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Evaluation of Mechanical Properties of the *Terminalia Catappa* Trees and Stems from South Western Nigeria

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Abstract: **This study evaluated the mechanical properties of *Terminalia catappa* trees sourced from five different South-western States of Nigeria. Five stumps of the *Terminalia catappa* were randomly selected and felled from Ondo, Ogun, Oyo, Osun and Lagos respectively. Five specimens were dimensioned from the each bolts derived from three stem portions (Top, Middle and Base) of the wood from each State. The mechanical properties which includes; modulus of rupture, modulus of elasticity, compression, impact bending strength and density were evaluated in accordance with British Standard D 373. The mean values obtained range from 0.50 – 1.34 g/cm^3, 27.00 – 86.62 N/mm^2, 6445.20 – 17606.01 N/mm^2, 20.10 – 42.05 N/mm^2 and 0.10 – 0.56 J/mm for the density, modulus of rupture, modulus of elasticity, compression and impact bending strength respectively. The results showed that there were significant differences between the stem portions and among the State of sourced in all the properties assessed at 5 % level of probability. It was observed that irrespective of the State of sourced, strength properties of the *Terminalia catappa* increased in mean values from Top to Base portion of the tree. Based on the findings of this study, *Terminalia catappa* tree could as well be used for structural applications both for furniture's and house noggin.**

***Keywords: Terminalia catappa*, Nigeria, mechanical, State, furniture's.**

I. INTRODUCTION

In Nigeria, the increase in population has brought increased pressure on timber resources as a result of high demand for wood product as raw materials for construction and building purposes, fuel wood and agricultural tools. Over the years, much exploitation of the forest has been done in order to meet the increasing demand for wood and its product for the teeming population. This situation has resulted in serious depletion of the resource base to such an extent that some favoured timber species have become scarce while others have become extinct in certain ecological zone [9]. The Nigeria forest cover is decreasing at an alarming rate due to increased demand for wood and wood products as a result of increasing population growth. Deforestation has been caused by destruction of the forest for agriculture and other infrastructural development [13]. The over-exploitation of the existing forest resources and the disappearance of economic hardwood species are of great concern to the wood scientists, technologists and users. The areas of constituted forests and woodland in Nigeria have declined progressively since the country independence in 1960 [3]. From the forest industry perspective, this situation is disheartening as Nigeria grossly falls short of the internationally recommended forest cover per unit area of land. In order to meet the wood and wood products need of the population on sustained yield basis, wood supplied from the natural forest need to be supplemented with wood raised in plantation. It has been estimated that there are currently more than 50,000 plant species worldwide. Astonishingly, only about 1000 different tree species are utilized globally while the other are either under-utilized, not utilized, or used inappropriately [18] and [7]. The present human population, estimated at approximately 6.5 billion in 2005 [4], has wood consumption needs within the range of 0.3 to 0.6 m^3/year/habitant. As a result, the annual wood and wood based products consumption have been calculated to be around 3.5 billion m^3, approximately 66% of which are hardwoods used mainly as fuel and the rest are softwoods used principally in industry [19]. Many tree plants are found to be under this categorises, which are under-utilized or used inappropriately. *Terminalia catappa* L plants are found in many places like schools, churches, offices and residential areas, used as shade and fodder for animals grazing. *Terminalia* L. is a pan tropical genus of at least 200 species, shrubs and trees, many of these species are important tall forest trees. Some are widely grown as shade trees or ornamentals and timber trees in both local and international timber market. These species are Idigbo and Afara (*Terminalia ivorensis* A. Chev and *Terminalia superba* Engl & Diels) [17]. *Terminalia catappa* L. is a native species of Southeast Asia. It is presently found in many countries of the tropics, including northern Australia, Pakistan, India, Sri Lanka and many other south Asian countries [10]. This species gradually extended it origin to Africa, most especially in Nigeria, Ghana, Cameroon and other countries. *Terminalia catappa* L. is commonly used as a shade tree in most of the countries, due to its shape with long horizontal branches and large leaves [10].

The demand for wood and wood products will continue to increase due to the Nigeria's growing population and rising standard of living of the people. In view of the ongoing stated detrimental features of the over-exploitation of forest resources on the nation forest reserves, a study of the strength characteristics of plantation grown *Terminalia catappa* wood is necessary in order to provide relevant information on how to make better quality use of the available wood resource base on the country.

