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Full Length Research

Functional Relationship between density and mechanical properties of *Ricinidendron heudelotii*

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One important aspect of the Sustainable Forest Management (SFM) scheme is the promotion of Lesser-Used" Timber Species (LUS) in substituting for the over-exploited and well-known timber species. The successful promotion and utilization of LUS require technical information relating to their processing, mechanical, physical, anatomical, and pathological properties. The main objective of the study was to determine the relationship between density on the mechanical strength properties of *Ricinidendron heudelotii* wood sampled from two ecological regions in Ghana. The study revealed strong correlations (85-99 %) between the density and mechanical strength properties. Regression equations in the power form of $Y= aX^n$ were derived with R^2 values of 0.67-0.81. This implies that a reasonable estimate of the strength of *R.heudelotii* could be made based on the density especially where tangible grading rules are absent. The study further revealed the variations along the tree height of the species. There was an overall decreasing trend from the butt portions to the top portions of the wood species in terms of density and mechanical strength properties. There was a significant difference between static bending, shear, compression, and tensile parallel to the grain within the tree height. The wood of *R. heudelotii* is considered a less dense wood with an average density of 388.7 kg/m^3 and mean strength values are as follows: - MOE (5,867 N/mm^2), MOR (41 N/mm^2), compression (17.9 N/mm^2), shear (6.0 N/mm^2), and tensile parallel to grain (29.6 N/mm^2). The wood is considered a potential substitute for Balsa Wood *(Ochroma pyramidale)* and Wawa *(Triplochiton scleryxylon)*.

Keywords: Wood Density, Tropical Lesser-used wood species, Mechanical strength properties

1. INTRODUCTION

Several different parameters provide clues to the properties and potential uses of wood. Wood density is revealing than any other indicator or measure (Ayarkwa, 2009). Knowledge of density allows the prediction of a greater number of properties than any other parameter. The term density is sometimes used interchangeably with specific gravity; however, these terms have precise and different definitions although they refer to the same characteristic (Haygreen & Boyer, 1996). Wood is a cellular material whose structure gives its unique properties. Wood density varies greatly within any species because of several factors. These factors include location in a tree, location within the range of the species, site condition (soil, water, and slope), and genetic source (Haygreen & Boyer, 1996). Density is defined as the mass or weight of wood per unit volume of the specimen at a given moisture content. Thus, units for density are usually expressed in terms of grams per cubic centimeter (gm/cm^3) or kilograms per cubic meter (kg/m^3). Wood density is directly related to other wood properties, and it is an important index of wood quality (Tsoumis, 1991). Density affects hygroscopicity, shrinkage and swelling, mechanical, thermal, acoustical, electrical, and other basic wood properties, as well as properties related to the industrial processing of wood such as machining, drying, etc. (Ayarkwa, 2009). Haygreen & Boyer, 1996 reported that the strength of wood is usually closely correlated to density, and it is possible to estimate wood strength based on density without detailed knowledge of the species. It is, therefore, possible to make a reasonable estimate of strength based on the density/ specific gravity of the wood. In developing countries, where grading rules for lumber are not highly developed or where many species are sawn and used interchangeably, the grading of structural lumber could be based primarily upon density (Haygreen & Boyer, 1996).

(Ishengoma & Chihongo, 1997) noted that density was the main criterion for the prediction of clear wood strength properties. The approximate relationship between mechanical strength properties and density for straight-grained wood of hardwoods and softwoods is in the form of power functions such as $Y = aX^n$ (Ofori, et al., 2009) (Krauss, 2009) and (Haygreen & Boyer, 1996). The main object of the study was to determine the functional relationship between the density and mechanical strength properties of *R. heudelotii* sampled from two ecological regions of Ghana.

2. MATERIALS AND METHODS

2.1 Material Collection

Wood Samples used in the study were collected from two forest districts in Ghana, Bosomtwe and Amenfi West. These forest districts were selected due to the range of distribution of *R.heudelotii* species forming part of two unique ecological zones in Ghana mainly Moist Semi-Deciduous and Wet Evergreen forest zones. The Bosomtwe District is located in the central portion of the Ashanti Region. The district falls within the forest belt of the Region, and it is within the West Semi-equatorial Climate region with a rainfall regime typical of the Moist Semi- Deciduous Forest zone of the country [10].

