believed that the organization 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 Mpa. [26, 27] categorized species' strength based on the MOE at 12% moisture content as follows: 'Very High' (19,000 Mpa), 'High' (14,000-19,000 Mpa), 'Medium' (11,000-14,000 Mpa), 'Low' (9,000-11,000 Mpa), and ' Very Low' (below 9,000 Mpa). 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 engineers such floor joist structures.

Compressive Strength Parallel to the Grain

Compressive Strength Parallel to the Grain (CPG) measures the performance of wood under crushing loads (Gupta et al., 1996). CPG 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 Figure 5,with average values of 28.93 – 28.20 Nmm^{-2} for TCR) and 29.15 – 23.42 Nmm^{-2} for TWR as in Figure 6. The compressive strength parallel to the grain of the sections decreased in the order of from the butt to the middle and the top. The variations in CPG 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 Mpa, 20-35 Mpa, 35-55 Mpa, 55-85 Mpa, and above 85 Mpa, 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].

Conclusions

In both zones, mechanical characteristics dropped from the bottom to the top parts. The mechanical strength qualities of *L. racemosa* were typically poor, but that of the heartwood was better than the sapwood. The categorization is Low because the stiffness and compression strength parallel to the grain do not change throughout the tree's different parts.

References

[1] Saenger, P. (2002). Mangrove Ecology, Silviculture and Conservation. Kluwe Academic Publishers, Dordrecht, 11-18. htpps://dx.org/10.1007/978-94-015-9962-7

[2] Tomlinson, P. B. (1995). The Botany of Mangroves-Cambridge Tropical Biology Series, Cambridge University Press.

[3] Rabinowitz, D. (1978). Early growth of mangrove seedlings in Panama, and a hypothesis concerning the relationship of dispersal and zonation. *J Biogeogr* 5: 113 – 133.

[4] Ishengoma, R. C., Gillah, P. R., Amartey, S. A., & Kitojo, D. H. (2004). Physical, mechanical and natural decay resistance properties of lesser known and lesser utilized

Diospyrosmespiliformis, Tyrachylobiumverrucosum and Newtoniapaucijuga timber species from Tanzania. HolzRohWerkst 62: 387-389.

[5] Simpson, W., & TenWolde, A. (1999). Physical properties and moisture relations of wood. Wood handbook: wood as an engineering material. Madison, WI: USDA Forest Service, Forest Products Laboratory. General technical report FPL; GTR-113: 3.1 – 3.24

[6] Chowdhury, M. Q., Rashid, A. Z. M. M., Newaz, M. S., & Alam, M. (2007). Effects of height on physical properties of wood of jhau (Casuarina equisetifolia). Australian Forestry 70 (1), 33-36. https://doi.org/10.1080/00049158.2007.10676260

[7] Tsoumis, G. (1991). Science and Technology of Wood: Structure, Properties and Utilization. Van Nostrand Reinhold New York 160-174

[8] Green, D. W., Winandy, J. E., & Kretschmann, D. E. (1999). Mechanical properties of wood. Wood handbook: wood as an engineering material. Madison, WI: USDA Forest Service, Forest Products Laboratory. General technical report FPL; GTR-113: 4.1-4.45

[9] Pereira, H., Graca. J., & Rodrigues, J.C. (2003). Wood chemistry in relation to quality. In: “Wood quality and its biological basis” (Barnett J, Jeronimidis G eds). John Wiley and Sons. Blackwell, Oxford, UK, 53-86.

[10] Jozsa, L. A., & Middleton, G. R. (1994). A discussion of wood quality attributes and their practical implications. SP-34. Pacific Forestry Centre. Canada-British Columbia Partnership Agreement on Forest Resource Development: FRDA II.

[11] British Standard Methods of Testing Small Clear Specimens of Lumber, BS 373. (1957). British Standard Institution, London.

[12] Hoyle, R. J. (1978). Wood Technology in the Design of Structures, Missoula Montana. Mounting Press Publishing Company.

[13] Rowell, M. R. (2005). *Handbook of Wood Chemistry and Wood Composite*. CRC Press. Retrieved from www.crcpress.com. (Accessed: 17/02/14). Saenger P. (2002). Mangrove Ecology, Silviculture and Conservation. Kluwer Academic Publishers, Dordrecth, 11 -18.

[14] Hoadley, R. B. (2000). *Understanding wood: A Craftsman's Guide to Wood Technology*. The Taunton Press, Newtown, Connecticut, USA.

[15] Stöd, R., Verkasalo, E., & Heinonen, J. (2016). Quality and Bending Properties of Sawn Timber from Commerical Thinnings of Scot pine (sylvestrish L.). Baltic Forestry 22(1): 148 – 162.

[16] Zelalem, G., Pradeep, P., & Omprakash, S. (2014). The Influence of Physical and Mechanical properties on Quality of wood produced from Pinus Patula Tree Grown at Arsi Forest. Advanced Research Journal of Plant and Animal Sciences, Spring Journals: ISN-2360-7947: 2(4): 032-041

[17] Farmer, R. H. (1972). Handbook of Hardwood. Second Edition. 2, 49-50 London, Her Majesty's Stationary Office.

[18] Ofori, J., & Appiah, J. K. (1998). Some drying characteristics of five Ghanaian lesser-known wood species. Ghana Journal of Forestry 6:19-27.

[19] Kumar, S. (2004). Genetic parameter estimates for wood stiffness, strength, internal checking, and resin bleeding for radiata pine. Can. *J. For. Res*. 34(12): 2601-2610.

[20] Schneider, M.H., Sebestian, L.P., & Seepersad, J. (1991). Bending strength and stiffness of Caribbean pine from Trinad and Tobago. *Wood and Fiber Science.* 23(4): 468 – 471.

[21] Barnett, J. R., & Jeronimidis, G. (Eds) (2003). Wood Quality and its Biological Basis. Blackwell Publishing Ltd. Oxford.

[22] Bowyer, J. L., Shmulsky, R., & Haygreen, J.G. (2003). Forest Products and Wood Science: An Introduction. Ames, Iowa State Press.

[23] Gnanaharan, R., & Dhamodaran, T. K. (1992). Mechanical properties of rubberwood from a 35-year-old plantation in central Kerala, *India. Journal of Tropical Forest Science* 6 (2): 136-140.

[24] Yang, J. L., & Evans, R. (2003). Prediction of MOE of eucalypt wood from microfibril angle and density. Holz als Roh-und Werkstoff 61: 449-452.

[25] Zziwa, A., Kaboggoza, J. R. S., Mwakali, J. A., Banana, A. Y., & Kyeyune, R. K. (2006). Physical and mechanical properties of some less utilised tropical timber tree species growing in Uganda. *Uganda Journal of Agricultural Sciences* 12 (1): 29-37

[26] Upton, D. A. J., & Attah, A. (2003). Commercial timbers of Ghana – The potential for lesser used species. Forestry Commission of Ghana, Accra. 58

[27] Timber Export Development Board (TEDB). (1994).The Tropical Timbers of Ghana. Timber Export Development Board, Takoradi. 5-6 & 40

[28] Shmulsky, R., & Jones, P. D. (2011). Forest products and wood science, an introduction (6th ed). West Susses: Willey Blackwell. https://dx. doi.org/10.1002/9780470960035

[29] Ayarkwa, J. (2009). Timber Technology for Researchers, Polytechnics and university students'. 2-7. Kumasi, Classic Graphics Print.