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Basic density, modulus of elasticity and modulus of rapture of *Artocarpus heterophyllus*

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Abstract

***Artocarpus heterophyllus* is increasingly being utilised in the furniture industry despite the limited information regarding its properties. This study was conducted to categorise *A. heterophyllus* based on its basic density, Modulus of Elasticity and Modulus of Rapture. Specimens were prepared from three mature trees (≥15 years of age) obtained from a farmland in Nyabyeya parish, Budongo Sub-county, Masindi district. From each tree three bolts of height 800 mm were cut at Diameter at Breast Height (1.3 m), 45% tree height and 75% of tree height. The bolts were sawn into scantlings using through and through method. Specimens for static bending and basic density tests were prepared according to Lavers (1983). Bending tests were done in accordance with BS 373 (1957) using a Testometric AX Universal Testing Machine. Basic density was determined by the water displacement method. The mean MOE was 6,378 Nmm^{-2}, the mean MOR was 119 Nmm^{-2} and mean basic density was 458 Kgm^{-3}. Based on these properties, *A. heterophyllus* qualifies as light construction timber. However, further research on other strength properties of *A. heterophyllus* is recommended for effective utilisation of its wood for structural purposes.**

Key words: Lesser-known, species, tree, wood

Introduction

Uganda is endowed with over 150 tree species that are capable of producing timber for furniture. Unfortunately only a few well known and usually expensive highly demanded species such as the mahoganies (*Khaya and Entandrophragma* species), "Nkoba" (*Lovoa brownie),* Pine (*Pinus caribae*) and "Mvule" (*Melicia excelsa*) are being utilised for a wide range of purposes, which other lesser-known but readily available timber could serve. With increasing population growth in Uganda, pressure has been put on the well-known species which are currently over harvested. The long rotation periods, high demand and dynamics of scarcity has made these hardwoods very costly in the market and this has prompted the extraction of non-traditional and lesser-known species including fruit trees such as *Artocarpus heterophyllus* and *Mangifera indica*. For instance, in the recent past tree branches of Guava (*Psidium guajava* L.) have been used for truss fabrication in Nigeria (Lucas *et al.*, 2006). The utilisation of non-traditional species has availed a larger volume of prime timber for utilisation and reduced pressure on the traditionally well-known species (Yeom, 1984). Zziwa *et al.* (2006a) observed that *A. heterophyllus* contributes about one percent of the timber used in the furniture industry in

Masaka districtof Uganda. However, keen consumers are reluctant to accept timber products derived from such species even in cases of low structural strength requirement due to lack of information on the structural suitability of the species, as the basis for their decisions (Zziwa *et al.*, 2006b).

Artocarpus heterophyllus is commonly known as Jack fruit (English),"Yakobo"or "Ffene" (Luganda). It belongs to the Mocaceae family and is well-known for its delicious fruit. The tree is medium sized with diameter at 1.3 m height (DBH) of up to 60 cm and thick branches up to 25 cm at 15 years. The bole is straight up to 2.5 m in height. The colour of *A.heterophyllus* timber ranges from plain yellow to golden yellow with increase in age. Proper growth of the species requires well-drained, deep and fertile soils and it is not tolerant to drought (Katende *et al*., 1995). The tree originated from Asia probably in the forests of western India (Katende *et al*., 1995). The species was first introduced in Uganda in the early 1940s at Entebbe botanical gardens and it is now being planted in most parts of the country. The promotion of fruit trees in agroforestry systems has also facilitated the growing of *A. heterophyllus* in most homesteads in Uganda. Nabanoga (2005) found that 43% of the *A. heterophyllus* trees were found in home gardens, 32% were randomly scattered on croplands, 9% on common land and 15% on state land. The species is widely spread in other parts of the tropics (Katende *et al*., 1995).

Artocarpus heterophyllus is a fast growing tree compared to the indigenous timber species in Uganda's forests such as *M.excelsa*, the Mahoganies *and Lovoa trichilioides* that are slow growing taking up to 80 years to grow to maturity (Kityo and Plumptre, 1997). Due to its abundance on farm, short rotation period and good quality wood, the species is becoming increasingly utilised in the furniture industry especially in making timber frames for upholstered furniture around Kampala.