The Amenfi West district falls under the High Rain Forest belt of the Western Region, and it is characterized by a semi-equatorial climate with high rainfall (1500-1750 mm) and daily temperatures between 22 and 34 °C. The high rainfall and the proximity to the Atlantic Ocean create moist atmospheric conditions that result in high relative air humidity, ranging between 70 and 90 % (Hall & Swaine, 1981).

2.2 Sampling and Conversion

Matured trees of *R.heudelotii* with an average diameter at breast height of 80-110 cm and an average height of 20-45 m for *R. heudelotii* were randomly selected. Three (3) trees were selected from 30 trees sampled within a given stand to give reasonable estimates of true mean values of the wood properties. Each tree was felled with a chainsaw machine and crosscut into three sections of butt/ bottom, middle and top and labeled accordingly. Each of the sections was again crosscut into billets of 1.5 m. The butt portion of the log was cut 1 m away from the diameter at breast height whilst the middle portion and top portions were sectioned at 1 m apart. The billets were then converted into lumber of 80 mm thick using a horizontal bandmill (Woodmizer).

2.3. METHODS

2.3.1 Basic Density

Two strips of 2.5 cm length from *R. heudelotii* were randomly selected from each of the sections, planed to 2 cm × 2 cm square sections, and then crosscut to 2 cm cubes. The cubes labeled per section per tree were soaked in water for 24 hours using vacuum impregnation.

The density on swollen volume and the oven-dry mass basis was determined by the immersion method. The weight of the beaker and the water it contained was determined by a digital balance of precision at 0.01 g 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 by the specimen in grams is numerically equal to the volume of water displaced in cm^3 since water has a density of 1. The wood samples were oven-dried at 103 – 105 °C until each sample obtained a constant mass which is equivalent to oven-dried mass, and the density per cube was determined in kg/m^3.

The density was calculated using the equation:

$$Density = \frac{oven\ dry\ mass\ (kg)}{Green\ volume\ of\ wood\ (m^3)} \quad \ldots\ldots\ldots\ldots.(1)$$

The basic density was adjusted to 12 % moisture content in accordance with ISO 13061-2:2014 as shown in equation (2).

$$\rho_{12} = \rho_w \frac{1 + 0.01\,(12 - W)}{1 + 0.01(12 - W)\frac{\rho_w}{\rho_{H20}}} \quad \ldots\ldots\ldots\ldots(2)$$

Where:

W= the moistur content below fiber saturation point at the time of test, in percent

P_{H20} = the density of water, 1000 kg/m^3

P_w = the basic density, kg/m^3

P_{12} = Density at 12 % moisture content, kg/m^3.

2.3.2 Conditioning

Before the preparation of samples for testing the mechanical properties in seasoned conditions, samples were brought practically to constant weight by storage under controlled temperature and humidity conditions of 20 °C and 65 % relative humidity as specified by DIN 52182 and BS 373 standards in a climate-controlled chamber. The climate chamber used for conditioning the samples was the Clima Temperatur Systeme (CTS). The initial weight of the various samples for each test was weighed and recorded periodically using a digital weighing balance until a constant weight with not more than 0.1 % significant difference after 24 hours were achieved for all samples.

2.4 Determination of strength properties

2.4.1 Static bending

The determination of static bending strength which includes Modulus of Elasticity (MOE) and Modulus of Rupture (MOR) was determined and analyzed following the standard procedures described by BS 373:1957 ISO 13061-4:2014, and ISO 13061-3:2014. The static bending was carried out by a three-point bending method (Figure 1) with samples dimensions of 20 mm × 20 mm × 300 mm dimension/ Each sample was loaded on a Universal Testing Machine (UTM) at a constant loading speed of 6 mm per minute.

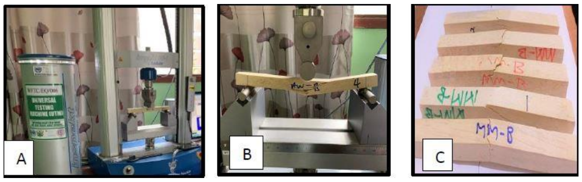

Figure 1: Static Bending Tests on Universal testing Machine (A,B) and samples after testing.

