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Evaluation Of Basic Strength Indicators Of *Mangifera Indica* Timber To Ascertain Its Suitability For Furniture Construction

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Abstract

Mangifera indica is increasingly being used in the furniture industry in Uganda despite the limited information about its strength properties. This study was conducted to examine the suitability of *Mangifera Indica* timber as a furniture construction material on the basis of its basic density, MOE and MOR as basic strength indicators. Wood samples were derived from two mature trees obtained from Mityana district in Central Uganda, which is a major source of *Mangifera Indica* timber. From each tree stem, logs each measuring 150 cm long were cross cut from three sections: butt end (breast height ≈1.3m); 45% of stem height and 75% of stem height. The logs were sawn into scantlings using through and through method and air seasoned. Thirty five small clear test samples for static bending and 50 samples for basic density tests were prepared according to standard methods. Static bending tests were carried out in accordance with BS 373 (1957) using a Testometric AX M500 25KN Universal Testing Machine at a loading rate of 6.6 mm min^{-1}. MOE and MOR results were adjusted to their 12% equilibrium moisture content equivalents. Basic density was determined by the water displacement method. The mean basic density of *Mangifera indica* ranged from 534 kg/m^3 to 585 kg/m^3. The mean MOE and MOR of *M. indica* ranged from 5,617.0 N/mm^2 to 8,027.8N/mm^2 and 46.6 N/mm^2 to 74.2 N/mm^2 respectively. Based on the strength property results, mature *M. indica* qualifies as a light construction timber suitable for furniture production. However, there is need to determine its machining properties and durability in order to promote the species for furniture construction.

Key words: *Mangifera indica, MOE, MOR, timber, density, strength, furniture*

1. Introduction

Wood utilization in Uganda was in the past focused on a few well-known traditional indigenous tree species. However, with increasing demand for furniture and increasing scarcity of the well-known species, users are resorting to other available and affordable trees species which can give usable timber in merchantable volumes (Odokonyero, 1998; Mugabi *et al*., 2005; Zziwa *et al*., 2006a & b; Zziwa *et al*., 2011). *Mangifera indica* is among the non-traditional tree species currently used furniture making in Uganda despite the fact that its properties are not well-known (Zziwa *et al*., 2006a). *Mangifera indica* is a mango species which belongs to the flowering plant family *Anacardiaceae*. It is among the most economically and culturally important tropical fruits, especially in Asia. The species was domesticated in India and then later introduced to Africa. It has been reported as one of the largest fruit trees in the world, which can grow to a height of one-hundred feet and an average circumference of 3.6 – 4.6 m at breast height. The colour of *Mangifera indica* timber ranges from yellow to golden yellow with increase in age. In Uganda the tree is widely known mainly for its fruit rather than timber and as such has been promoted widely as an agro-forestry fruit tree species (Katende *et al.*, 1995). However, mango tree logs are currently being sawn into timber once their most-productive fruit bearing lifespan has elapsed, a trend which is on the rise in Uganda to cope with increasing timber scarcity in the country and the east African region at large. It has been reported that the wood of *Mangifera indica* is prone to damage from fungi and insects, hence the need for preservative treatment prior to its application for long-term applications such as beams, rafters, trusses, and door and window frames (Green Clean Guide, 2015). The wood is used for musical instruments such as ukuleles, plywood, low-cost furniture and charcoal owing to its high calorific value. It has also been found to be highly suitable for ammunition boxes, slate frames, bobbins, carving and turnery work (Negi, 1996; Green Clean Guide, 2015).