In Nigeria, the bulk of timber and other wood based forest products are obtained from forest reserve and free area in the high forest zones of the country. Over the years, much exploitation of the forest has been done in order to meet the increasing demand of wood and wood product by the teeming population [9]. This has resulted in serious depletion of the resource base of the country and consequently a reduction in the supply of logs to wood dependent industries. FAO [6] reported that, deficit in sawn wood supply will increase from 1.8 million m^3 in 2010 while that of pole supply is expected to rise from 0.9 million m^3 in 1995 to 2.3 million m^3 in 2010. Today, more attention is being devoted to plantation forestry in order to meet the countries requirement of wood product on sustainable basis. To this end certain tree species such as *Tectona grandis, Nauclea diderichii, Terminalia superb, Terminalia ivorensis, Triplochiton scleroxylon and Mansonia ultissima* are raised in plantation to supplement wood supplied from the natural forest [9]. These planting exercises were initiated based on the previous information gathered for the potentials of each of the wood specie. There are other wood species like *Terminalia catappa* that are widely planted in free areas for shady purposes, beautification or food purposes which are being neglected due to insufficient information for their mechanical properties. To this reason, this study was carried out to investigate and provide adequate information's for the mechanical properties of the *Terminalia catappa* sourced from south western States of Nigeria.

II. MATERIALS AND METHODS

Five stumps of *Terminalia catappa* trees were selected from each of these locations (Ondo, Lagos, Ogun, Oyo and Osun) States. The trees were felled at 13 m above breast height (DBH) in accordance with Forest Product Laboratory [8] of Forestry Research Institute of Nigeria, Ibadan. The felled stumps were transported to Wood Workshop Laboratory at Federal College of Forestry (FCF) Ibadan, Oyo State for conversion. The tree stem were converted into three sections namely base, middle and top portion respectively. Experimental samples were obtained at a distance of 0.3 m to 2 m from the bark of the wood to the pith of the wood in each of the stem portions. Experimental specimens were dimensioned into specific sample sizes using crosscutting machine at Wood workshop unit of Federal College of Forestry, Ibadan in accordance with [5].

Mechanical properties are used to describe the wood strength and the ability of the wood to resist applied or external forces [16]. The final use of the wood is dependent on these properties. The mechanical properties of *Terminalia catappa* wood were tested on wood specimens free from defects under control climatic conditions (65 ± 3 % RH and 20±1°C). The tests were focused on determining modulus of elasticity, modulus of rupture, compression strength and impact bending strength. Dimensional size of (20 x 20 x 300) mm and (20 x 20 x 60) mm were subjected to Hounnsfield tensiometer machine to determine the modulus of rupture and modulus of elasticity; and compression strength. Impact bending test was carried out using Hatt impact testing machine. The test specimen for impact bending strength was supported over a span of 240 mm on supporting radius 15 mm, spring restricted yokes were filled in order to arrest rebounded. This was then subjected to a repeated blow from a hammer weight of 1.5 kg at increasing height which was recorded in meters as the height of maximum hammer drops. The specimens were placed in such a way that rings are parallel to the direction of the hammer drops.

The methods used in processing the test data obtained for the appraisal of the study variables incorporated in this study included graphical analysis and analysis of variance. Graphical analysis provides an easy means of observing the trend of any relationship which might exist between the study variable and a specific wood property. The experimental method adopted was 3 x 5 factorial experiments in completely randomized design while follow up test using Duncan's Multiple Range Test [DMRT] at 5 % level of probability was carried out to determine the means separation. These were done to know the differences between the means and to choose the best variables. The analysis of variance (ANOVA) was conducted using SPSS (Statistical Package for the Social Sciences) version 20.0 package.

