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Technological properties of *Memecylon lateriflorum* wood: a timber species from Ghana

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ABSTRACT: A critical aspect of the Sustainable Forest Management scheme is promoting lesser-used timber species in substituting the over-exploited timber species of similar technical characteristics. The study's main objective was to evaluate the technological properties within the tree height of *Memecylon lateriflorum* (G. Don) Bremek. They were using small clear, defect-free, straight-grained wood samples. Using standardized procedures, the samples were harvested, prepared, and conditioned from the diameter at breast height (DBH), middle, and top portion of the trees. The results indicated that the density of *M. lateriflorum* was 840 kg/m^{3,} *which characterizes it as a high-density wood.* The study again revealed a strong correlation (83-99 %) between the woods' densities and mechanical strength characteristics. Also, the overall average tangential and radial shrinkage from green to 12 % moisture content was 9.46% and 6.57%, respectively, whereas that of longitudinal was 0.65%. The mean strength values recorded in N/mm^2 at 12% moisture content were: modulus of elasticity (19.724), modulus of rupture (143.00), compression (62.40), shear (20.50), and tensile parallel to grain (149.20). Janka hardness test recorded mean values of 15.70 and 14.30 kN in the radial and tangential directions. Thus, *M. lateriflorum* could be promoted as an efficient choice for construction and structural applications.
Keywords: valorization of wood; physical-mechanical properties; wood quality.

Propriedades tecnológicas da madeira de *Memecylon lateriflorum*: uma espécie madeireira de Gana

RESUMO: Um aspecto crítico do Manejo Florestal Sustentável é a promoção de espécies madeireiras menos utilizadas em substituição às espécies madeireiras traidionais. O objetivo principal do estudo foi avaliar as propriedades tecnológicas na altura da árvore de *Memecylon lateriflorum* (G. Don) Bremek. usando pequenas amostras de madeira clear (grã reta e sem defeitos). As amostras foram colhidas, preparadas e acondicionadas a partir do diâmetro à altura do peito (DAP), porção média e superior das árvores, utilizando procedimentos padronizados. Os resultados indicaram que a densidade de *M. lateriflorum* foi de 840 kg/m^3 o que a caracteriza como uma madeira de alta densidade. O estudo revelou novamente uma forte correlação (83-99%) entre as densidades das madeiras e as características de resistência mecânica. Além disso, a retração tangencial e radial da madeira verde até 12% de umidade foi de 9,46% e 6,57%, respectivamente. A retração longitudinal foi de 0,65%. Os valores médios de resistência registrados em N/mm^2 com 12% de umidade foram: módulo de elasticidade (19.724), módulo de ruptura (143), compressão (62,4), cisalhamento (20,5) e tração paralela às fibras (149,2). O ensaio de dureza Janka registrou valores médios de 15,7 e 14,3 kN nas direções radial e tangencial. Assim, *M. lateriflorum* poderia ter seu uso promovido como uma escolha eficiente para construção e aplicações estruturais.
Palavras-chave: valorização da madeira; propriedades físico-mecânicas; qualidade da madeira.

1. INTRODUCTION

Globalization and innovation drive of forest products' markets have reshaped trade in timber and wood products. The international market dynamics concerning demand and supply for timber and wood products have changed over the last two decades (BUONGIORNO et al. 2003). The highly competitive and volatile market conditions coupled with an inadequate supply of raw materials pose a considerable challenge to the sustainable development and growth of the timber industry (Owen et al. 2013), thus making it a daunting task to promote lesser-known timber species (LKS) and lesser-used timber species (LUS) on to the international market.

Agyeman et al. (2003) reported that one of the biggest problems arising out of the uncontrolled expansion of the timber industry in Ghana is the dependence on a few species, resulting in the "creaming" of the affected species, a reduction in the raw material base and an increase in the cost of sawmilling operations. According to Benhin; Barbier (2000), Gyamfi et al. (2021), and the Forest Commission of Ghana (2019), there is a high demand for tropical timber species such as *Triplochiton scleroxylon* (Wawa), *Piptadeniastrum africanum* (Dahoma), *Khaya spp.* (Mahogany), *Cylicodiscus gabunensis* (Denya), and *Milicia excelsa* (Odum) make up the five dominant wood products such as Air-dried and Kiln-dried Lumber, Plywood, Billets, and Veneer. The over-exploitation of the well-known and merchantable species has exacerbated the demand-supply situation, consequently causing the harvest of immature tree species and species of inadequate scientific data (DOVIE, 2003; NGAMAU et al., 2004).

According to Aiyeloja et al. (2011), Ewudzie et al. (2018), and Racelis; Barsimantov (2008), an essential part of Sustainable Forest Management schemes is to promote LKS and LUS in the timber market. Notably, as certain timber species are becoming scarce and extinct (such as teak, Odum, and mahogany, especially when certified), buyers are increasingly open to substituting them with so-called "lesser-known timber species" that have similar characteristics but are not yet commonly known in the international timber market. If their characteristics are accurately communicated, this situation can represent an opportunity for exporters (STANKEY; SHINDLER, 2006). However, if technical information does not exist, testing is required to obtain their applicability. This procedure, however, is often not feasible for small-scale exporters due to the expensive technological requirements.