Mangifera indica is one of the non-traditional timber species being used in the furniture industry in Uganda (Sseremba *et al.*, 2012), yet information on its strength quality indicators such as density and other important strength properties such as Modulus of Elasticity (MOE) and Modulus of Rupture (MOR) are not documented. In order to ensure appropriate use in furniture design and construction, it is imperative that the basic indicators of strength quality are determined to guide its utilization in Uganda. Awareness of strength properties of timber species gives an informative insight into their appropriateness as construction materials though availability sometimes dictates which species are used for particular purposes, especially in developing countries (Zziwa *et al*., 2009; Turinawe *et al*., 2014). It should be noted that selection of any timber for a particular structural application such as furniture depends not only on one but a combination of its strength properties, much as it is a fact that a structural application is any use for which strength is one the primary criteria for material selection. Therefore, use of wood of *M. indica* without prior knowledge of its strength properties may result in material wastage and uncertainty in the safety of the furniture construction (Zziwa *et al*., 2016). This may result from unknowingly applying wood of low strength in cases requiring high structural strength or use of unnecessarily large dimensions where there are less structural strength requirements (Zziwa *et al*., 2010). Accordingly, there are circumstances where use of prescriptive design approaches has led to material wastage and unnecessary cost simply because there was inadequate material strength data.

Using basic density to classify *M. indica* with reference to other popular tree species that are currently being used in the furniture industry and carpentry and joinery works can help to judge the strength value of the species. Although emphasis on density as a non-destructive predictor of timber strength has been contested to a certain extent particularly in technologically advanced countries, it continues to be used as an indicator of timber strength and because most of the properties are closely correlated with density (Treacy *et. al*. 2000). Accordingly Kityo and Plumptre (1997) classified well-known Uganda timbers on the basis of density as heavy construction timber with density above 720kg/m^3; medium construction timber with density ranging from 480 to 720kg/m^3; light construction with density ranging from 400 - 479kg/m^3 and very low density timber with density below 400kg/m^3. Much as non-traditional timbers like *M. indica* are currently being used for making furniture, there is no guarantee that they satisfy the strength requirement in the furniture and construction industry (Zziwa *et al*. 2006a; Zziwa *et al*. 2011). Therefore, this paper investigated basic density and static bending properties including MOE and MOR as basic strength indicators. Strength properties of wood reflect its behaviour and relative stability under various stress conditions and thus indicators of resistance to external forces (Bowyer *et al*., 2003). The MOE and MOR measurements are intended to give an idea of its respective stiffness/elastic properties and load-carrying capacity as a basis to ascertain its strength quality (Bergman, *et al*., 2010). The results of this study are important in helping carpenters and particularly road-side furniture makers to know how *Mangifera indica* compares with other timbers that are currently becoming scarce and too costly to use in their industry. If found promising the results will also help to reduce pressure on other timber species in Uganda since the booming furniture business in response to the increasing population and improving standards of living contributes greatly to deforestation in Uganda.

2. Materials and Methods

2.1 Research Design

Materials used for this study were obtained from farmland in Nakaseeta village, Nakaseeta Parish Busimbi subcounty. Nakaseeta lies between 0°27'16.8"N 32°05'13.1"E and is about 5.91km North of Mityana Town. Two mature trees in the diameter range of 50-60 cm were felled with a chain saw. Mature trees were chosen because they had become less productive for fruit purposes and in addition they had more late wood compared to juvenile wood. According to Haygreen and Bowyer, (1996), density of juvenile wood zone is low because there are relatively few latewood cells and a high proportion of cells have thin wall layers. Small clear samples were obtained from parts of the stem with no visible defects and with good stem qualities. This was based on the assumption that such parts of the selected trees were free of strength reducing defects particularly knots. The logs were cross cut into three sections each of 150 cm long at the following positions along the log: butt end (breast height ≈1.3m), 45% of stem length and 75% of stem length (Zziwa *et al.*, 2011). Odokonyero (1998) argued that sampling from different heights enables investigation of the variation in wood properties along the tree height so that the means are representative of the entire tree span. To this end samples were taken from three sections labelled as: B for Butt section; M for middle section at 45% of stem length; and T for top section at 75% of the stem length. Sample boards were radially sawn into 30 mm × 30 mm × 1500 mm scantlings by through and through method. Test specimens were then prepared according to International Standards Organisation BS 373 (1957). A total of 35 small clear samples were obtained for static bending (MOE and MOR) test and 50 pieces from each of the three sampling heights for basic density test. Before testing for basic density the specimens were trimmed to dimensions of 20 × 20 × 20mm while those for static bending test were trimmed to 20 mm × 20 mm × 280 mm BS 373(1957). Air seasoning was initially carried out to reduce moisture content (MC) and ensure structure stability of the specimens. They were later on dried under a shade at a temperature of $25^0C \pm 3^0C$ for 10 days to attain moisture content of 12±3% at Wood Science Laboratory in the Department of Forestry, Biodiversity, and Tourism, College of Agricultural and Environmental Sciences, Makerere University. An electrical moisture meter was used to determine the MC of the wood specimens.

