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ORIGINAL ARTICLE

Determination of the utilization potentials of the wood of *Borassus aethiopum* Mart. through its strength properties

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Abstract The study was conducted to evaluate variations in selected mechanical properties of *B. aethiopum*. Fifteen *B. aethiopum* trees from savanna zones in Nigeria were sampled at the base (10%), middle (50%) and top (90%) of the merchantable length and partitioned into outerwood, centrewood and innerwood along the radial plane. Selected strength properties such as impact bending strength (IMB), modulus of elasticity (MOE), modulus of rupture and maximum compressive strength parallel to grain (MCS//) were evaluated. Data were analysed using descriptive statistics and ANOVA at a 0.05. The IMB at base was (22.46 ± 0.07 kJ/m^2), middle (20.38 ± 0.08 kJ/m^2) and top (11.68 ± 0.0 kJ/m^2). The MOE was 14,365.96 ± 284.74 N/mm^2, 13,242.54 ± 525.83 N/mm^2 and 12,066.129.03 N/mm^2 at the base, middle and top, respectively, and the MOR was 130.96 ± 1.06 N/mm^2 at the base, 102.98 ± 1.30 N/mm^2 at middle and 70.56 ± 1.03 N/mm^2 at top. The MCS// decreased from 59.79 ± 16.95 N/mm^2 at the base to 45.18 ± 29.16 N/mm^2 at the top. Radially, all the parameters assessed (IMB, MOE, MOR and MCS//) decreased from outerwood to the centrewood and further to the innerwood. It is therefore concluded that *B. aethiopum* mechanical properties were superior at the base and outerwoods. It has the potentials required by construction industries to substitute the primary timber species.

Keywords *Borassus aethiopum* · Utilization · Strength · Properties

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Introduction

Wood is one of the natural products of the forest that has been in use throughout the whole world. In many countries of the world, wood is considered the most important of all the forest resources available. This is so because wood is versatile and is a raw material for many constructional end-uses.

Wood has been one of the oldest constructional materials, but only recently, it has been scientifically applied and its potentials fully studied and understood. This is because the designers knew very little about its strength properties and consequently, and the use of wood was based on the rule-of-the-thumb design methods (Oluwayemisi 2002). Through research, the strength properties of wood have been revealed and there is better understanding in the use of wood. Wood exhibits a lot of variations in properties in terms of durability, strength, vigour, density and grain. Due to this diversity in character, exploitation was selective and was limited to the very strong and durable species, such as *Milicia excelsa, Khaya ivorensis, Afzelia africana and Nauclea diderrichii* (Ogunsanwo et al. 2007).

Today, there is an increasing demand for wood and its products and these products are still valued for many services especially in building materials or construction despite the development of products like plastic, steel and concrete, which are substitutes for wood. Thus, wood is used for various purposes; for instance, wood is used for industrial wood products like pulp and paper, particle boards, pencil and many more. There is also timber used for electric poles, furniture making and even fuel wood. However, the use of which this wood is put principally depends on its properties.

A comprehensive knowledge of the structure of wood, its chemical and physical behaviour and the causes of variability as they affect its utilization forms the basis of present and potential utilization of wood (Panshin and de Zeeuw 1980). Timber, like all other materials of construction, has the ability to resist applied or external forces. In practice, timber is frequently subjected to a combination of stresses (compressive, bending tensile and shearing), although one usually predominates.

Efficient utilization of alternative species such as *Borassus aethiopum* requires adequate understanding of their wood properties and within tree variations. The use of monocotyledon wood species as a substitute for dicotyledon woody plants may have been established. The properties of some monocotyledon especially the Nigeria grown monocotyledon are yet to be fully researched into. For instance, the suitability of the species such as *Elaeis guineensis* (Mijinyawa and Omobowale 2007) and *Cocos nucifera* (Arancon 1997) has been established for structural applications; however, there is little or no information on the properties of *B. aethiopum* grown in Nigeria, though Ayarkwa (1997), Asafu-Adjaye et al. (2013) and Acheampong (2014) had investigated different properties of *B. aethiopum* grown in Ghana. It is therefore expedient for the mechanical properties of *B. aethiopum* grown in Nigeria to be established before it can be put to appropriate and best use. This study was therefore conducted to evaluate variations in selected mechanical properties of the wood of *B. aethiopum.*

Borassus aethiopum belongs to the family of Palmae, Genus: Borassus. It is a diecious palm tree of African origin. The English names are Ron Palm, Giant Africa Palmyra Palm, African fan palm or Elephant palm (Sanon and Sacande 2007). *B. aethiopum* is locally sawn and used as posts and for the construction of bridges and houses. The boards cut from the trunk are used for roofing and for the construction of door frames. It is therefore essential to establish the strength properties of *B. aethiopum* with a view to establish its appropriate utilisation potentials.