The daunting task for the timber industry is maximizing the resource base by utilizing LKS and LUS for several applications. There is inadequate technical information on the technological characteristics of native Ghanaian tropical species such as *Memecylon lateriflorum* (locally known as 'Otwese'), thereby limiting their end-use applicability and their processing efficiency. This species under study is of no known commercial importance due to its inadequate technical information. However, it has a promising feature as a potential substitute for some of the endangered, well-known, and well-established timber species. A study on properties of *Milletia oblata*, a lesser known and utilized timber species, has found it to be comparable to *Milicia excelsa*, *Pterocarpus angolensis,* and *Ocatea usambarensis* to the extent of recommending some of their uses to be replaced by these species (ISHENGOMA et al., 1998). Several other species have also been studied and recommended, such as *Uapaca kirkiana* (Gillah et al. 2007), *Brachystegia bussei* and *Berchemia discolor* (Bangura et al. 2001), *Trichilia ametica* and *Pterocarpus stolzi* (ISHENGOMA et al., 1997). However, the limited use of the potential LKS and LUS is caused by the scarcity and inaccessibility of technological information on their own properties for utilization (BARANY et al. 2003).

M. lateriflorum belongs to the Melastomataceae family (SOSEF et al. 1998). *Memecylon* taxa have been reported from montane forests, tropical lowland forests, grasslands, tropical rainforests with low to high rainfall, rocky mountain regions, and regions with low to high temperatures and considerable overlap between ranges of different taxa (KARE, 1981; STONE, 2014; STONE, 2012). In Ghana, *Memecylon* spp is mainly found in the primary forest. There are about eight different identified species of *Memecylon* distributed in Ghana. Among them is *M. lateriflorum*, which is found abundantly in the Wet and Moist Evergreen zone and sparsely found in Moist semi-deciduous forest zones (HALL; SWAINE, 1981). The International Union cites it for Conservation of Nature and Natural Resources (2004) as a lower risk of most minor conservation concerns and no information on the wood trade. Hence, since there is no or less technological information on the physical and mechanical properties of *M. lateriflorum*, it is imperative to evaluate these properties and compare them to other highly known and overutilized timber species and assess how best the use of Otwese can substitute them.

2. MATERIAL AND METHODS

2.1. Study area and sample preparation

Samples were collected from two districts in two different regions of Ghana in the Ashanti and Western Regions. These forest districts were selected due to the range of distribution of the species forming part of two unique ecological zones in Ghana, mainly Bosomtwe District (GPS: 6.524545, -1.491) Moist Semi-Deciduous (MSDZ) and Amenfi West district (5.613891, -2.306868) Wet Evergreen Forest Zones (WEFZ) as indicated in Figure 1.

Figure 1. The specific area where the Timber samples were taken from.
Figura 1. Localização da área específica de coleta das amostras de madeira.

Three (3) matured *M. lateriflorum* trees with an average age of fifty (50) years were purposively selected from each ecological zone, and diameter at breast height (dbh) and total tree height were measured and recorded, using digital veneer caliper, dendrometer and a tape measure. The trees were crosscut into logs, and from each log, a sample of 1.5 m long was harvested for all three portions (base, middle, top). The samples were sawn into cants using a 14HP petrol/5.4 kW electric LT5START wood mizer of maximum cant width 50 cm and 27 cm full depth cut. Small, clear, straight-grained pieces of wood, reflecting the highest quality that can be obtained, were prepared for the study according to each test standard, as shown in Table 1.

Table 1. Experimental design.
Tabela 1. Desenho experimental.

Properties	Dimensions*	n	Standards
Moisture content	20 x 20 x 20	60	ISO 3129:2019
Density	20 x 20 x 20	60	ISO 13061-2:2014
Shrinkage	20 x 20 x 10	60	Bantly (2012)
Compression	20 x 20 x 60	60	BS 373:1957
Static Bending	20 x 20 x 300	60	ISO 13061-4:2014/
Shear	50 x 50 x 50	60	BS 373 (1957);
Hardness	50 x 50 x 150	60	ISO 3129:2019
Tensile	6 x 20 x 300	60	BS 373 (1957)

*dimensions in millimeters (mm); n = number of replicates.

These specimens were then conditioned at 20 °C and 65 % relative humidity in accordance with DIN 52182, BSI 373 (1957) standards in a Clima Temperatur Systeme (CTS) climate-controlled chamber of serial number CTS177010 (Figure 2).

2.2. Moisture Determination

Cuboids of size 20 mm thick specimens were prepared from the sampled wood, and their green masses were determined and oven-dried at 101– 105 °C until constant groups (D) were attained per standard. MC was then calculated according to Equation 1:

$$MC = \frac{W - D}{D} \times 100\ \% \qquad (01)$$

where: MC = moisture content, in %, W = green mass, in g; D = dry mass, in g.

2.3. Basic Density

Specimens of sizes 20 x 20 x 20 mm were prepared from *M. lateriflorum* and soaked in clear water for 24 hours, as reported by HILL (2006) and OFORI et al. (2009). The immersion method determined the density on swollen volume and the oven-dry mass basis. The weight of the beaker and the water it contained was determined by a digital balance of 0.01 g precision and then re-zeroed. The specimen was then submerged in the water, and the mass of the container plus water plus specimen was determined.

The increase in the mass of water displaced by the specimen in grams is numerically equal to the volume of water displaced in cm^3 since water has a density of 1 (Figure 2c). The wood samples were oven-dried at 103-105 °C to constant mass, and the oven-dry mass was determined and density recorded in kg/m^3 according to Equation 2. Method as used by OHEMENG (2022).

$$Den = \frac{M_o}{V_g} \qquad (02)$$

where: Den = Density, in kg/m^3; Mo = oven mass, in kg; Vg = green volume of wood, in m^3.