III. RESULTS AND DISCUSSION

TABLE I: THE MEAN VALUES FOR THE MECHANICAL PROPERTIES OF THE *TERMINALIA CATAPPA*

Location of tree	Stem portion	Density (g/cm^3)	Modulus of rupture (N/mm^2)	Modulus of elasticity (N/mm^2)	Compression (N/mm)	Impact bending (J/mm)
Lagos	Base	1.20±0.03	50.63± 26.99	7839.7±8662.46	28.85±1.99	0.27± 0.02
	Middle	1.12±0.03	33.78± 8.89	7706.8±8720.96	27.75±0.17	0.23±0.00
	Top	0.83±0.17	27.00 ±2.52	6245.2±1600.04	20.10±2.96	0.10± 0.01
Ogun	Base	1.18±0.05	59.62±3.08	10231.0±8913.59	33.55±1.72	0.32± 0.02
	Middle	0.72±0.09	55.13±7.33	9700.0±2282.22	32.70±3.99	0.30±0.03
	Top	0.50±0.06	39.38±6.89	8238.3±2132.24	20.90±0.57	0.17± 0.01
Osun	Base	1.34±0.02	82.13±7.55	11627.0±7046.82	39.30±.371	0.36±0.01
	Middle	1.06±0.04	74.25±4.71	10298.0±2165.62	34.30±2.15	0.23±0.00
	Top	0.70±0.05	38.25±7.33	8171.9±9570.31	32.60±1.59	0.21±0.01
Ondo	Base	1.26±0.05	86.62±7.55	17606.0±9097.40	40.15±3.18	0.56±0.08
	Middle	1.10±0.08	82.13±19.32	15281.0±2971.19	35.30±2.09	0.23±0.01
	Top	0.68±0.07	69.75±18.05	11294.0±2165.62	34.20±2.98	0.21±0.07
Oyo	Base	1.29±0.05	66.38±7.33	9035.6±10075.83	42.05±2.79	0.29±0.02
	Middle	1.20±0.04	59.97±9.79	8636.9±1993.14	35.50±4.62	0.22±0.02
	Top	0.96±0.20	32.63±6.16	6776.7±5546.82	28.55±0.78	0.14±0.02

Each of the value represents the mean value of 5 replicates with standard deviation.

The results obtained for the density, modulus of rupture, modulus of elasticity, compression strength and impact bending of the *Terminalia catappa* are presented in Table I. The mean values for the density, modulus of rupture, modulus of elasticity, compression and impact bending strength of the *Terminalia catappa* ranged from 0.50 – 1.34 g/cm^3, 27.00 – 86.62 N/mm^2, 6245.20 – 17606.00 N/mm^2, 20.10 – 42.05 N/mm and 0.10 – 0.56 J/mm respectively. The values obtained for density in this study were higher than the density values of 0.43 g/cm^3 and 0.46 g/cm^3 for the *Terminalia ivorensis* (Idigbo) and *Terminalia superba* (Araba) [15] and [1]. The modulus of rupture obtained in this study was within the range of values obtained for *Terminalia ivorensis* and *Terminalia superba* of 85.22 N/mm^2 and 112.0 N/mm^2 respectively [15] and [1]. Meanwhile, the modulus of elasticity was higher than the previous report by [15] and [1] for the *Terminalia*