Materials and methods

The study area

The study area is savannah zones of Nigeria. Nigeria is located in the tropical zone (between latitude 4° and 14°N and longitude 2°E) with a vast area having savannah vegetation (Salako 2003). This is a region that is itself diverse, necessitating a classification into derived savannah, southern Guinea savannah and northern Guinea savannah and Sudan savannah where the species are numerous.

Sample selection and harvesting

Fifteen trees were felled. In order to ensure minimal influence of age, lack of management and other variables, trees initiating swollen top with uniformly close diameter were chosen. Because the literature shows that before *B. aethiopum* can have swollen top, it must have attained the age of 25 years (Sanon and Sacande 2007).

Bolts of 50 cm long were cut from each sample trees at the base (10%), at the middle (50%) and at the top (90%) of the merchantable length.

Selection of representative samples for test was carried out from the central planks obtained from from the base, middle and top from 15 tress (replicates) to make 45 central planks, and the central planks were further sectioned into six equal portions from bark to bark resulting into 270 test samples for each of the parameters tested: sections 1 and 6 forming the outerwood, portion 2 and 5 forming the centrewood and also 3 and 4 forming the innerwood portion. The experimental design adopted was a two-factor split-plot with the main plot arrange in a randomized complete block design, and the data obtained were subjected to analysis of variance and descriptive statistics with Statistica (data analysis software system) version 7.0 (2004).

Impact strength

The impact bending test was carried out using the Hatt–Turner impact testing machine at the Department of Forest Products Development and Utilization, Forestry Research Institute of Nigeria, Ibadan; following British Standard BS 373. In this method, standard test specimen 20 × 20 × 300 mm was supported over a span of 240 mm on a support radius 15 mm, and spring restricted yokes are fitted in order to arrest rebounce.

Samples were subjected to a repeated blow from a weight 1.5 kg at increasing height initially from 50.8 mm, and then every 25.4 mm, until complete failure occurred at which point the height was recorded in metre as the height of maximum hammer drop with which the impact strength was evaluated.

Static bending test

The test was carried out in accordance with British Standard Method BS 373. This involves the use of standard test specimens (20 mm × 20 mm × 300 mm). Instron 3369 model Universal Testing Machine (UTM) was used in testing. The load was applied at the rate of 0.1 mm/s with the grain perpendicular to the direction of loading; that is, specimens were loaded on the radial face. The bending strength of the wood which is the equivalent fibre stress in the extreme fibres of the specimen at the point of failure was determined by the machine. Load–deformation graphs were plotted automatically which were displayed on a computer monitor for the entire test samples until the samples failed. The maximum load that caused failure in each sample was recorded. Strength properties determined from the test were the modulus of elasticity (MOE) and modulus of rupture (MOR). The MOR was calculated by the equation below:

$$\mathrm{MOR} = \frac{3PL}{2bd^2} \quad (1)$$

where P = maximum load at failure (N); L = span of the material between the supports (mm); b = width of the material (mm); d = thickness of the material (mm); and the unit of MOR is $\mathrm{N/mm^2}$.

The modulation of elasticity (MOE) was calculated with the following equation:

$$MOR = \frac{PL^3}{\Delta bd^3} \quad (2)$$

where P = maximum load at failure (N); L = span in (mm); b = width in (mm); d = depth in (mm); Δ = the deflection at beam centre at proportional load.

Maximum compressive strength// to grain (MCS//)

Test specimens of 20 mm × 20 mm × 60 mm according to BS 373 were also used on Instron 3369 model Universal Testing Machine (UTM).