Figure 2. Wood specimens in the climate chamber (a); determination of density of Wama (b); prepared specimens for shrinkage test (c); and measuring with micrometer screw gauge (d).
Figura 2. Espécimes de madeira na câmara climática (a); determinação da densidade de Wama (b); corpos de prova preparados para ensaio de retração (c); e medição com medidor de parafuso micrométrico (d).

2.4. Longitudinal, radial, and tangential shrinkage

Shrinkage tests were evaluated from samples at the green condition. Samples of square sections of length 100 mm were used to provide the tangential and radial surfaces described by Ofori et al. (2009) (Figures 2d and 2e). These specimens were prepared from the base, middle, and top portions of *M. lateriflorum*. The samples were seasoned and conditioned to 12 % MC in constant humidity and temperature and oven-dried at 103 ± 2 °C.

Samples were weighed periodically, and the dimensions of each specimen were measured using a digital micrometer screw gauge in the radial and tangential directions and digital veneer calipers in the longitudinal direction. Shrinkage in drying at various moisture contents and from the green to 12 % moisture content and oven-dried state were determined in percentage for the radial, tangential, and longitudinal directions (Equation 3).

$$S = \frac{D_g - D_c}{D_g} \text{ x } 100 \qquad (03)$$

where: S = shrinkage, in %; Dc = dimension of sample in moisture content condition, in mm; Dg = dimension of sample in green condition, in mm.

2.5. Static bending properties

Moduli of Elasticity (MoE) and Rupture (MoR) of *M. lateriflorum* were determined by the standard (Table 1). An Instron Universal Testing Machine (UMT) (Model Inspekt 50-1) operating with a load cell capacity of 50 kN was used for the test. The loading rate applied to determine the MoE and MoR was 4 mm/min, as shown in Figure 3. Equations 4 and 5 were used to determine the MoE and MoR of *M. lateriflorum*.

$$\text{MoE} = \frac{3 \times P \times L}{b \times h^2} \qquad (04)$$

$$\text{MoR} = \frac{\Delta P \times L}{4 \times \Delta y \times b \times h^3} \qquad (05)$$

Where: P = Maximum load, in Newtons (N); L = Span length, in mm; b = Breadth of the span, in mm; h = height of the test piece, in mm; ΔP = Change in load in Newtons at the elastic forming area; Δy = Deflection in mm; L = Span length in mm of the test piece.

2.6. Compression strength parallel to the grain

The test was conducted according to standard using Instron UTM (Model 4482) operating with a load cell capacity of 100 kN at a rate of 0.635 mm per min (Figure 3c) to determine the behavior of *M. lateriflorum* under applied crushing load. The compression strength at maximum load in N/mm² was computed using Equation 6. Method as used by OHEMENG (2022).

$$\text{fc0} = \frac{\text{Fmax}}{A} \qquad (06)$$

where: F = Maximum load in Newtons; A = Cross-sectional area in mm².