The MOR and MOE were computed using equations (3) and (4) respectively:

$$MOR = \frac{3PL}{2bh^2} \qquad \text{……………..}(3)$$

Where:
P = Maximum load in Newtons (N)
L = Span of the test piece in mm
b = Breadth of the test piece in mm
h = height of the test piece in mm.

$$MOE = \frac{\Delta PL^3}{4\Delta ybh^3} \qquad \text{…………….}(4)$$

Where:
P = Change in load in Newtons at the elastic forming area
Δy = Deflection in mm equal to the difference between the results obtained in measuring upper and lower limits of loading.
L = Span of the test piece
b = Breadth of the test piece in mm
h = Height of the test piece.

2.4.2 Compression strength parallel to the grain

Compression parallel to the grain experiment was conducted as described in BS 373:1957. Test specimens of 20 cm × 20 cm × 60 cm dimensions were compressed in the direction along the grain at a constant loading rate of 0.635 mm per minute to determine their behavior under applied crushing loads. The load was applied through a spherical platen fixture of which the plates between the test specimens were aligned parallel to each other until the end of the test period. This enabled uniform distribution of stress to obtain true compression values. A total of 60 samples from *R. heudelotii* with their ends smooth, parallel, and normal to the axis were tested using the Instron Universal testing machine. The compression strength at maximum load in N/ mm^2 was computed using equation 5:

$$Compressive\ strength = \frac{Fmax}{A} \qquad (5)$$

Where:
F = Maximum load in Newtons
A = Cross-sectional area of the test piece in mm^2.

2.4.3 Shear strength parallel to the grain

The shear strength parallel to the grain was conducted as described in BS 373 (1957) for testing small clear specimens and ISO 3347 (1976) for determining ultimate shear stress. Test samples of dimensions 20 mm × 20 mm × 20 mm were tested using Instron UTM. The load was applied at a constant rate of 0.635 mm per min. 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 6:

$$Shear\ strength = \frac{Fmax}{bh} \qquad \text{…………..}(6)$$

Where:
F = Maximum load in Newtons (N)
bh = Area in shear in square millimeter (mm^2)

2.5.3. Tensile strength parallel to the grain

The resistance to tension parallel to the grain was determined as described in BS 373 (1957) for *R.*

heudelotii. The form and dimensions of the test sample are illustrated in Figure 2. The specimen was orientated such that the direction of the annual rings is perpendicular to the greater cross-sectional dimensions. The load was applied to the samples at a constant head speed of 1.27 mm per min using the Inspekt 50 Universal Testing Machine.

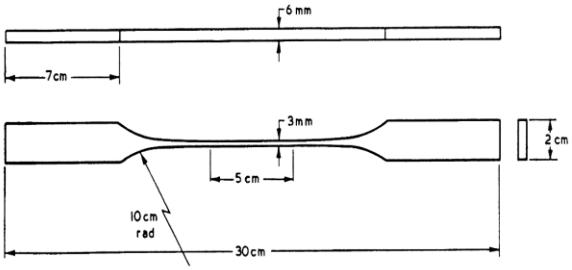

Figure 2: Form and dimension of the test piece used for tensile strength parallel to the grain tests.

2.5 Data Analysis and Interpretation

The data from the experiments were analyzed determine the physical and strength properties of *R. heudelotii,* the variability from the breast height (butt) to the middle, and the top portion using Microsoft Excel. Statistical analysis was used to compare the mean physical and strength values of *R. heudelotii* species. Analysis of variance (ANOVA) was used to determine the variations in the physical properties and strength properties within the height of the tree species and between the two ecological regions. Correlation and regression analysis were conducted to determine the relationship between density and mechanical properties of *R. heudelotii*.

3. RESULTS AND DISCUSSIONS

3.1. Density

Results indicated that within tree height average density at 12 % moisture content of *R. heudelotii* ranged from 312.72 – 450. 89 kg/m^3 with a standard deviation of 46.47 kg/m^3 and a coefficient of variations of 12.47 % for a total of 60 samples (Table 1) below. Results indicated no statistical significance (p= .807) between the two ecological regions and within the tree portions.