Load at failure was recorded, and the corresponding PC monitored values were taken directly from the machine. The MCS// was determined by the equation:

$$\mathrm{MCS//} = \frac{P_{\max}}{A} \quad (3)$$

where $P_{\max}$ = maximum load at failure; A = sectional area of test sample.

Result and discussion

Impact bending (IMB)

The result shows that average impact strength was 18.17 ± 0.002 $\mathrm{kJ/m^2}$, with mean value 22.46 ± 0.07 $\mathrm{kJ/m^2}$ at the base, 20.38 ± 0.08 $\mathrm{kJ/m^2}$ at the middle and 11.68 ± 0.004 $\mathrm{kJ/m^2}$ at the top (Table 1). Across the bole, it ranges from 41.67 ± 0.01 to 5.88 ± 0.01 $\mathrm{kJ/m^2}$ at the

Table 1 Mean value of strength properties

Sampling height	Radial position	Impact strength ($\mathrm{KJ/m^2}$)	MOR ($\mathrm{N/mm^2}$)	MOE ($\mathrm{N/mm^2}$)	Compressive strength// ($\mathrm{N/mm^2}$)
Base	1	41.67 ± 0.01[a]	238.20 ± 3.23[a]	20,761.58 ± 662.68[a]	87.21 ± 2.17[a]
	2	20.58 ± 0.06[a]	111.46 ± 1.77[b]	18,430.04 ± 454.91[b]	76.14 ± 0.43[b]
	3	5.88 ± 0.002[c]	42.89 ± 0.95[c]	3908.83 ± 136.38[c]	16.90 ± 0.25[c]
	4	5.88 ± 0.01[c]	42.87 ± 0.96[c]	3894.95 ± 99.34[c]	17.06 ± 0.92[c]
	5	21.56 ± 0.04[b]	112.10 ± 0.68[b]	18,465.40 ± 378.35[b]	75.20 ± 1.75[b]
	6	40.18 ± 0.07[a]	238.26 ± 2.61[a]	20,734.94 ± 820.73[a]	86.21 ± 1.83[a]
	Mean	22.46 ± 0.07	130.96 ± 1.06	14,365.96 ± 284.74	59.79 ± 16.95
Middle	1	39.94 ± 0.02[a]	206.14 ± 5.01[a]	19,080.73 ± 358.52[a]	81.24 ± 0.80[a]
	2	16.42 ± 0.006[b]	70.31 ± 1.42[b]	17,161.25 ± 785.31[b]	69.24 ± 0.65[b]
	3	4.67 ± 0.002[c]	32.74 ± 1.81[c]	3326.76 ± 412.15[c]	14.87 ± 0.11[c]
	4	4.67 ± 0.001[c]	33.06 ± 1.70[c]	3388.01 ± 373.12[c]	15.11 ± 0.10[c]
	5	17.39 ± 0.003[b]	70.22 ± 1.35[b]	17,280.21 ± 633.52[b]	69.56 ± 0.43[b]
	6	39.20 ± 0.001[a]	205.38 ± 5.40[a]	19,218.25 ± 381.54[a]	81.15 ± 1.12[a]
	Mean	20.38 ± 0.08	102.98 ± 1.30	13,242.54 ± 525.83	55.31 ± 31.70
Top	1	20.90 ± 0.001[a]	141.42 ± 1.32[a]	18,307.14 ± 394.94[a]	73.18 ± 0.83[a]
	2	12.25 ± 0.005[b]	50.81 ± 3.83[b]	14,975.21 ± 302.39[b]	53.46 ± 1.89[b]
	3	2.70 ± 0.007[c]	19.24 ± 2.13[c]	2912.66 ± 8c.61[c]	8.99 ± 1.06[c]
	4	2.70 ± 0.003[c]	18.74 ± 1.52[c]	2895.87 ± 85.98[c]	9.14 ± 0.53[c]
	5	12.25 ± 0.003[b]	51.26 ± 3.38[b]	14,954.80 ± 163.51[b]	53.71 ± 1.53[b]
	6	20.90 ± 0.005[a]	141.89 ± 0.58[a]	18,354.14 ± 294.49[a]	72.32 ± 0.87[a]
	Mean	11.68 ± 0.004	70.56 ± 1.03	12,066.64 ± 129.03	45.18 ± 29.16
	Pooled mean	18.17 ± 0.002	94.61 ± 23.49	13,223.30 ± 315.14	53.43 ± 13.47