In the past wood density has been the focus of most wood material research and has traditionally been the factor on which most wood quality improvement programmes were based (Walker and Butterfield, 1996). However, in recent years the emphasis on density as an absolute indicator of wood quality has declined. This is because previous studies have shown density to be a poor indicator of stiffness as a result of poor correlations between MOE and density (Addis-Tsehaye *et al.,* 1995a). Trials carried out by Brazier (1986) indicated that density, though of some significance in wood strength, was not as important as some other factors which lowered performance of wood in use. Therefore, stiffness (MOE) is increasingly considered to be a better indicator as it is the characteristic that most often governs the design of timber structures (Addis-Tsehaye *et al.*, 1995b; Bengtsson, 1999; Armstrong, 2003). High stiffness enables the use of minimal material and low weight in designs of furniture products, leading to efficient use of the resource. Knowledge of strength properties of wood forms a major consideration in characterization of its behaviour and making a decision on its suitability as a construction material (Bowyer *et al*., 2003). Unfortunately, the most important strength properties such as MOE and MOR of *A. heterophyllus* are not documented. Therefore, the main objective of the study was to categorise *A. heterophyllus* according to its MOR, MOE and density thereby providing information necessary for its appropriate use in the furniture industry and general construction purposes.

Materials and methods

Materials used in this study were obtained from Nyabyeya Parish in Budongo sub-county, Bujenje County, Masindi District (Figure 1). Nyabyeya lies between $1^0 40^1$ and $1^0 42^1$ N and $31^0 32^1$ and $31^0 33^1$ E and located west of Masindi town. It is bordered by Kinyara Sugar plantation in the South, and Waki and Simba rivers in the west. Nyabyeya is a sentinel hill at an altitude of 1,140m above sea level (Kerali, 2005).

Three sample trees in the diameter range 40 - 49 cm were purposively selected from a