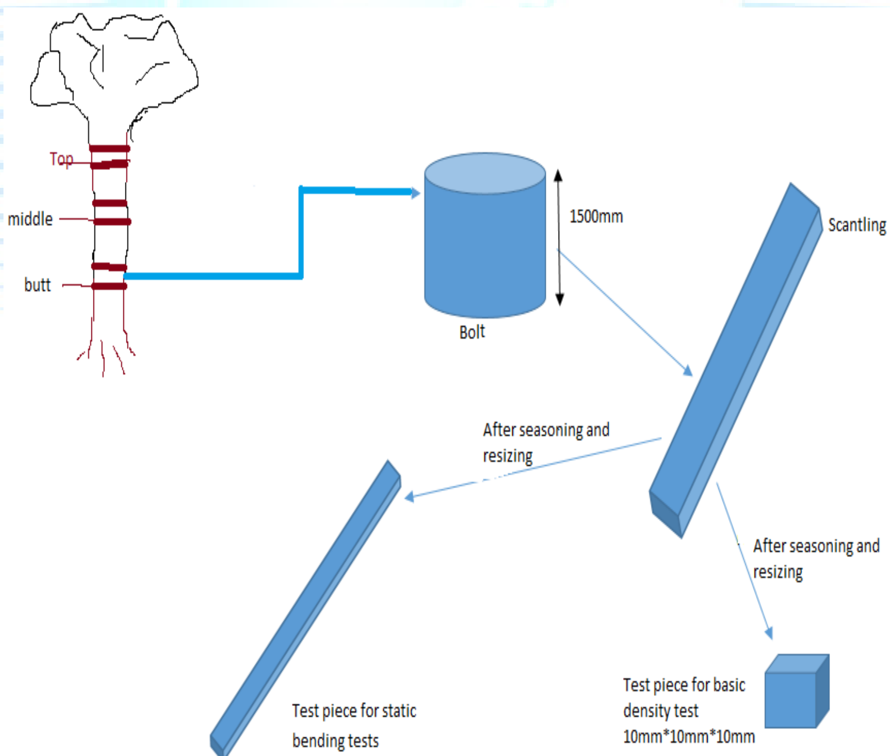

Figure 1: Procedure for Specimen Preparation

2.2 Experimental Procedure

Static bending properties and basic density were tested using British Standards (BS) 373 (1957) method of testing small clear specimen for timber. MOE and MOR were determined in a static bending test on small clear specimen of 20 mm x 20 mm x 280 mm using a testometric AX M500 25 KN universal testing Machine at a loading rate of 6.6 mm min^{-1} in accordance with (Dinwoodie, 1981). The above loading rate had to be adopted because as with most materials, there is inherent variability in the strength of small, clear sample of wood under short-time loading (Abubakar, 2014). The specimens were loaded to failure in a three point loading over a span of 280 mm.

The MOE *(E)* in N/mm^2 for each specimen was calculated using Equation (1)

$$E = \frac{0.5PL^3}{\beta b d^3} \quad (1)$$

The MOR will be calculated using equation (2).

$$MOR = \frac{1.5\ PL}{b d^2} \quad (2)$$

Where; *P* is load at the proportionality limit, *L* is the length of span (280 mm), *b* is the breadth of test specimen (20 mm), *d* is the depth of test specimen (20 mm) and β is the deflection in mm at the proportionality limit.