Mean with the same alphabets in the column is not significantly different from one another for each of the base, middle and top at 0.05 level of probability

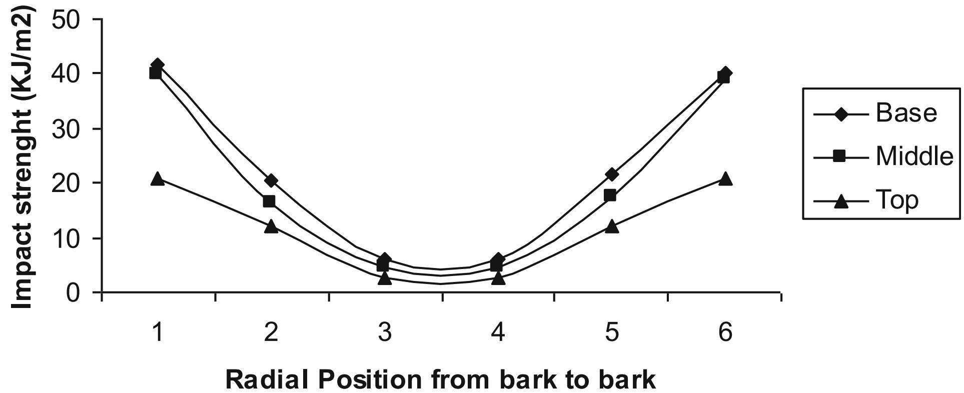

Fig. 1 Impact strength (kJ/m^2) of the wood of *B. aethiopum*

base, 39.94 ± 0.001–4.67 ± 0.002 kJ/m^2 at the middle and 20.90 ± 0.001–2.70 ± 0.007 kJ/m^2 at the top. IMB decreases from base to the middle and further decreased to the top. Radially, IMB was consistent because it decreased from peripheral (outer) to the centre (inner) and later increased to the bark again (Fig. 1). The decrease in IMB of *B. aethiopum* from the bark to the inner part disagrees with Ogunsanwo (2000) and Adedipe (2004) which showed an increase in IMB from outerwood to innerwood for *Tryplochiton scleroxylon* and *Gmelima arborea,* respectively.

However, result of analysis of variance of IMB as a result of changes in sampling heights revealed that both radial position and sampling heights are significantly different at 5% level. Effect of interaction between radial and sampling position was significant at this level as shown in Table 2. At the radial position, there is vast difference among the positions, that is, the outerwood, centrewood and innerwood.

Modulus of elasticity (MOE)

The mean MOE was 13,223.64 ± 129.30 N/mm^2. It ranges between 14,365.96 ± 284.74 N/mm^2 for the base, 13,242.54 ± 525.83 N/mm^2 for middle and 12,066.129.03 N/mm^2 for top (Table 1). Radially, it decreases towards the centre and later increases towards the bark again (Fig. 2). Across the bole, the values range between 20,761.58 ± 662.68 and 3894.95 ± 99.34 N/mm^2 for the base, 19,218.25 ± 381–3326.76 ± 412.15 N/mm^2 for the middle and 18,354.14 ± 294.49–2895.87 ± 85.98 N/mm^2 for the top.

Ayarkwa (1997) obtained 11300 N/mm^2 for *B. aethiopum* from Ghana, and this work is in line with Asafu-Adjaye et al. (2013), who discovered the same trend in the species from Ghana, and he opined that there is variation along and across the bole of *B. aethiopum*. Panshin and de Zeeuw (1980) opined that the extent of wood maturity plays a major role in magnitude and patterns of wood property variability. MOE varied consistently along the bole.