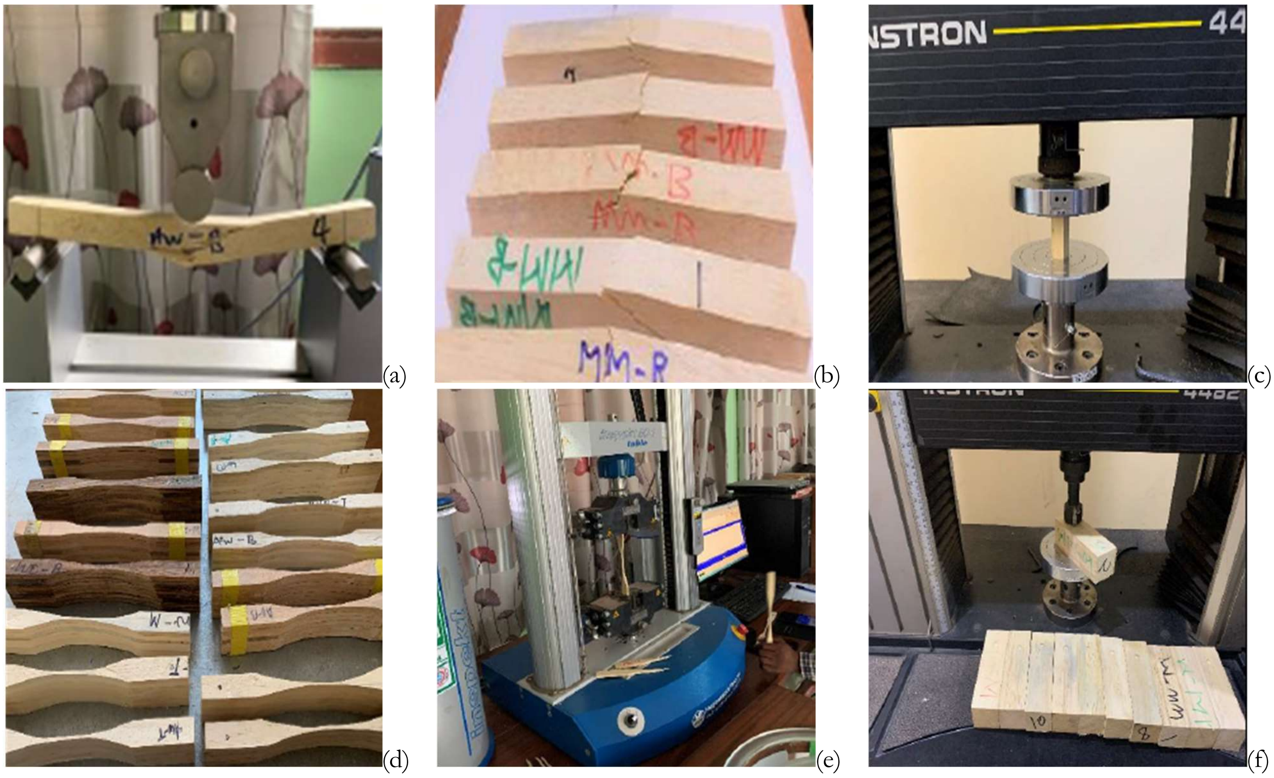

Figure 3. Mechanical properties assay: static bending (a) and specimens after test (b); determination of compressive strength parallel to the grain (c); specimen used for tensile strength parallel to the grain tests according to standard (d) and tensile strength test (e); Janka indentation tests (f).

Figura 3. Ensaios de propriedades mecânicas: flexão estática (a) e corpos de prova após ensaio (b); determinação da resistência à compressão paralela à fibra (c); corpo de prova utilizado para resistência à tração paralela aos ensaios de grãos conforme norma (d) e ensaio de resistência à tração (e); Testes de indentação Janka (f).

2.7. Shear strength parallel to the grain

Shear strength parallel to the grain of *M. lateriflorum* was determined by standard (Table 1). The test used an Instron Universal Testing Machine (UMT) (Model Inspekt 50-1) operating with a load cell capacity of 50 kN at a rate of 0.635 mm per minute. The direction of the shearing was parallel to the longitudinal direction of the grain. The shear strength from the maximum load was computed using Equation 7.

Method as used by OHEMENG (2022).

$$fv0 = \frac{Fmax}{bh} \quad (07)$$

z F = Maximum load in Newtons (N); bh = Area in shear in square millimetre (mm^2).

2.8. Tensile Strength parallel to the grain

The resistance to tension parallel to the grain was determined as described in DIN 52182, BSI 373 (1957) for *M. lateriflorum* species. The specimen was orientated such that the direction of the annual rings was perpendicular to the more excellent cross-sectional dimensions (Figures 3d and 3e). The load was applied to the samples at a constant head speed of 1.27 mm per minute using the UTM Inspekt 50-1. Method as used by OHEMENG (2022).

2.9. Janka Indentation Tests

Janka ball test was used for determining the hardness of *M. lateriflorum* using Instron UTM (Model 4482) operating with a load cell capacity of 100 kN at the penetration rate of 6.35 mm per min (Figure 3f). The test was conducted radially and tangentially to determine the load required to force a steel ball of 11.278 ± 0.0508 mm diameter into the wood specimen to a depth of 0.222 inches.

2.10. Strength Classification of *M. lateriflorum*

The strength value in this study is the average value determined in the laboratory tests based on the testing of clear, defect-free specimens. However, large pieces of timber used in construction are seldom defect-free (FAGGIANO et al. 2011; JAILLON; POON, 2008). In determining the strength values (characteristic value) for *M. lateriflorum*, the study adopted the 5 % point of exclusion limit. The expected value of the survey used Equation 8.

$$F_{05} = F_{mean} - 1{,}654 \times \sigma \quad (08)$$

where: F_{05} = strength values at 5%; F_{mean} = Mean of the strength property; σ = standard deviation.

3. RESULTS

The morphology of *M. lateriflorum* and the structure of the selected species indicate that the diameter at breast height (dbh) and total height of the three trees, and the density variations within the size of the tree species from the base to the top portions showed no dominant pattern were as recorded in Table 2. Table 3 depicts the technical description of *M. lateriflorum* in terms of density in kg/m^{3,} which conforms well with already '*well-known'* commercial species, providing fundamental technical information on their strength, working characteristics, and end-product use applicability.

The total mean tangential shrinkage from green to 12 % moisture content for 60 samples of *M. lateriflorum* from both ecological zones was 9.46 %, and the mean radial shrinkage was 6.57 %. The total mean of the coefficient of anisotropy was 1.44. In contrast, the measure of percentage shrinkages of *M. lateriflorum* from green to 12 % MC was extracted from sections of the stems of the three trees, as shown in Table 4. Generally, the highest shrinkages were recorded by the base of all the trees for tangential and radial in decreasing order to the top of all the trees from both ecological zones. At the same time, the longitudinal shrinkage recorded values differently for each section of the three trees. However, regardless of the tree height from both ecological zones, the tangential direction recorded the highest overall averages compared to the radial and longitudinal directions.

The coefficient of anisotropy for *M. lateriflorum* is relatively low and is, therefore, of good wood quality in terms of dimensional stability compared to some well-known species (Table 5). However, in areas of heavy structural construction where shrinkage characteristics are essential, design detailing must be very critical.