Table 1: Mean values of the basic density at 12 % MC within the tree height of *R. heudelotii*

Ecological zone	Tree portion	Number of test samples	Mean ± Std. deviation (kg/m3)
MS	Butt	10	420.10 ± 30.32
	Middle	10	386.16 ± 10.25
	Top	10	376.12 ± 9.32
WE	Butt	10	450.89 ± 58.93
	Middle	10	385.91 ± 34.57
	Top	10	312.72 ± 60.22
Total/ Mean		**60**	**388.65 ± 46.47**

The variations of wood density within the tree species indicated by the 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 the uniformity of wood density. The bottom portion of trees consists of a high proportion of matured wood compared to the top portion which consists mainly of juvenile wood.

Juvenile wood tends to contain less latewood within a growth ring than mature wood found within the same tree. This implies that the growth rings within the juvenile wood zone contain a greater proportion of earlywood than later growth rings. As a result, the average cell wall thickness is lower in juvenile wood than in non-juvenile wood meaning that wood density (mass per unit volume) is also lower (Ayarkwa, 2009) (Zobel & Buijtenen, 1989) (Haygreen & Boyer, 1996). This indicates that the bottom portion of wood could be more suitable for structural end-use applications compared to the top portion. The wood formed by young trees (juvenile wood) is of particular importance to manufacturers of lumber, structural panels, and other products using wood in solid form because every significant characteristic of juvenile wood is inferior to those of normal wood (matured wood).

3.2. Mechanical strength properties

3.2.1 Static Bending

3.2.1.1 Modulus of Elasticity (MOE)

Results obtained from three-point static bending indicated that the mean value of MOE for *R. heudelotii* was **5,867 N/mm^2** with a standard deviation of **1,035 N/mm^2** from both ecological zones for a total of **60 test samples**.

Table 2: Descriptive statistics of MOE for both ecological regions

Eco zone	Tree portion	Number of test samples	Mean ± Std. deviation (N/mm^2)
MS	Butt	10	6,650 ± 1,445.75
	Middle	10	6,116 ± 943.43
	Top	10	4,763 ± 1,220.74
WE	Butt	10	7,127 ± 1,442.86
	Middle	10	6,039 ± 2,363.91
	Top	10	4,509 ± 1,087.76

Modulus of Elasticity shows a decreasing trend towards the top portion thereby indicating that the butt portions of the two species were stiffer as compared to the middle and top portions. The variations within the tree height observed could be attributed to the amount of matured wood presence, cell dimensions, moisture content, fiber length (Dinwoodie, 1981), and environmental factors such as relative humidity and temperature (Ayarkwa, 2009).

3.2.1.2 Modulus of Rupture (MOR)

The mean MOR of *R. heudelotii* for both ecological zones was **41 N/mm^2** with a standard deviation of **5.6 N/mm^2** for **60 test samples.** Within the tree height, results indicated statistical significance with a P value less than 0.05 (Table 3).

Within the tree height of *R. heudelotii*, there was a decreasing trend of mean MOR values from the bottom to the top. This could be attributed to juvenility within the tree height from butt to top. As reported by Zobel & Buijtenen (1989) in Wood Variations Its Causes and Control, mature wood tends to possess higher density which thereby affects the strength characteristics.

The wet evergreen zone recorded the highest MOR values as compared to the moist semi-deciduous zone. The variability may be influenced by a combination of several other factors such as climatic conditions (Tsoumis, 1991), and the heterogeneous composition and structure of the tropical rain forest from which the trees grow (Hall & Swaine, 1981) (Table 3).

Table 3: Analysis of Variance of MOR at 12 % MC within the tree height of *R. heudelotii* from the ecological zones

Ecological zone	Number of test samples	Degree of freedom	P-value	F-crit
MS	30	2, 27	0.043	3.354
WE	30	2, 27	0.00112	3.354

3.2.2. Compression parallel to the grain

The statistical description of the mean compression strength parallel to the grain of 60 test samples at 12 % MC was **17.9 N/mm^2** and a standard deviation of **1.5 N/mm^2.** The coefficient of variation was **8.38 %.** Table 4 shows a breakdown of the mean values of the various tree portions.