Shupe et al. (1997), when working on pine and Sanwo (1983), in his study on *Tectona grandis* noted contrary pattern. This also contradicts the findings of Panshin and de Zeeuw (1980), in *Cryptomeria japonica* and *Pseudotsuga menziesii*. It is believed to have been influenced by the extent of cell wall development. Panshin and de Zeeuw (1980) reported a decreasing fibril angle and increasing proportion of cellulose to be the factors responsible for the trend. But this may not be obtainable in *B. aethiopum* which is a monocot as this may be as result of the fact that

Table 2 Analysis of variance showing the *F* value of parameters assessed

Source of variation	*df*	*F* value of parameters			
		IMB	MOR	MOE	MCS//
Trees (block)	14	0.67ns	1.55ns	0.59ns	1.53ns
Sampling height (SH)	2	3173.08*	4843*	898.77*	1455.96*
Major plot error	28				
Radial position (RP)	5	8076.92*	14,790*	5564.2*	13,086.10*
Interaction (SH, RP)	10	346.15*	275.89*	41.21*	42.81*
Subplot error	210				
Total	269	26.26			

*Significant at $P < 0.05$; *ns* not significant at $P > 0.05$

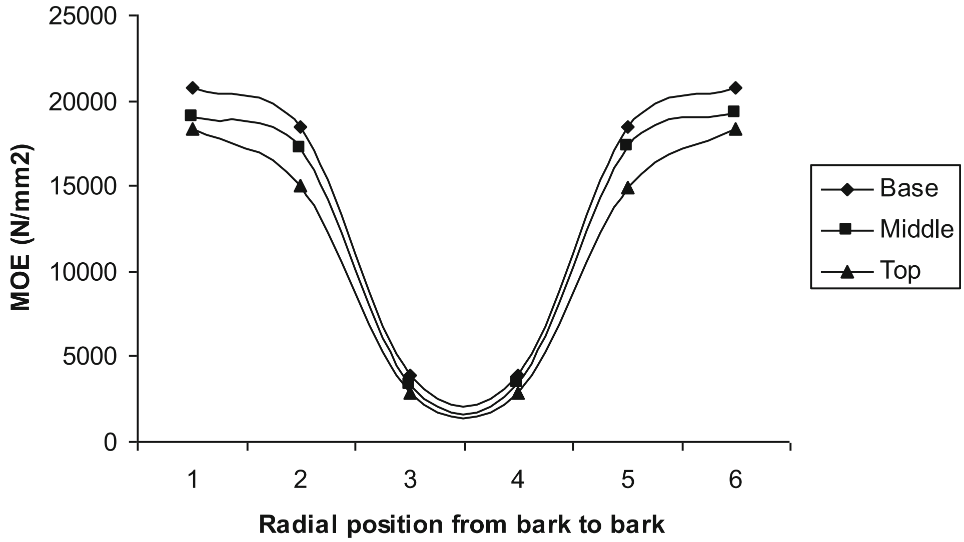

Fig. 2 MOE of the wood of *B. aethiopum* with respect to wood samples across the bole

the wood does not undergo secondary thickening during wood formation

MOE, which according to Shrivastava (1997), measures the stiffness of a wood and is indispensable in the determination of the deflection of a beam under load and can be said to be medium because Upton and Attah (2003) and TEDB (1994) classified strength of species based on the MOE at 12% moisture content as follows: 'Very High' (19,000 N/mm^2 and more), 'High' (14,000–19,000 N/mm^2), 'Medium' (11,000–14,000 N/mm^2), 'Low/Medium' (9000–11,000 N/mm^2) and 'Low'(below 9000 N/mm^2).

The above classification indicates that the strength of the species, disregarding the individual zones, is medium. Nonetheless, the various portions within the trees vary in terms of stiffness and the classification is 'High' in the outer zone, 'Medium' in the central zone and 'Low' in the innermost zone.

The result of analysis of variance of MOE as a result of changes in sampling heights revealed that there is significant difference among the radial position and sampling height at 5% level, while effect of interaction between radial and sampling position was significant at this level as shown in Table 2 and no significant different observed among the trees.

Modulus of rupture (MOR)

The mean value for MOR was 94.61 ± 23.49 N/mm^2 ranging from 130.96 ± 1.06 N/mm^2 for the base, 102.98 ± 1.30 N/mm^2 for the middle and 70.56 ± 1.03 N/mm^2 for the top (Table 1).