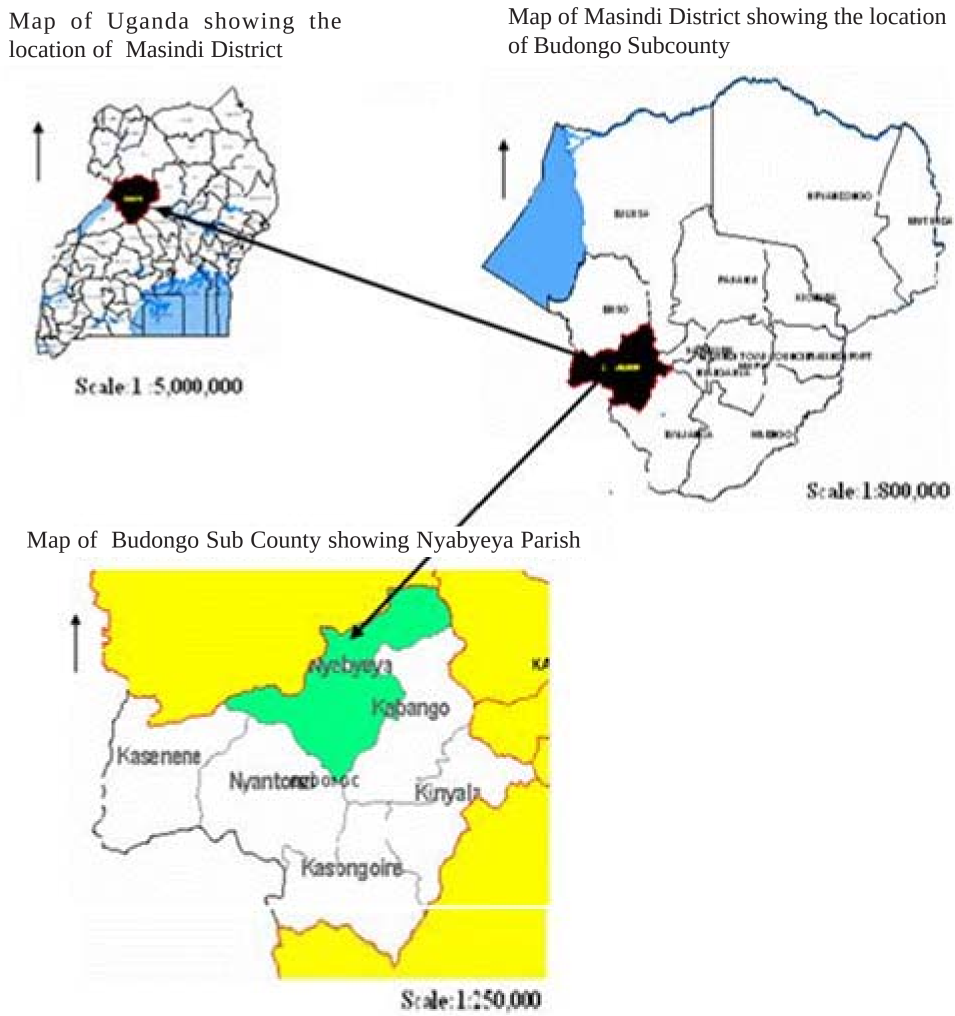
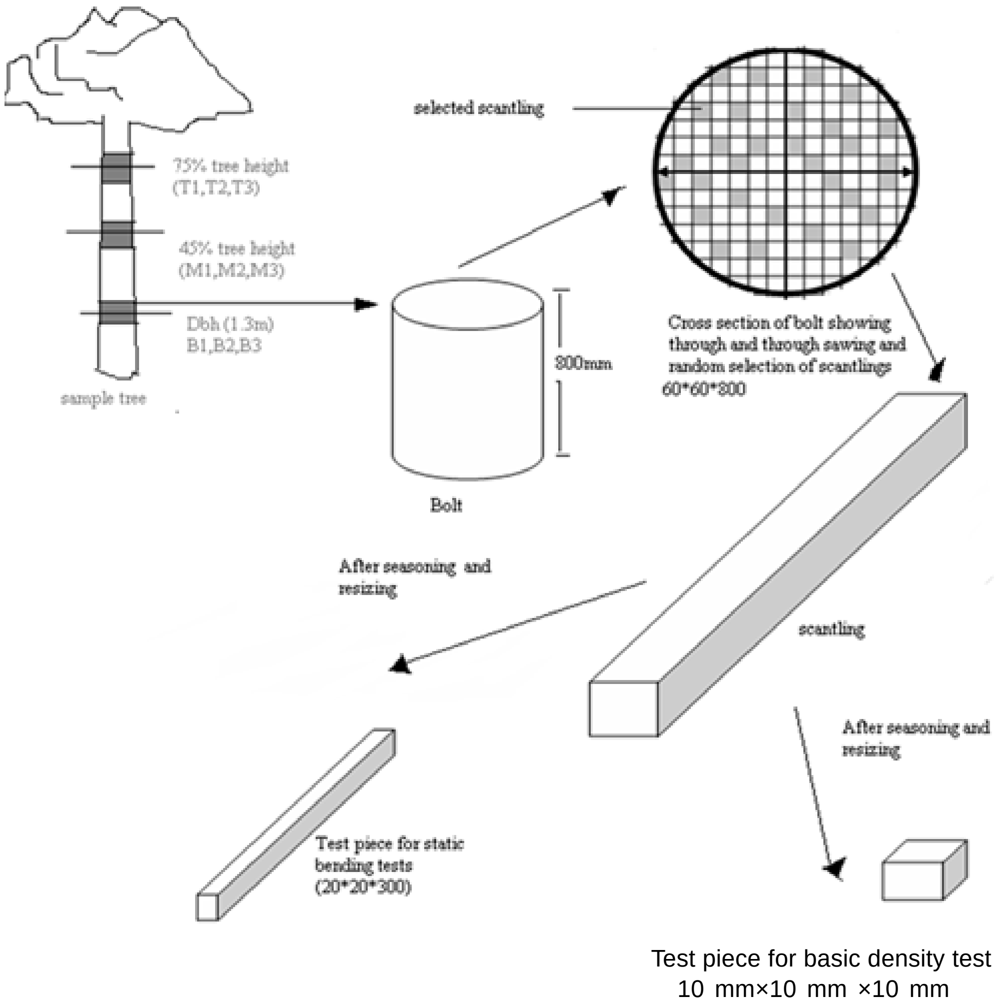


Figure 1. Location of Nyabyeya Parish in Masindi District of Uganda.