Table 4: Statical description of the compressive strength parallel to the grain of *R. heudelotii* originating from two ecological regions

Eco zone	Tree portion	Number of test samples	Mean ± Std. deviation (N/mm^2)
MS	Butt	10	18.98 ± 0.86
	Middle	10	18.15 ± 1.17
	Top	10	16.24 ± 1.42
WE	Butt	10	19.82 ± 0.94
	Middle	10	17.92 ± 1.67
	Top	10	15.99 ± 1.34

Within the tree height of *R. heudelotii*, there were variations for the two ecological areas. There was a decreasing trend from the butt to the top portion in terms of the mean compressive strength values. The variations could be attributed to the chemical composition of the wood species. The high number of extraneous materials in wood species contributes to wood properties such as colour, odor, density, hygroscopicity (Ayarkwa, 2009). Extractives include tannins, and other polyphenolics, resins, waxes, fats, gum, starch constituting 5 % to 30 % of wood substance depending on wood species, growth conditions, and the time of year the tree is harvested (Ayarkwa, 2009). In our case, the trees were harvested in January or the harmattan season. The wet evergreen zone recorded the highest strength compared to the moist semi-deciduous. This could be attributed to the fact that the wet evergreen zone is floristically rich with annual precipitation of 1,750 mm and 2,000 mm (Oteng, 2006).

High strength in compression parallel to the grain is required of timber used as columns, posts, and notched timbers (Ayarkwa, 2009).

3.2.3. Shear Strength parallel to the grain

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). The mean value of shear strength parallel to the grain with the 60 test samples of *R. heudelotii* from both ecological zones was **6 N/mm^2** and a standard deviation of **0.6 N/mm^2**. The coefficient of variations indicated **10 %.**

Table 5: Statistical description of shear strength parallel to the grain at 12 % MC

Eco zone	Tree portion	Number of test samples	Mean ± Std. deviation (N/mm^2)
MS	Butt	10	6.76 ± 0.39
	Middle	10	5.59 ± 0.75
	Top	10	5.46 ± 1.05
WE	Butt	10	6.74 ± 0.32
	Middle	10	6.00 ± 1.26
	Top	10	5.49 ± 1.26

There were variations within the tree height from the butt portion to the top portion. The butt portion recorded the highest strength followed by the middle and top portions.

3.2.4 Tensile strength parallel to the grain

Tensile strength parallel to the grain is an important strength parameter in measuring the resistance of wood to forces that tend to stretch the fibers of the wood to failure. The results of the study indicated that the mean tensile strength parallel to the grain on 60 test samples of *R. heudelotii* was **29.6 N/mm^2**, and a standard deviation of **6.6 N/mm^2** for both ecological zones. The coefficient of variations between the tree portions indicated **4.9 % (Table 6).**
The trend of tensile strength indicated a decreasing order from the butt portions to the top portions of the tree species.

Table 6: Statistical description of tensile strength parallel to the grain at 12 % MC

Eco zone	Tree portion	Number of samples	Mean ± Std. deviation (N/mm^2)
MS	Butt	10	27.33 ± 7.77
	Middle	10	24.49 ± 4.77
	Top	10	20.07 ± 2.80
WE	Butt	10	44.28 ± 9.74
	Middle	10	39.59 ± 7.40
	Top	10	21.96 ± 7.21

Record (1914) (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 force upon the remainder. The ability of the material to do so depends upon the property of cohesion. The result is an elongation or stretching of the material in the direction of the applied force. This action is the opposite of compression. Several authors have emphasized this report in the case of roof truss engineering.

3.3. Mathematical relationships between the density and the mechanical strength properties of *R. heudelotii*

The approximate relationship between mechanical strength properties and density or straight-grained wood of hardwood and softwoods is in the form of power functions such as $Y = aX^n$ (Ofori, et al., 2009) (Krauss, 2009) (Haygreen & Boyer, 1996). Correlations between densities and the various strength characteristics recorded in this study revealed a strong correlation as shown in table 7. This implies that the higher the density the higher the strength of wood. This general relationship holds for static bending strength, compression and tensile strength parallel to the grain, hardness, and shear strength (Ayarkwa, 2009).
Comparing *R. heudelotii* species with well-known European wood species using the normalization method in table 8, indicated *M. lateriflorum* as the strongest wood followed by Red Oak (*Quercus species*) with the least strength recorded by *R. heudelotii* (Wama).