Results of mechanical properties of *M. lateriflorum* wood shown in Table 6. obtained from three-point static bending, indicated that the mean value of MoE for *M. lateriflorum* was 19.724 N/mm² with a standard deviation of 2.336 N/mm² from both ecological zones for a total of 60 samples. The mean MoR of *M. lateriflorum* for both environmental zones was 143.09 N/mm² with a standard deviation of 12.70 N/mm² for 60 pieces. The average characteristic value was 122 N/mm². These values give a clear indication that *M. lateriflorum* is of high strength. The results of the compression strength parallel to the grain (indicated that the mean compressive strength for 60 samples of *M. lateriflorum* was 62.40 N/mm² and a standard deviation of 5.8 N/mm². The results for the characteristic values for *M. lateriflorum* were 52.9 N/mm².

The mean shear strength value parallel to the grain for 60 samples of *M. lateriflorum* for both ecological zones was 20.50 N/mm² and a standard deviation of 2.23 N/mm². The indentation hardness test was conducted both in the radial and tangential directions. The experiment results indicate that the mean hardness of *M. lateriflorum* was 15.70 kN and 14.30 kN for both ecological zones in the radial and tangential directions, respectively.

Table 2. Tree morphology and values of the essential density at 12 % MC within the tree height of *M. lateriflorum*.
Tabela 2. Morfologia das árvores e valores da densidade básica a 12% MC dentro da altura das árvores de *M. lateriflorum*.

Ecological zone	Tree portion	n	Dbh (cm)	Height (m)	Density (Kg/m³)
Moist Semi-deciduous	Base	30	-	-	843.5 ± 12.9
	Middle	30	-	-	837.6 ± 10.4
	Top	30	-	-	826.2 ± 12.6
	Tree	3	86.39 ± 13.21	3.66 ± 0.65	835.7 ± 12.0
Wet Evergreen	Base	30	-	-	851.6 ± 11.0
	Middle	30	-	-	849.7 ± 13.6
	Top	30	-	-	831.9 ± 11.1
	Tree	3	99.23 ± 10.41	4.15 ± 0.36	844.4 ± 11.9

n = number of replicates; Dbh = diameter at breast height; mean values ± standard deviation.

Table 3. Comparison of the mean densities at 12 % MC of *M. lateriflorum* with well-established and most exported hardwood species in Ghana and with well-established European hardwood timber species.
Tabela 3. Comparação das densidades médias a 12% MC de M. lateriflorum com espécies de madeira de folhosas bem estabelecidas e mais exportadas no Gana e com espécies de madeira de folhosas europeias bem estabelecidas.

Scientific names	Local name	Density (Kg/m³) at 12 % MC	Density category[x]
Memecylon lateriflorum	Otwese	824 – 853	Heavy
Triplochiton scleroxylon	Wawa	490	Medium
Ceiba pentandra	Onyina/Ceiba	450	Light-Medium
Terminalia superba	Ofram	537	Medium
Khaya ivorensis	African mahogany	570	Medium
Cylicodiscus gabunensis	Denya	935	Very heavy
Piptadeniastrum africanum	Dahoma	900	Heavy
Populus spp	Poplar	350 – 500	Low
Ochroma pyramidale	Balsa wood	110 – 140	Very low
Populus tremuloides	Quaking aspen	401 – 420	Low
Quercus spp	Oak	600 – 900	Heavy

[x]Categorization is based on the established Forestry Commission Technical description for tropical wood species (LEMMENS et al., 2012)

Table 4. Longitudinal, radial, and tangential shrinkage (%) and coefficient of anisotropy in *M. lateriflorum* from green to 12 % MC.
Tabela 4. Encolhimento longitudinal, radial e tangencial (%) e coeficiente de anisotropia em *M. lateriflorum* de verde a 12% MC.

Shrinkage	N	Ecological zones					
		Moist semi-deciduous			Wet evergreen species		
		Base	Middle	Top	Base	Middle	Top
Longitudinal (%)	20	0.37 ± 0.01	0.85 ± 0.02	0.66 ± 0.02	0.75 ± 0.01	0.56 ± 0.01	0.68 ± 0.01
Radial (%)	20	7.35 ± 0.07	6.54 ± 0.08	5.35 ± 0.07	7.55 ± 0.56	6.90 ± 0.08	5.74 ± 0.07
Tangential (%)	20	9.92 ± 0.12	9.74 ± 0.07	8.64 ± 0.30	10.33 ± 0.52	9.48 ± 0.34	8.65 ± 0.28
T/R (%)	20	1.35 ± 0.09	1.49 ± 0.07	1.61 ± 0.19	1.37 ± 0.54	1.37 ± 0.21	1.51 ± 0.17

n = number of replicates; T/R = coefficient of anisotropy; mean values ± standard deviation.

Table 5. Comparison of radial and tangential shrinkages from green to 12 % MC of *M. lateriflorum* with some well-known species.
Tabela 5. Comparação das contrações radiais e tangenciais do verde a 12% MC de *M. lateriflorum* com algumas espécies bem conhecidas.

Species	% Radial shrinkage	% Tangential shrinkage	Coefficient of anisotropy(T/R)	*Quality
M. lateriflorum	6.57	9.45	1.44	Excellent
***Khaya ivorensis*	5.00	8.40	1.68	Normal
***Poroderma africanum*	5.20	13.40	2.58	Bad
***Palicourea elata*	3.00	6.40	2.13	Bad
Picea sitchensis	4.30	7.50	1.74	Normal

Sources: * Christoforo; Hendrigo (2016); Logsdon; Penna (2004); ** Prota4u database

Table 6. Results of mechanical properties of *M. lateriflorum* at 12 % MC.
Tabela 6. Resultados das propriedades mecânicas de *M. lateriflorum* a 12% MC.