2.3 Adjusting Values to their 12% Moisture Content Equivalents

Strength and stiffness increases with decrease in moisture content which is one of the decisive factors for the behavior of timber components in building (Johansson and Kliger, 2000). All strength values were adjusted to their 12% EMC equivalents in accordance with Desch (1981) and Ishengoma and Nagoda (1991) to allow for the comparison of results by various researchers using Equation (3):

$$S_{t\ 12\%} = S_t(1+z)^n \quad (3)$$

Where, z is the correction factor for moisture content, equivalent to the percentage change in strength values for 1% change in Moisture content (Table 1), n is the difference in MC from 12% at the time of test. $S_{t\ 12\%}$ is the strength value at 12% moisture content and S_t is the strength value at the time of test.

Table 1: Correction factor for moisture content

Property	z-values
MOE	0.02
MOR	0.04

Source: Zziwa *et al*. (2010)

Basic density was obtained using green volume and oven dry weight of 20 mm × 20 mm× 20 mm specimens which were socked in distilled water until they attained a green volume (Lavers, 1993). The green volume was measured using displacement method according to Archimedes' principle. The specimens were then oven dried at a temperature of 103±2^{0}C to a constant weight. Each specimen was reweighed and the basic density ρ in kg/m^3 calculated using equation (4):

$$\rho = \frac{Wd}{V_g} \times 100 \quad (4)$$

Where; w_d is the constant dry weight, and v_g is the green volume of specimens.

2.4 Statistical Data Analysis

The raw data were analyzed using Microsoft excel software to obtain means, coefficients of determination and standard deviations of MOE and MOR. Single factor ANOVA tests were carried out to ascertain whether there was a significant difference in MOE, MOR and basic density strength properties amongst the tree positions (butt, middle and the top sections) at 95% confidence.

3. Results and Discussion

The mean basic density of *Mangifera indica* ranged from 534.0 kg/m^3 to 585.2 kg/m^3 with the highest mean registered at the middle portion and the lowest at the butt end (Table 2). Single factor ANOVA test results for density further revealed a significant difference in density among the three tree positions (Table 3).

Table 2: Mean basic density (kg/m^3) at the three height positions (n=50)

Groups	*Average*	*Standard Deviation*
Butt	534.0	27.1
Middle	585.2	20.9
Top	581.0	19.6

Table 3: Summary of Single Factor ANOVA tests for Density

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	80748.32	2	40374.16	77.8863	8.62E-24	3.057621
Within Groups	76200.84	147	518.3731			
Total	156949.2	149				

The variation in basic density was found to be non uniform along the trees with the butt having the lowest mean basic density and middle with the highest basic density. This is characteristic of wood given its anisotropic behaviour. This variation was also noted by Ishengoma and Nagoda (1995) and Ishengoma, *et al.* (1997) who reported that the variation in the tree trunks can be increasing from base to top in a non-uniform pattern. Zziwa (2011) noted that the properties of biological materials such as wood vary within trees, among trees, stands and species and this is attributed partly to differences in genetic composition. The annual growth ring pattern is another cause of variation in wood material properties (Desch and Dinwoodie, 1996; Ishengoma *et al.,* 2004). The variations are also attributed to difference in composition of early and latewood. The middle portion had the highest mean basic densities followed by top section and lastly butt portion. This means that the middle and top portion are more suitable for higher strength demanding structural applications and the butt end can be used for applications that are not subjected to excessive loading such as furniture as recommended by Zziwa *et al.* (2010). This implies that the middle portion could be utilized most because it is the region with best strength properties. According to Kityo and Plumptre (1997) the observed basic density values qualify *Mangifera indica* in the medium construction category (Table 7). Wood density is a measure of the cell wall material per unit volume and therefore it is a very good indicator of the strength properties. Brazier and Howell (1979) also suggested that density is one of the most important properties that influence the use of a timber.