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ivorensis and *Terminalia superba* of 9443 N/mm^2 and 6,300 N/mm^2. The mean values obtained for density of the *Terminalia catappa* at different locations were as follows; 1.15, 0.80, 1.02, 1.03 and 1.15 g/cm^3 for Lagos, Ogun, Ondo, Osun and Oyo respectively. The mean values obtained for the density of the *Terminalia catappa* at different stem portions were as follows; 0.73, 1.04 and 1.25 g/cm^3 for Top, Middle and Base portions respectively. The mean values obtained for the modulus of rupture of the *Terminalia catappa* at different locations were as follows: 37.13, 51.38, 52.99, 64.88 and 79.50 N/mm^2 for Lagos, Ogun, Oyo, Osun and Ondo respectively. The mean values obtained for the modulus of rupture of the *Terminalia catappa* at different stem portions were as follows: 43.88, 63.52 and 64.13 N/mm^2 for Top, Middle and Base portions respectively. The mean values obtained for the modulus of elasticity of the *Terminalia catappa* at different locations were as follows: 7263.90, 9389.91, 8149.70, 10032.01 and 15069.01 N/mm^2 for Lagos, Ogun, Oyo, Osun and Ondo respectively. The mean values obtained for the modulus of elasticity of the *Terminalia catappa* at different stem portions were as follows: 8678.50, 10138.01 and 10869.01 N/mm^2 for Top, Middle and Base portions respectively. The mean values obtained for the compression strength of the *Terminalia catappa* at different locations were as follows: 25.57, 29.05, 35.37, 25.40 and 36.55 N/mm for Lagos, Ogun, Oyo, Osun and Ondo respectively. The mean values obtained for the compression strength of the *Terminalia catappa* at different stem portions were as follows: 27.27, 30.78 and 33.11 N/mm for Top, Middle and Base portions respectively. The mean values obtained for the impact bending strength of the *Terminalia catappa* at different locations were as follows: 0.20, 0.26, 0.22, 0.26 and 0.34 J/mm for Lagos, Ogun, Oyo, Osun and Ondo respectively. The mean values obtained for the impact bending strength of the *Terminalia catappa* at different stem portions were as follows: 0.16, 0.24 and 0.36 J/mm for Top, Middle and Base portions respectively. Irrespective of location of source, modulus of rupture, modulus of elasticity, compression and impact bending strength values of the *Terminalia catappa* decreased from Base portion to Top portion (Fig 1.0 – 1.5). The trend of variation observed in Fig 1.0 for density within *Terminalia catappa* trees arises from changes in cell size and cell wall thickness that are associated with annual or periodic growth cycles and with the increasing age of the cambium. This is in agreement with previous reports by [12] and [2]. The differences in density of *Terminalia catappa* at different location could be attributed to the effects of environmental factors, as well as those of topography, soil, climatic, silvicultural conditions and heritable differences in growth behaviour. This is similar to the reports by [14] and [2]. Hillis and Brown [11] also reported that rainfall affects density variations in wood; this might have caused the variations observed in density of *Terminalia catappa* sourced from different State. It has also been reported by authors that density has influence on the strength properties of the wood, [12] reported that wood density can be used to predict the strength properties of *Tectona grandis*, this was also similar to the previous findings by [9] of plantation grown *Nauclea diderichii*. The observation trends of the mechanical properties to stem portion is in agreement with previous findings by [12] on 15 – 25 –year-old *Tectona grandis* wood. This observation is also similar to the previous findings by [9] on mechanical properties of *Nauclea diderichii* wood. This might be due to the normal and consistent stem tapering and variations in some morphological factors such as fibre length, fibre diameter, lumen width and cell wall thickness at different stem portion. The morphology of wood fibres, especially the dimensions of tracheid wall thickness and lumen diameter at different stem portion, directly influences wood mechanical properties [12] and [9].

Analysis of variance carried out at 0.05 % level of probability to test for significant differences in Modulus of rupture, modulus of elasticity, compression and Impact bending strength obtained for the *Terminalia catappa* between locations and stem portions are presented in Table I. The results showed that there were significant differences in Modulus of rupture and compression strength while only location was significantly different in modulus of elasticity. Both the stem portions and interaction between the locations and stem portions were not significantly different at 5 % level of probability.

The results of DMRT at 5% level of probability shows that the mean values of MOR for Base and Middle portions of the stem had the highest MOR values while Top portion of the stem had the least MOR value. *Terminalia catappa* from Ondo had the highest MOR value while *Terminalia catappa* from Lagos had the least MOR value. Also, the MOE value for Base portion had the highest value while Top portion of the wood had the least MOE value. The MOE value of *Terminalia catappa* from Ondo had the highest and was significantly different from others. Similarly, the compression strength from Base portion of the wood had the highest mean value for compression strength while Top portion had the least compression strength value. Of the location of source, compression strength from Ondo and Oyo were significantly different to others, Ondo had the highest compression strength while Lagos had the least compression strength.

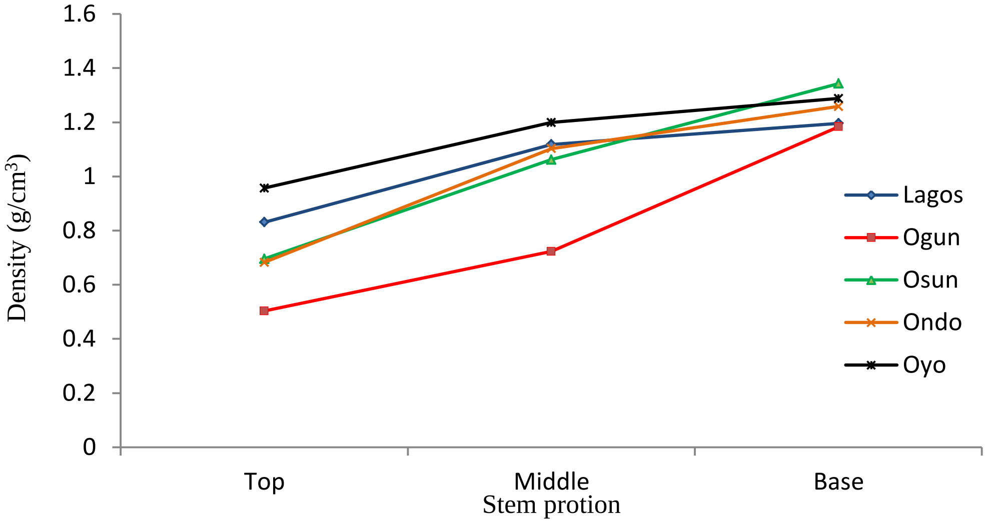

Figure 1.0: Effect of stem portion and location for the density of *Terminalia catappa*