Mechanical properties	n	Ecological zones					
		Moist semi-deciduous			Wet evergreen species		
		Base	Middle	Top	Base	Middle	Top
MoE (GPa)	20	19.48 ± 0.54	18.74 ± 0.71	17.55 ± 0.39	22.57 ± 0.74	21.08 ± 0.86	18.94 ± 0.98
MoR (MPa)	20	141.78 ± 2.52	136.92 ± 1.83	129.80 ± 0.29	160.95 ± 6.53	152.41 ± 4.08	137.67 ± 4.09
fc0 (MPa)	20	62.64 ± 0.71	55.83 ± 1.72	51.39 ± 5.63	72.88 ± 2.32	69.45 ± 1.29	62.20 ± 3.68
fv0 (MPa)	20	20.73 ± 1.52	18.97 ± 4.86	52.27 ± 5.88	25.53 ± 6.95	21.45 ± 6.64	18.93 ± 14.57
ft0 (MPa)	20	123.11 ± 2.93	116.27 ± 4.86	110.53 ± 5.88	207.33 ± 6.95	179.69 ± 6.64	158.28 ± 14.57
Hr	20	15.8 ± 0.0	15.2 ± 0.0	14.0 ± 0.0	18.9 ± 0.0	15.3 ± 0.0	15.2 ± 0.0
Ht	20	15.6 ± 0.0	13.8 ± 0.0	12.9 ± 0.0	15.3 ± 0.0	14.1 ± 0.0	13.8 ± 0.0

n = number of replicates; Den = Density; MoR = Modulus of rupture; MoE = Modulus of elasticity; Shear; fc0 = Compression parallel to grain; fv0 = shear parallel to grain; ft0 = Tensile strength parallel to grain; Hr = Radial hardness; Ht = Tangential hardness; Mean values ± standard deviation.

Table 7 indicates that *M. lateriflorum* is superior to some lesser-known timber species in terms of static bending strength properties. It could be the preferred choice for applications with significant static bending strength. Correlations between density and the various strength characteristics conducted in this study revealed a strong correlation, as shown in Table 8. This implies that the higher the density, the higher the strength of the wood. This general relationship holds for static bending, compression, and tensile strength parallel to the grain, hardness, and shear strength.

The functional relationship was established between the density of *M. lateriflorum* and its mechanical properties, as shown in Figure 4. The figure indicates the relationship between density and MoR, MoE, Shear, Compressive strength, Tensile strength, Radial hardness, and Tangential hardness were analyzed.

Table 7. Comparison between *M. lateriflorum* with other Ghanaian less-known and less-used timber species.
Tabela 7. Comparação entre *M. lateriflorum* com outras espécies madeireiras menos conhecidas e menos utilizadas do Gana.

Wood species	Local	MoE (N/mm^2)	F_{05} MoE (N/mm^2)	MoR (N/mm^2)	F_{05} MoR (N/mm^2)
M. lateriflorum	Otwese	19.724	15.861	143.09	122.00
**C. africanum*	Essia	9.74	7.25	104.12	81.11
**N. papaverifera*	Danta	10.36	7.99	117.03	92.02
**Lophira alata*	Ananta	17.622	13.484	188.00	155.00
**Celtis mildbraedii*	Celtis (Esa)	12.545	9.241	130.00	93.00

MoE = Modulus of Elasticity; F_{05} MoE = strength characteristic values; MoR = modulus of rupture; F_{05} MoR = strength distinct values.
Sources: *Ofori *et al.* (2009)

Table 8. Correlation between density and strength properties at 12 % moisture content for *M. lateriflorum*.
Tabela 8. Correlação entre propriedades de densidade e resistência a 12% de umidade para *M. lateriflorum*.

Correlated properties	Den	MoR	MoE	fv0	fc0	ft0	Hr	Ht
Density	1							
MoR	0.89	1						
MoE	0.92	0.99	1					
Shear	0.89	0.94	0.95	1				
Compression parallel to the grain	0.94	0.96	0.99	0.94	1			
Tensile parallel to the grain	0.89	0.98	0.99	0.98	0.98	1		
Radial hardness	0.93	0.98	0.96	0.94	0.95	0.95	1	
Tangential hardness	0.75	0.86	0.86	0.96	0.82	0.91	0.88	1

Den = Density; MoR = modulus of rupture; MoE = Modulus of elasticity; fv0 = shear parallel to grain; fc0 = Compression parallel to grain; ft0 = Tensile parallel to grain; Hr = Radial hardness; Ht = Tangential hardness.