Across the bole, it ranges between 238.26 ± 2.61 and 42.87 ± 0.96 N/mm^2 for the base, 206.14 ± 5.01–32.74 ± 1.81 N/mm^2 for the middle and 141.89 ± 0.58–18.74 ± 1.52 N/mm^2 for the top. Ayarkwa (1997) and Asafu-Adjaye et al. (2013) obtained 104 N/mm^2 and 65 N/mm^2, respectively, for *B. aethiopum* from Ghana. The value obtained in this study compares well with most of species already used for structural applications. From this, it will be observed that MOR decreased from the bark (peripheral) to the inner most part of the wood and increase towards the bark again (Fig. 3). This agrees with Ogunsanwo (2000), for *Triplochyton.*

Ogunsanwo (2000) emphasized that such increase in MOR from core wood to outerwood might be due to variations in some morphological parameters such as fibre length, wall thickness and fibre diameter, which also increased in the same pattern. From (Table 1), MOR decreased from the base to the top.

Comparatively, the mean MOR obtained in this study is rated high in respect of Farmer's ratings. The preceding classification points out that the outer (Peripheral) zone is rated high, that of the central zone is rated medium, and low in the case of the inner zone. Since density is an excellent index of the amount of wood substance contained in a piece of wood, it is a good index of mechanical properties as long as the wood is clear, straight grained and free from defects (Forest Products Laboratory 2010). Consequently, the value for the maximum load-carrying capacity of the species in bending recorded for the outer (peripheral), central and the innermost zones is a function of their densities.

The strength value of the innermost zone is extremely low compared to the other parts of the trees and could possibly be due to the presence of juvenile sclerenchyma fibres, and higher proportion of ground tissues as the tissues are very soft and spongy.

The result of analysis of variance of MOR as a result of changes in sampling heights revealed that both radial position and sampling heights are significantly different at

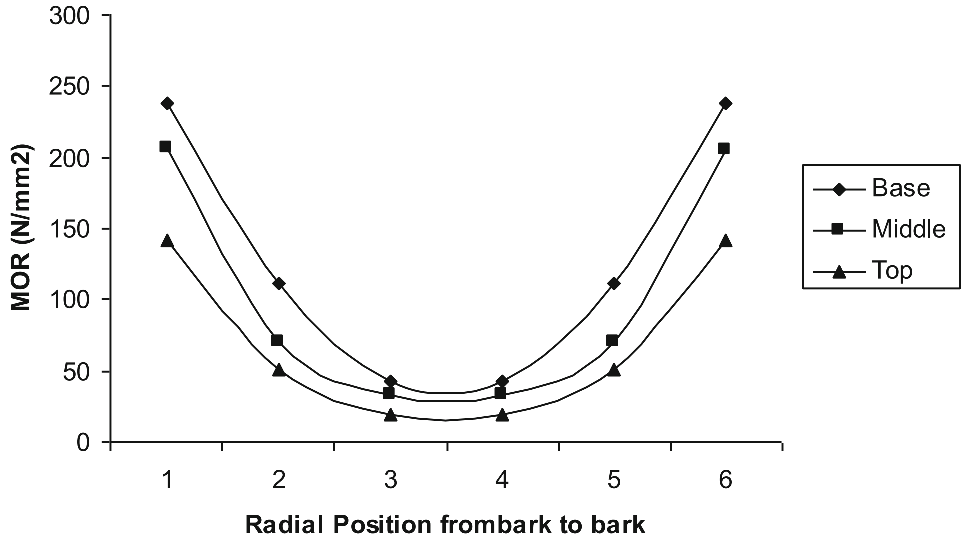

Fig. 3 MOR of the wood of *B. aethiopum* with respect to wood samples across the bole

5% level of probability. Effect of interaction between radial and sampling position was also significant at this level as shown in Table 2.

Maximum compressive strength parallel to grain (MCS//)

The mean maximum compressive strength parallel to grain was 53.43 ± 13.47 N/mm^2 ranging from 59.79 ± 16.95 N/mm^2 for the base, 55.31 ± 31.70 N/mm^2 for the middle and 45.18 ± 29.16 N/mm^2 for top along the axial direction (Table 1). Across the bole, the value ranges between 87.21 ± 2.17 N/mm^2 and 16.90 ± 0.25 N/mm^2 at the base, 81.24 ± 0.80–14.87 ± 0.11 N/mm^2 at the middle and 73.18 ± 0.83–8.99 ± 1.06 N/mm^2 at the top. It was observed that it decreases from the bark to the centre and later on increases towards the bark again (Fig. 4). Akira (1978) reported 16 N/mm^2 for *B. aethiopum* sampled in Ghana, Guinea, Sudan and Kenya, while Ayarkwa (1997) reported 58 N/mm^2 and Asafu-Adjaye et al. (2013) reported 35.10 N/mm^2 for *B. aethiopum* from Ghana. The difference could have been caused by ages of trees sampled for the studies and sampling position. Lausberg et al. (1995) were of the opinion that genetic factors and growing conditions could cause such variation. FPRL (2010) recorded 16.94 N/mm^2 for *Hildegardia barteri*, 30.45 N/mm^2 for *Afzelia africana* and 34.44 N/mm^2 for *Daniellia oliveri*. This indicates that value obtained from the present study is in the same range with those from primary species that are already popular in structural applications.