farmland in Nyabyeya parish. Stem qualities were considered and only trees of good form straight bole and minimal visible defects such as early branches were selected. The trees were felled with a chain saw and each was sectioned into three bolts at different heights. From each bolt, several scantlings were extracted using the through and through sawing method. The scantlings from which the test specimens were obtained were selected after eliminating the juvenile wood from the pith (Figure 2) in such a way that the probability of obtaining a scantling at any distance from the center of the cross section of a bolt was proportional to area of timber at that distance (Lavers, 1993).The randomly selected scantlings (60 mm x 60 mm x 800 mm) were stacked and seasoned at Nyabyeya Forestry College timber yard for two weeks. Scantlings were planed to standard dimensions according to Lavers (1993) and conditioned in the Faculty of Forestry and Nature Conservation laboratory for another 2 weeks. Standard procedures were followed to prepare the test specimens to appropriate shapes and dimensions. The specimens were then conditioned in the laboratory for 2 weeks to 12 ± 3% moisture content before testing. The British Standard (BS 373: 1957) method of testing small clear specimens for timber was



T1, T2, and T3 represent bolts derived from the top region of tree 1, 2 and 3, respectively.
$M_{1,}$ M_2 and M_3 represent bolts derived from the middle region of trees 1, 2, and 3, respectively.
B_1 B_2 and B_3 represent bolts derived from the bottom region of trees 1, 2, and 3, respectively

Figure 2. Sample preparation chart

used to determine MOE and MOR. ISO 3130 (1975) procedures were followed to determine the moisture content.

A total of 90 small clear specimens of dimensions 300 × 20 × 20 mm were obtained from each tree for static bending test and 30 specimens from each tree for basic density determination. Basic density tests were done in accordance with international standard procedures BS 373 (1957). Moisture content determination was in accordance to ISO 3130 (1975). The green volume was obtained by the water displacement method based on Archimedes principle, which states that "the weight of water displaced by a body is equal to the volume of the body". Test specimens for basic density determination were immersed in distilled water till they were fully submerged. A beaker of distilled water was placed on a digital weighing balance and reset to zero reading. Using a needle hung on a stand, each specimen was gradually immersed under water and the green weight (G_w) of water displaced recorded. The test specimens were then oven-dried at 104 ±2ºC until constant weight (D_w). Basic density was calculated from equation (i),

$$\rho = \frac{D_W}{G_W} \times 1000 \quad \text{.........................(i)}$$

Where

ñ is basic density,
G_w = Green weight (in grammes)
D_w = Oven dry weight (in grammes)

Prior to testing for MOE and MOR, all test specimens were conditioned to within 12± 3% moisture content to minimise the "skin-effect" caused by the occurrence of differential moisture contents within specimens (AS/NZS 2878: 2000). A Testometric AX universal testing machine was used to carry out static bending test. The load was applied centrally to the radial face of the specimen supported over a span of 280 mm. Testing was carried out in a laboratory under temperature of 20 ± 3ºC and relative humidity of 65 ± 3% as specified in (BS 373, 1957; Zziwa *et al.*, 2006[b]). A loading rate of 6.6mm per minute was used for all static bending tests (Dinwoodie, 1981).

Static bending tests were carried out according to ISO 3133 (1975) procedures; specimens were loaded to failure; the load to the limit of elasticity (P) and the corresponding deflection (δ) were recorded and used for computation of MOE values using equation (iii). The ultimate breaking load ($P_{u)}$ was recorded and used for computation of bending strength, MOR, using equation (ii). After the specimen failing, its rupture surface was examined to ensure that the specimen complied with the target requirements of clear wood samples; failure should not result from invisible defects. Any non-compliance, such as the occurrence of hidden defects led to rejection of specimens (AS/NZS 2878:2000). From the static bending test results the modulus of elasticity (MOE) and modulus of rapture (MOR) were computed. Stress-strain curves were plotted automatically. The modulus of rapture for each test piece at moisture content, w, MOR_w, (N/ mm^2) was calculated using equation (ii)

$$MOR_W = \frac{1.5 P_u L}{b d^2} \quad \text{.......................(ii)}$$

Where

P_u = the maximum load
L = the span (280 mm)
b = the width of the sample (=20 mm)
d = the depth of the sample (=20 mm)

Equation (iii) derived from the equation (ii), by substituting the dimensions of the specimen, was used to compute MOR_w values.

$MOR_w = 0.0525P_u$ .... (iii)

The Modulus of Elasticity of each test piece at moisture content, w at the time of test, MOE_w (N mm^{-2}) was calculated using the formula:-

$$MOEw = \frac{P L^3}{4 \ \delta \ b d^3} \quad \text{................ (iv)}$$

Where

P = load to the limit of proportionality;
L = span length (= 280 mm);
b = width of sample (= 20 mm);
d = the depth of the sample (=20 mm); and
δ = the deflection (in mm) at the limit of proportionality.