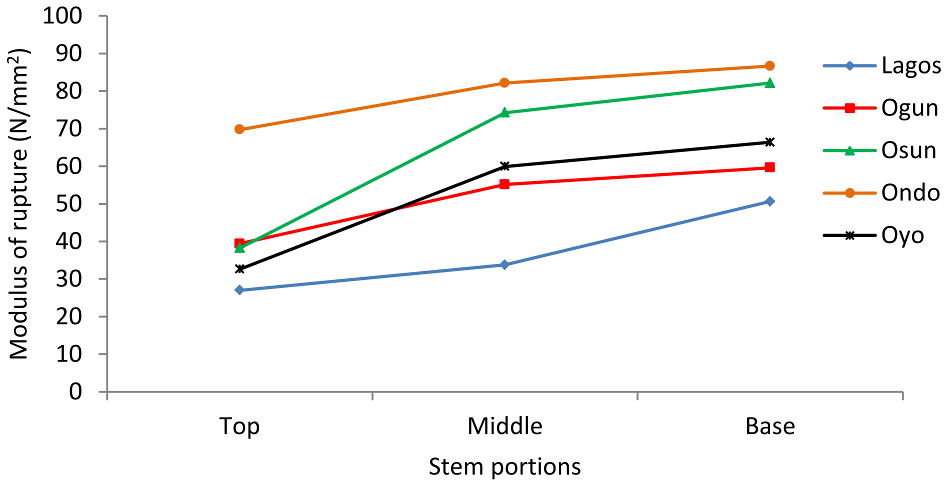

Figure 1.1: Effect of stem portion and location for the Modulus of rupture of *Terminalia catappa*

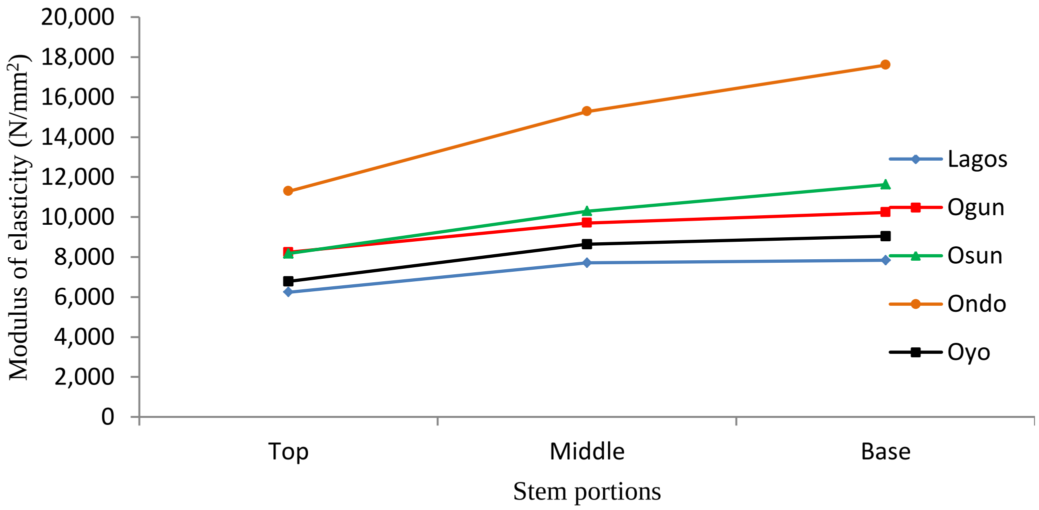

Figure 1.2: Effect of stem portion and location for the Modulus of elasticity of *Terminalia catappa*