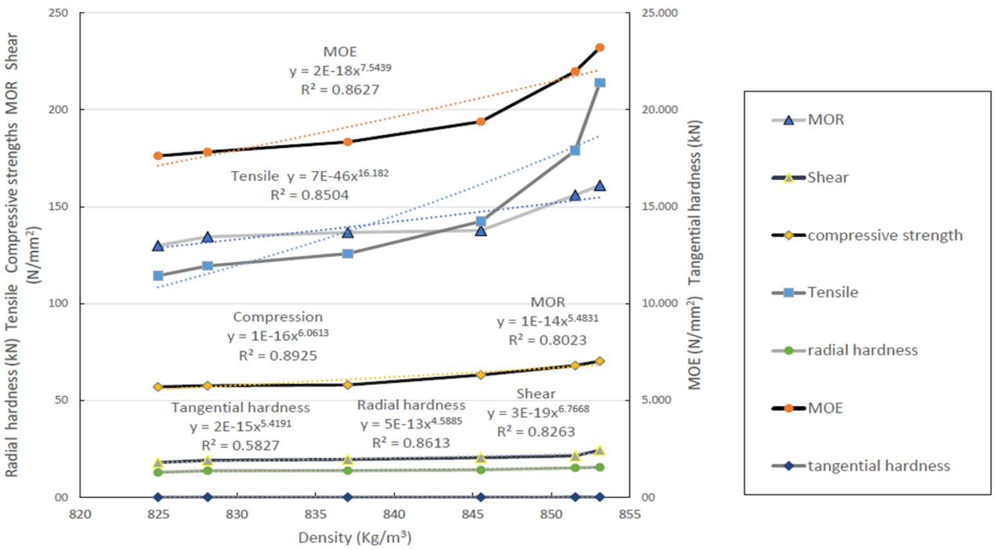

Figure 4. Functional relationship between density and mechanical strength properties at 12 % moisture content for *M. lateriflorum*.
Figura 4. Relação funcional entre propriedades de densidade e resistência mecânica com teor de umidade de 12% para *M. lateriflorum*.

4. DISCUSSION
4.1. Physical properties

Density is the amount of wood substance per unit volume and the moisture content. Frodeson et al. (2019), Gendek et al. (2018), and Wang; Winistorferf (2000) emphasized that it is a wood property that correlates very well with the physical and mechanical properties of the wood. *M. lateriflorum* from both ecological zones at 12 % MC recorded a mean density of 840.10 kg/m^3, with a standard deviation of 11.92 kg/m^3 (Table 2). Within tree heights, the average density ranged from 826,2 to 831,9 kg/m^3. According to Lemmens et al. (2012), such wood could be graded as high density (Table 3). The pattern of the results of variations of density within the height aligns well with many authors' claims of the inconsistent variations of density within tree height, most especially among tropical hardwood species (KING et al., 2006; KING et al., 2005; SWENSON; ENQUIST, 2007; WEEDON et al., 2009). In wet evergreen and moist semi-deciduous ecological zones, the base portion recorded the highest mean density value compared to the middle and the top pieces. The density indicated slight significant differences in the increase from the top to the base portions of the timber.

The variation of wood density within the tree species proven by this study may be caused by several characteristics of the wood species, such as cell size and wall thickness, the ratio of earlywood to latewood, growth rate, the number of ray cells, the size and vessel elements (ZOBEL; BUIJTENEN, 1989). In addition to cell characteristics, factors such as chemical deposits within and between the cells, juvenile wood, environmental conditions, site conditions, climate, geographic location, age, and silvicultural management could affect wood density (FILIPESCU et al., 2014; OHEMENG, 2022; RAMAGE et al., 2017).

The variation of wood density within the tree species also aligns with the studies of Panshin; De Zeeuw (1980) and Zobel; Buijtenen (1989) of the fact that the base portion of trees consists of a high proportion of matured wood compared to the top portion which consists mainly of juvenile wood.

The results (Table 5) affirm the report by Bodig; Jayne (1993), and Poku et al. (2001) that the tangential shrinkage is generally more significant than radial shrinkage by a factor between 1.50 and 3.00. According to Eric Meier, The Wood Database (2015), most wood species fall in the range of about 3 % to 5 % radial shrinkage and 6 % to 10 % tangential shrinkage. However, the magnitude of shrinkage is dependent on density. This is due to the more significant amount of wood substance and greater cell wall thickness in higher-density wood. When moisture is lost and gained, the cell cavity does not change in size, but cell dimensions vary due to changes in cell wall dimensions (AYARKWA, 2009). The overall longitudinal shrinkage from green to 12 % MC for *M. lateriflorum* was 0.65. Generally, the longitudinal shrinkage of wood species is negligible. For most wood species, the average values for longitudinal shrinkage from green to oven-dry are between 0.10 % and 0.20 %. However, certain types of wood exhibit excessive longitudinal shrinkage, and these species should be avoided in uses where longitudinal shrinkage is significant (FPL, USA, 2010).

The shrinkage variations could be a result of several combinations of factors, including the presence of ray tissue, which provides a restraining influence in the radial direction, frequent pitting on the radial walls, the domination of latewood in the tangential direction, and differences in the amount of cell wall material radially and tangentially (POKU et al., 2001).

Similar results indicate that tangential shrinkage in wood is more significant than radial shrinkage (MIRZAAKBAROVNA, 2021; POKU et al., 2001; SCHULGASSER; WITZTUM, 2015; XUE et al., 2018). This may be due to factors such as the strands in the fiber walls being bent around the pits that predominate in the radial walls of the fibers rather than being parallel to the long axis of the fiber (GETAHUN et al., 2014; SULAIMAN et al., 2012).

For the coefficient of anisotropy, these values are good guidelines for estimates of dimensional stability (HAYGREEN; BOYER, 1996). The low coefficient of anisotropy in the species indicates that wide splits, checks, and distortions are minimal during the drying of these species (CHAUHAN; ARUN KUMAR, 2014; REDMAN et al., 2016).

The strength properties of wood species provide the best index for its use for structural and construction applications (ASDRUBALI et al., 2017; AYARKWA et al., 2011; CHEN et al. 2020; MI et al., 2020).