There were consistencies in the pattern of variation from the base to the top. An increasing pattern was noted in

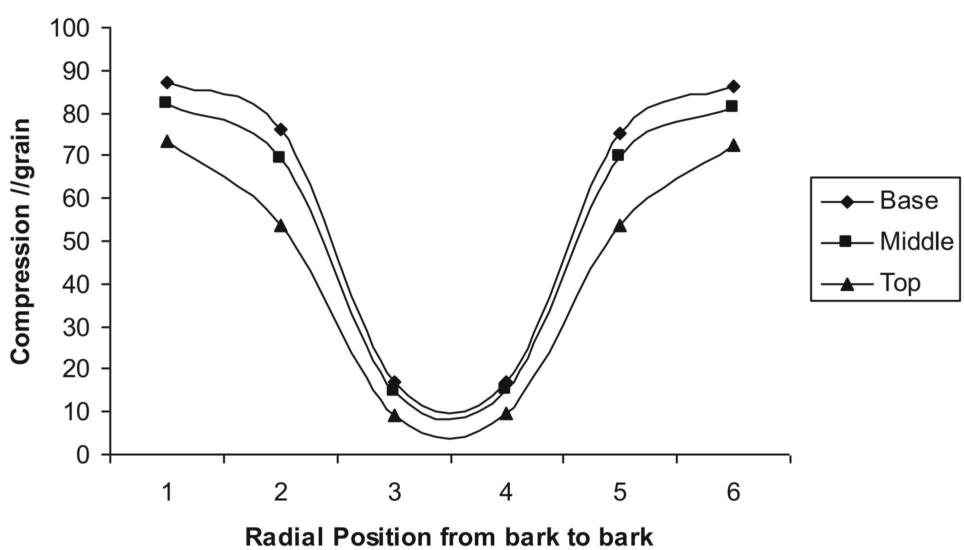

Fig. 4 MCS// of the wood of *B. aethiopum* with respect to wood samples across the bole

MCS// across the radial plane from inner to bark (Table 1). High strength in compression parallel to the grain is required of timber used as columns, posts and as notched timbers. It is worth noting that the variation in strength properties found among different sections of the same wood species influences the selection of a section for a particular use.

Cell wall thickness could have contributed to this because Panshin and de Zeeuw (1980) noted that it controls mechanical properties especially MCS//.

The compression strength parallel to the grain has been classified as very low, low, medium, high and very high when the strength values are under 20 N/mm^2, ranging from 20 to 35 N/mm^2, 35–55 N/mm^2, 55–85 N/mm^2 and over 85 N/mm^2, respectively. This classification consequently rates the outer zone as high, medium in the central zone and low in the inner zone. Generally, *B. aethiopum* can be classified according to maximum compressive strength parallel to grain as medium with the value of 53.43 N/mm^2. According to Desch and Dinwoodie (1983), the strength of a piece of wood in compression is closely related to its density. The very low compressive strength parallel to the grain recorded for the innermost zone was expected, as the samples from these region easily buckled under relatively low stresses and could be explained by their densities.

Statistically, result of changes in sampling heights revealed that both radial position and sampling heights are significantly different at 5% level. Effect of interaction between radial and sampling position was also significant at this level as shown in Table 2.

Conclusions

The use of lesser-known species for this study has provided useful information as regards the potentials of *Borassus aethiopum* as a good substitute for primary timber species that are going into extinction. Based on the findings of this study, the following conclusions were made.