Equation (v) derived from equation (iv), by substituting the dimensions of the specimen, was used to compute MOE values.

$$MOEw = \frac{34.3P}{\delta} \quad \text{..........................(v)}$$

The moisture content of each tested specimen was determined following ISO 3130 (1975) procedures. All static bending strength values were adjusted to their 12% equilibrium moisture content (EMC) equivalents because wood in internal use usually is subjected to that EMC. Adjustments were made using the equation (vi) below according to Ishengoma and Nagoda (1991).

$P12\% = P\,(1+Z)^n$ ……......………………… (vi)

Where

Z = the correction factor for moisture content, equivalent to the percentage change in strength value for 1% change in moisture content (Table 1)
n = (moisture content at the time of test -12)
P12% = the strength value at 12% moisture Content
P = the strength value at the time of test

Table 1. Correction factors for moisture content

Property	Z-values
Modulus of Elasticity (E)	0.02
Modulus of Rapture (R)	0.04

Source: Zziwa (2004).

Data analysis
Means, coefficients of determination (R^2) and standard deviations of MOE and MOR were obtained using MS Excel and MINITAB software packages. Paired t-tests were used to compare basic density, MOR and MOE from the butt to the top of the tree. All tests were performed at 95% significance level (p= 0.05).

Results and discussion

The basic density of the butt portion did not differ significantly from that of the middle part ($P>0.05$) whereas there was a significant difference between basic density of the middle portion and the top ($P<0.05$). Basic density varied non-uniformly along the three trees and there was no consistent pattern of variation in MOE and MOR with height for the three trees (Figure 3). Basic density varied non-uniformly from base to top and there was no significant difference between basic density of the middle and the butt implying that on the basis of wood density any part of the tree can be utilised for structural purposes.

The basic density of *A. heterophyllus* reduced along the height of the tree; however, the reduction was non-uniform (Figure 3). The difference between the butt and middle portions was insignificant meaning that the butt and middle portions of the tree should be used for structural applications requiring extra strength. In addition, the top portions can be used for applications that are not subjected to excessive loading for instance the bracing pieces in a sofa set.

Density variation did not differ from that reported by other researchers. For instance Ishengoma and Nagoda (1991) reported that the variation in density along the tree trunk can be one of the following; decreasing uniformly, decreasing in the lower trunk and increasing in the upper trunk and increasing from base to top in a non-uniform pattern. In this study, all tested properties varied non-uniformly and this confirmed the anisotropic behaviour of wood.

The basic density, modulus of elasticity, and modulus of rapture of *Artocarpus heterophyllus* are comparably similar to those of light construction timbers such as *Alstonia boonei*, and *Antiaris toxicaria* which are commonly used species in the Uganda small scale furniture industry. The mean modulus of raptureof *A. heterophyllus* puts it in the medium construction group, while its modulus of elasticity puts it the very low density category (Table 2) according to Kityo and Plumptre (1997). However, the mean basic density value of *A. heterophyllus* does not put it in the medium construction category. Since modulus of elasticity and modulus of rapture are the most important elastic properties; *A. heterophyllus* timber can be classified conservatively as timber for light construction on the basis of MOR and MOE. This therefore shows that it is suitable for use in the furniture industry where the common