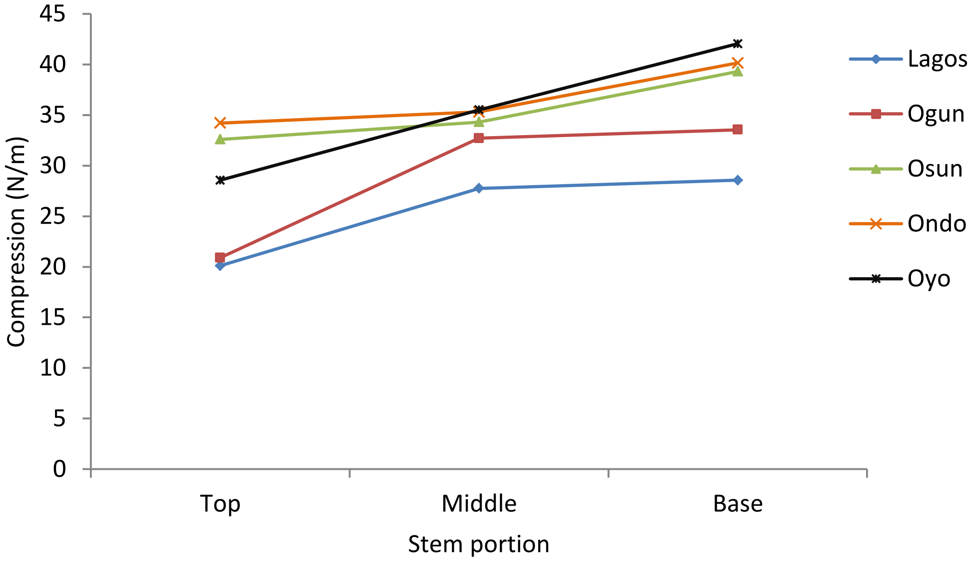

Figure 1.3: Effect of stem portion and location for the compression of *Terminalia catappa*

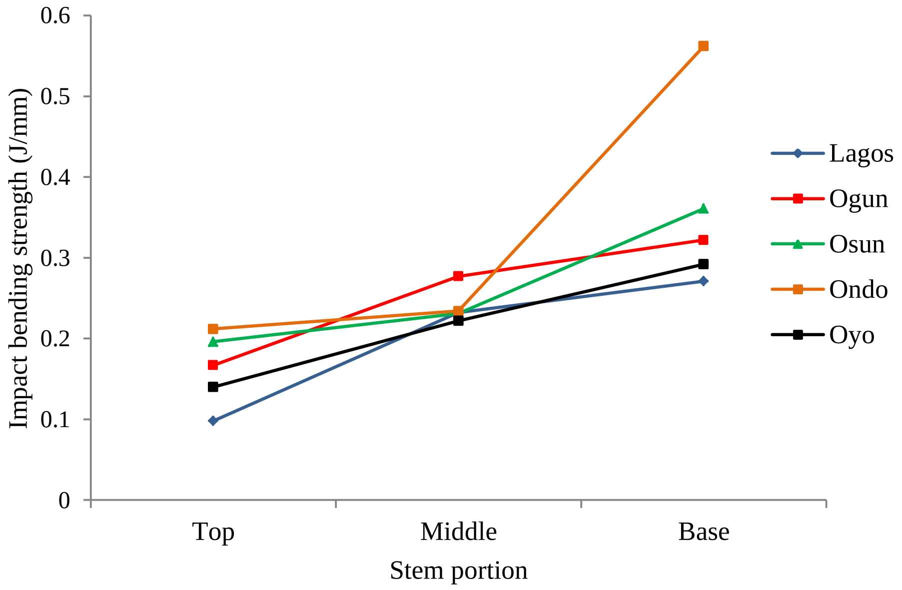

Figure 1.4: Effect of stem portion and location for the Impact bending strength of *Terminalia catappa*

IV. CONCLUSION

This study found results that coincided with the previous trends and fostered knowledge into the relationship between the stem portions of wood derived from different environmental conditions. The findings from the study show a particular trend and pattern of variations in wood properties between the trees of the same species. Generally, wood properties such as density, modulus of rupture, modulus of elasticity, compression and impact bending strength decreased gradually from the base to the top. The relationship between wood properties and stem portion and location were highly significant. This is an indication that stem portion and location greatly influences the variations in mechanical properties of *Terminalia catappa*. Knowledge of wood properties variations therefore is important in order to make appropriate and adequate utilization of *Terminalia catappa*. This study has therefore provided basic information on the density and mechanical properties of *Terminalia catappa* wood which will serve as a base for its efficient and better utilization.

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