Table 7: Correlation between density and mechanical strength properties at 12 % moisture content for *R. heudelotii*

CORRELATION	Density	MOR	MOE	Shear	Comp IIg	Tensile IIg
Density	1					
MOR	0.85	1				
MOE	0.91	0.91	1			
Shear	0.84	0.97	0.88	1		
Comp IIg	0.91	0.93	0.99	0.90	1	
Tensile IIg	0.89	0.95	0.90	0.98	0.92	1

Table 8: Comparison of wood properties at 12 % MC between well- known timber species with *R. heudelotii* using normalization method

Species	MOE	MOR	TENSILE	SHEAR	COMP
T. scleroxylon	100 %	100 %	100 %	100 %	100 %
R. heudelotii	99 %	80 %	62 %	88 %	66 %
Ceiba pentandra	63 %	58 %	-	56 %	61 %
Ochroma pyramidale	58 %	42 %	-	31 %	55 %

With the two most important strength properties i.e. respectively. Given the very large price differential and exploitation between the wood species, *R.heudelotii* as a less-known timber species remains an efficient choice for structural and construction, furniture, and other engineering applicationsbending strength and compression parallel to the grain, *R. heudelotii* recorded about 66-99 %, Ceiba and Balsa wood recorded between 58-63 % and 42-58 %,

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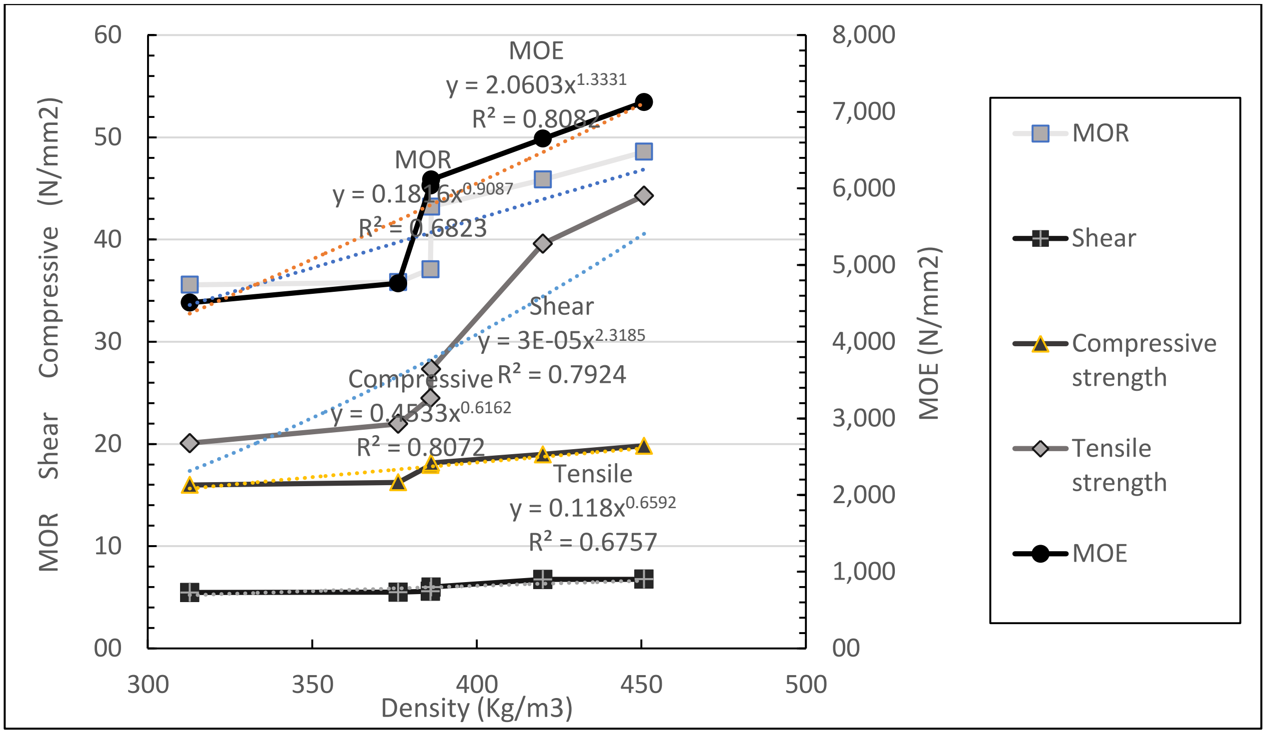