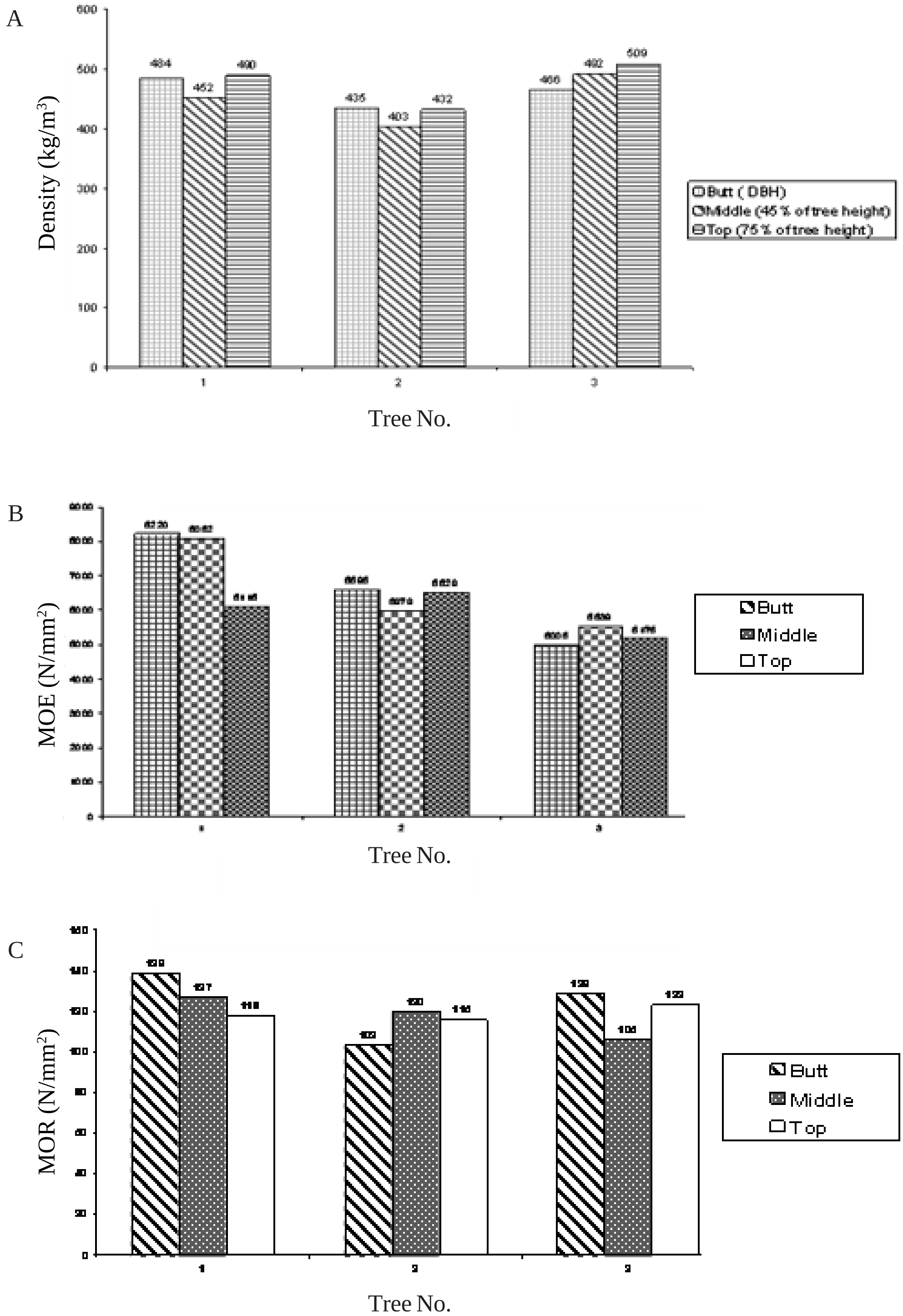


Figure 3A. Variation in basic density with tree height. B. Variation in MOE with tree height. C. Variation in MOR with tree height.

Table 2. Classification of timber species basing on density, MOE and MOR

Classification	MOR (Nmm^{-2})	MOE (Nmm^{-2})	ñ (k gm^{-3})
Heavy construction	$\geq$ 133	$\geq$14,700	$\geq$720
Medium construction	89-132**	9,900-14,700	480-720
Light construction	39- 88	6860-9800	400 - 480**
Very low density [very light construction]	< 39	< 6860**	< 400
Artocarpusheterophyllus [Results from this study]	119**	6378**	458**

*Source: Kityo and Plumptre (1997). **Values referred to in discussion

practice is to use off-cuts and low grade timber. Therefore use of *A. heterophyllus* will provide a better construction material compared to the off-cuts and low grade timber.

Conclusions

The mean MOE was 6,378 Nmm^{-2},the mean MOR was 119 Nmm^{-2} and mean basic density was 458 kgm^{-3}. Based on the properties, *A. heterophyllus* qualifies as light construction timberin Uganda's small scale furniture making industry.

Promotion of *A. heterophyllus* for use in the furniture industry should consider its value as fruit tree if food security is not to be affected adversely. Besides, there is need to determine other strength properties *of A. heterophyllus* in order to develop the species for sustainable utilisation in the timber industry.

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