The mean MOE and MOR of *Mangifera indica* ranged from 5,617.0 N/mm^2 to 8,027.8N/mm^2 and 46.6 N/mm^2 to 74.2 N/mm^2 with the highest mean registered at the middle portion (Table 4). There was a significant difference ($P < 0.05$) MOR and MOE among the groups (top, middle and butt tree positions) as evidenced by the fact that observed critical F-value was less than F-calculated (Tables 4 to 6). As expected the observed variation in strength property indicators along the tree height is attributed to the anisotropic behaviour wood as reported by earlier authors (Mugabi *et al*., 2005; Zziwa *et al*., 2010). According to Haygreen and Bowyer (1996), basic density alone is not a reasonable basis for estimating strength properties of timber, hence the need to use other strength indicator such MOE and MOR to examine the strength quality of *M. indica*. The observed MOE and MOR of *Mangifier indica* at the three tree positions put it in the light construction timber category together with other species such as *Alistonia boonei*, *Antiaris toxicaria* and *Artocarpus heterophyllus*, which are commonly, used species in Uganda's small scale furniture industry (Zziwa *et al.,* 2010).

Table 4: Mean MOR and MOE at the three height positions (n=35)

Parameter	*Groups*	*Average*	*Standard Deviation*
MOR (**N/mm^2**)	Butt	63.5	14.3
	Middle	74.2	20.2
	Top	46.6	11.4
MOE (**N/mm^2**)	Butt	5617.0	1,123.4
	Middle	8027.8	1,179.3
	Top	6434.5	1,239.0

Table 5: Summary of Single Factor ANOVA tests for MOR

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	13567.56	2	6783.78	27.4849	2.8313E-10	3.085
Within Groups	25175.49	102	246.8185			
Total	38743.05	104				

Table 6: Summary of Single Factor ANOVA tests for MOE

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	105220850.3	2	52610425.2	37.6884	5.56E-13	3.085465
Within Groups	142385019.6	102	1395931.565			
Total	247605869.9	104				

Table 7: Classification of timber species basing on basic Density, MOE and MOR

Classification	**MOR(N/mm^2)**	**MOE (N/mm^2)**	**Basic Density (Kg/m^3)**
Heavy Construction	≥133	≥14700	≥720
Medium Construction	89-132	9900-14700	480-720*
Light Construction	39-88*	6860-9800	400-480
Very Low density	<39	<6860*	<400
Mangifera indica	***46.6 - 74.2*****	***5,617.0 - 8,027.8 *****	***534.0 - 585.2***

**Source: Kityo and Plamptre (1997) and **Values referred to in the discussion*

The observed MOR values and density values of *Mangifera indica* in this study are not far from those reported by other researchers. For instance Rajput *et al*. (1996) and Jain *et al.* (2000) in their study on flexural properties of finger jointed Mango reported specific gravities of around 0.5 and MOR around 27.6 - 56.9 MPa. It is not surprising that there is increasing research interest to enhance utilisation of mango wood sections for various end uses like furniture (Orwa *et al*., 2009; Kishan Kumar *et al.*, 2005; Kishan Kumar *et al*., 2015). Therefore, detailed research on other properties such as compressive strength, machining properties, shear strength, cleavage resistance and durability of Ugandan grown *M.indica* is necessary to get a comprehensive picture of the appropriateness of the potentially good furniture construction material.

4. Conclusions and Recommendations

The mean basic density of *Mangifera indica* ranged from 534.0 kg/m^3 to 585.2 kg/m^3; the mean MOE ranged from 5,617.0 N/mm^2 to 8,027.8 N/mm^2 and mean MOR ranged from 46.6 N/mm^2 to 74.2 N/mm^2. Based on the properties, *Mangifera indica* qualifies as a light construction timber which can be used for structural framework in the furniture making industry. In addition, during utilization of the tree species preference should be given to the middle portion of the entire tree stem on account of the better strength properties. Promotion of *M. indica* for use in the furniture industry should consider its value as fruit tree and any promotional efforts should focus on conversion of mango trees at the peripheral ages of fruit production to minimize the impacts of its competitive use for furniture versus food security. However, there is need to determine machining properties, cleavage resistance and durability in order to promote the species for furniture construction.

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