Figure 3: Relationship between density and mechanical strength properties at 12 % moisture content for *R. heudelotii.*

Table 9: Relationship between the basic density and the mechanical properties of clear, straight-grained wood of *R. heudelotii*

Mechanical Strength Property	Wood at 12 % moisture content	
	Density (X) Strength (Y) Relationship	R^2
MOR (N/mm^2)	$Y = 0.1816\ X^{0.9087}$	0,68
MOE (N/mm^2)	$Y = 2.0603\ X^{1.3331}$	0,80
Tensile parallel to the grain (N/mm^2)	$Y = 0.118\ X^{0.6592}$	0,67
Compression parallel to the grain (N/mm^2)	$Y = 0.4533\ X^{0.6162}$	0,81
Shear parallel to the grain (N/mm^2)	$y = 3E\text{-}05\ X^{2.3185}$	0,79

4. CONCLUSION AND RECOMMENDATION

Results indicated a wide range of variations, with differences occurring among trees within and between the ecological zones as well as within individual tree portions (butt, middle and top) which relates well with several reports indicating high variations of density and strength properties in tropical hardwood species. Many factors including site, climate, geographic location, conditioning, and the heterogeneous composition and structure of tropical hardwoods affected the physical and mechanical strength properties of the species. Since many of the factors occur in combination, it is difficult to separate the independent effects. Site-related factors (ecological factors) such as moisture, availability of sunlight and nutrients, wind, temperature, amount of rainfall attributed to the variations of the wood properties. These factors are in turn determined to a large extent by elevation, aspect, slope, latitude, soil type, stand composition, and spacing indicating inconsistent patterns and genetic differences within the tree species. Based on the average densities, R. heudelotii (Wama) is considered light wood with variations in density from 312.72 – 450.89 kg/m3 and a coefficient of variations (CoV) of 12.47 %. The butt portion recorded the highest average density, followed by the middle portion the top portion being the least from both ecological zones indicating a high amount of mature wood in the butt portion and a high amount of juvenile wood at the top portions of the species.

Statistical analysis indicated statistical significance between static bending, shear, compression, and tensile parallel to the grain within the tree height with relatively low strength values (MOE- 4,509 – 7,127 N/mm2, MOR- 36 – 49 N/mm2, Tensile parallel to the grain- 20.07- 27.33 N/mm2, Compression parallel to the grain- 15.99 – 19.82 N/mm2, and shear strength parallel to the grain- 5.46 – 6.76 N/mm2).

Approximate relationships between the various strength properties and density for clear straight-grained wood of the two species are in the form of power functions. Correlations between the densities and strengths indicated a good correlation (85 ~ 99 %) for the wood species. It is possible to make a reasonable estimate of strength based on the density/ specific gravity of the wood. In developing countries, where grading rules for lumber are not highly developed or where many species are sawn and used interchangeably, the grading of structural lumber could be based primarily upon density.

4.1 Potential end use of R. heudelotii.

In view of our findings, R. heudelotii can be promoted for the use of artifacts, carvings, and handicrafts, boxes, packaging cases, joinery, and furniture products. The wood is a potential substitute for Ochroma pyramidale (Balsa wood) and Ceiba pentandra (Ceiba) for making plywood, particleboards, wood pulp, and hardboards. Secondly, the wood can be promoted for the application of lightweight panels and lightweight construction which has strongly been driven by aerospace technology and subsequently in the automotive industry. The wood could be considered for the application of engineered wood products such as Oriented Strand Board, Medium Density Fiber Board, Brettstapel panels, Composite Boards, and Laminated Boards.

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