As shown in Table 6,\ the MoE shows a decreasing trend towards the top portion, indicating that the species' base portions were stiffer than the middle and top portions. The variations between the tree species observed could be attributed to genetic differences (Ishengoma et al., 2004), density, fiber length (Dinwoodie, 1981), and environmental factors such as relative humidity and temperature (AYARKWA, 2009).

The strength classification of *M. lateriflorum* based on MoE at 12 % MC is 15.861 N/mm² (Table 7). According to the Forestry Commission (2019) category, this is very high. Hence, *M. lateriflorum* has high stiffness since MoE measures the stiffness of wood species (BRANCHERIAU et al., 2002; NOCETTI et al., 2013).

Modulus of Rupture is an accepted criterion of strength before rupture (AYARKWA et al., 2011; TIRYAKI; HAMZAÇEBI, 2014). Within the tree height, there was a decreasing trend of mean MoR values from the base to the top (Table 6). This could be attributed to juvenility within the tree height from bottom to top (GETAHUN et al., 2014; OHEMENG, 2022; PIISPANEN et al., 2020). Poorter et al. (2010) and Van-Gelder et al. (2006) reported that mature wood tends to possess higher density, affecting the strength characteristics.

The shear strength parallel to the grain is an important property that comes into play in the structural use of timber in jointing (OFORI et al., 2009).

Within the tree height, there were variations from the base portion to the top portion. The base portion recorded the highest Shear Strength values, followed by the middle and top portions. The difference in variability between and within the tree species could be attributed to morphological differences, the heterogeneous composition and structure of tropical species, climatic conditions (HALL; SWAINE, 1981), and density (DINWOODIE, 1981).

Tensile strength parallel to the grain is a vital strength parameter in measuring the resistance of wood to forces that tend to stretch the fibers of the wood to failure. The study's results indicate that the mean tensile strength parallel to the grain on 60 samples of *M. lateriflorum* was 149.20 N/mm² and a standard deviation of 47.5 N/mm² for both ecological zones. On the other hand, the strength characteristic values (F05) recorded a mean value of 84.00 N/mm².

The results in Table 6 indicate a significant variation in tensile strength properties parallel to the grain of *M. lateriflorum* from Moist semi-deciduous and Wet evergreen species. This could be a result of substantial changes in annual tree-ring formation, the effect on tree species ring as a result of site-specific growth, anatomical variation as a result of diameter growth rates and growth quality (AYARKWA et al., 2011; GROENENDIJK et al., 2014).

The Tensile strength properties of wood species depend upon the strength of the fibers and are affected not only by the nature and dimensions of the wood elements but also by their arrangement (HASSAN et al., 2010; HUGHES, 2012; PELTOLA et al., 2014). Record (1914) reported that tension results when a pulling force is applied to opposite ends of a body. The external force is communicated to the inner part of the wood so that any portion of the material exerts a tensile strength upon the remainder. The ability of the material to do so depends upon the cohesion property. The result is an elongation or stretching of the material in the direction of the applied force. This action is the opposite of compression. Hence, Tensile strength parallel to the grain is greatest in straight-grained samples with thick-walled fibers compared to cross-grain of any timber species. Record (1914) indicated that tensile strength at right angles to the grain is only a tiny fraction of that parallel to the grain.

The term hardness is used in two cases: resistance to indentation and resistance to abrasion. This study focused on the opposition to indentation as this property primarily depends on the wood density (RECORD, 1914). The hardness of wood has a good relationship with various mechanical properties (KOLLMANN, 1951). This indicates that hardness is an essential parameter for wood quality.

The mean hardness values increased from the top portion to the base for both species (Figure 4), showing no dominant pattern. Statistical analysis of variance revealed a significant difference of p-value less than 0.05 for both tree species from the two ecological zones. While resistance to indentation depends mainly upon the density of the wood, the wearing qualities may be governed by other factors such as toughness and the size, cohesion, and arrangement of the fibers (RECORD, 1914).

The density of wood is directly related to wood properties such as hygroscopicity, shrinkage, and swelling, mechanical, thermal, acoustical, electrical, and other basic wood properties relating to the industrial processing of wood such as machining and drying (AYARKWA, 2009). It is an imperative index of wood quality (TSOUMIS, 1991). However, density values are also affected by gums, resins, and extractives, which add to their weight and contribute little to their mechanical strength properties (GREEN et al., 1999; LAVERS, 1983; OFORI et al., 2009). Density is directly related to strength properties; the *greater* the density of wood, the *greater* the strength (LARJAVAARA; MULLER-LANDAU, 2012; SARANPÄÄ, 2003).

5. CONCLUSIONS

The study has evaluated some physical and mechanical properties of *Memecylon lateriflorum* wood at 12% moisture content, which is a lesser-known (LKS) and lesser-used (LUS) tropical timber species originating from two unique ecological zones in Ghana, mainly Wet Evergreen and Moist semi-deciduous regions.

M. lateriflorum recorded high density and strength values. The wood can be promoted for use in constructional applications (roof trusses, columns, posts, and as notched timber), bridges, railway sleepers, exterior furniture, flooring, joinery applications, or for other several engineering applications such as glue-laminated timber (Glulam) and cross-laminated timber (CLT). Due to its physical and mechanical properties, *it* could be promoted for use in ship and boat building, wagon trays, sea defense and dock works, mining timber, and other agricultural implements.

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