Modulus of rupture (MOR), modulus of elasticity (MOE), maximum compressive strength parallel to grain (MCS//) and impact bending strength (IMB) varied consistently and statistically significant along the sampling height and decreased from the bark wood to the innerwood and then rise again to the bark. The results obtained from this study revealed that *Borassus aethiopum* has the potentials required by construction industries to substitute the primary timber species.

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Compliance with ethical standards

Conflict of interest The corresponding author states that there is no conflict of interest.

References

Acheampong JB (2014) Physico-chemical properties and natural durability within two varieties of *Borassus aethiopum.* Dissertation, Kwame Nkrumah University of Science and Technology, p 133

Adedipe OE (2004) Machining and mechanical properties of plantation grown *Gmelina arborea* wood. Dissertation, Federal University Technology, Akure, p 81

Akira T (1978) Compilation of data on the mechanical properties of foreign woods. No 7, Part III (Africa). January, 1978. A monograph published by Matsue, Shimane University

Arancon Jr RN (1997) Asia-pacific forestry sector outlook study working papers: focus on coconut wood. Working paper no. APFSOS/WP/23. FAO paper October 1997, pp 1–36. www.fao.org/forestry/en

Asafu-Adjaye OA, Frimpong MK, Darkwa NA (2013) Assessment of the effects of density on the mechanical properties variations of *Borassus aethiopum*. Sch Res Libr Arch Appl Sci Res 5(6):6–19

Ayarkwa J (1997) Potential for the utilization of *Borassus aethiopum* (Fun Palm) in construction in Ghana. Forest Research Institute of Ghana. WOOD, January–March 1997, pp 15–18

British Standards (BS) 373 (1957) Method of testing small clear specimens of timber. British Standard Institute, London, p 32

Desch HE, Dinwoodie JM (1983) Timber: its structure, properties and utilization, 6th edn. Macmillan Education, London

Forest Products Laboratory (2010) Wood handbook—wood as an engineering material. General technical report FPL-GTR-190. U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, Madison, p 508

Lausberg MJF, Cown DJ, MacConchie S, Skipmith JH (1995) Variation in some wood properties of *Pseudotsuga menziesii* provenances grown in New Zealand. N Z J For Sci 25(2):133–146

Mijinyawa Y, Omobowale MO (2007) Determination of the moduli of elasticity and rupture, and impact energy of oil palm trunk. Adv Agric Eng 1(4):26–33

Ogunsanwo OY (2000) Characterization of wood properties of plantation grown obeche (*Triplochiton sceleroxylon.* K. Schum) in Omo Forest Reserve, Ogun State, Nigeria, dissertation. University of Ibadan, p 253

Ogunsanwo OY, Terziev N, Elowson T (2007) Evaluation of physical and mechanical properties of two lesser known hardwoods from Nigeria. J Trop For Resour 23(1):28–36

Oluwayemisi TA (2002) Study of some selected physical and mechanical properties of *Calistemon rigidus*. (R.Br). Dissertation, University of Ibadan, p 64

Panshin AJ, de Zeeuw C (1980) Textbook of wood technology, 4th edn. McGraw-Hill, New York, p 722

Salako FK (2003) Soil physical conditions in Nigerian savannahs and biomass production. Lecture given at the College on Soil Physics Trieste, Department of Soil Science and Agricultural Mechanization, University of Agriculture, Abeokuta, Nigeria. 3–21 Mar 2003, pp 365–377

Sanon M, Sacande M (2007) Seed leaflet. *Borassus aethiopum* mart. no. 120 September 2007. Forestry and land scape. Millennium Seed Bank Project. www.kew.org/msbp

Sanwo SK (1983) Variations in the wood characteristic of plantation grown teak (*Tectona grandis*) in Nigeria. Dissertation, University of Wales, p 287

Shrivastava MB (1997) Wood technology. Vikas Publishing House PVT LTD, New Delhi

Shupe TF, Hse CY, Choong ET, Groom LH (1997) Effect of silvicultural practice and moisture content on loblolly pine veneer mechanical properties. For Prod J 47(11 and 12):92–96

StatSoft Inc (2004) STATISTICA (data analysis software system), version 7. www.statsoft.com

TEDB (1994) The tropical timbers of Ghana. Timber Export Development Board, Takoradi, p 87

Upton DAJ, Attah A (2003) Commercial timbers of Ghana—the potential for lesser used species. Forestry Commission of Ghana, Accra, p 56