Comparative Assessment of Selected Acoustic Properties of Talking Drums Made from Wood of Gmelina arborea (Roxb) and Brachystegia eurycoma (Harms)

***Noah, A. S; Abiola, J. K; Ayeni, O. D and Bamidele, O. D**
Department of Wood and Paper Technology Federal College of Forestry
Ibadan, Nigeria
*Corresponding author: email address: alloynoah@gmail.com

Alao, O. J
Department of Forest Products Development and Utilisation (FPD&U)
Forestry Research Institute of Nigeria (FRIN)
Ibadan, Nigeria

***Abstract*—The study was based on comparative assessment of selected acoustic properties of talking drums produced from known wood species (*Gmelina arborea*) and lesser known wood species (*Brachystegia eurycoma*). A tree of *Gmelina arborea* and *Brachystegia eurycoma* was purposively selected, felled and cut into merchantable height. Wood samples were obtained at the base, middle and top portions of the bole of the respective species, for selected physical and mechanical tests. A billet of 30 cm long was obtained from each of the wood species for the production of talking drum, to assess the following acoustic properties: frequency, wavelength, velocity of sound and impedance. The results show that *Brachystegia eurycoma* has higher mean values for density (642.96 kg/m$^{3)}$, moisture content (40.31%) and modulus of elasticity(MOE) (16609.33 N/mm^3), compared to *Gmelina arborea* with a lower mean density of 475.56 kg/m^3, moisture content of 30.79% and modulus of elasticity (MOE) of 11145.77N/mm^3. The values for the acoustic properties of the drum produced are also higher for *Brachystegia eurycoma* (Frequency of 170 Hz, Wavelength of 21.55 m, sound velocity of 3712.36 m/s and impedance of 5.08 kg/m^2 s) compared to frequency of 159 Hz, wavelength of 10.73 m, sound velocity of 3068.66 m/s and impedance of 4.84 kg/m^2 s for the *Gmelina arborea* drum. From the study, *Brachystegia eurycoma* wood has higher values in acoustic, physical and mechanical properties than the wood of *Gmelina arborea*. Hence, *Brachystegia eurycoma* can be recommended as a good and suitable wood substitute for *Gmelina arborea* in talking drum production.**

Keywords—Brachystegia eurycoma; Gmelina arborea; talking drum; moisture content; density; modulus of elasticity; sound velocity; impedance; frequency; wavelength.

INTRODUCTION

Wood is a hard fibrous tissue found in many trees, and has been in use for thousands of years for both domestic and industrial purposes [1]. Over the decades, the demand for wood has made wood to be an outstanding material; it is versatile, inexhaustible and renewable. Hence, these properties have made wood useful in various ways and forms [2].

An important area of wood utilization which has often been ignored is the production of musical instrument. Wood is acoustic in nature and has the ability to produce sound effect. Because of this unique property, wood is used in producing a number of musical instruments such as guitar, violin, piano, xylophone and percussion instrument (talking drum), amongst others [3]. Wood can produce sound by direct striking and can amplify or absorb sound waves originating from other bodies. For this reason, it is a unique material for musical instrument and other acoustic applications. The pitch of sound produced depends on the frequency of vibration, which is affected by such parameters as density and moisture content. According to "unpublished" [4], wood with high density and elasticity produces sound of higher pitch. The value of the velocity of sound in a material depends on the appropriate elastic modulus, which is a characteristic of the vibration stress applied to it, and also on the density of the material [5].

Normally, wood absorbs a very small portion of acoustic energy (3.5 percent), but special construction like incorporation of empty spaces and porous insulating boards can increase absorption to as high as 90%. As posited by [6], the speed of sound in wood is about 3500-5000 metres per second axially, and is ten times higher than that in air. The velocity of sound in wood is reduced by moisture, which by extension contributes to faster damping of sound for musical instrument. Hence, the preference for selected known wood species such as birch, fir, pine, maple and some tropical wood species like Gmelina, Cordia, Teak and Afzelia in the music industries. However, the over exploitation of these species tends to lead to their extinction. Therefore, according to [7], there is urgent need to research into lesser known or lesser used species such as *Brachystegia eurycoma*, and thereby, explore their potential for utilisation in diverse areas, including construction of musical instrument.

Brachystegia eurycoma belongs to the family of leguminosae. This tree is common along river banks and may be readily recognized by its large size irregular bole and huge trusted spreading branches, and by the rough fibrous bark which peels off in untidy patches. For musical instrument, the unique mechanical, physical and acoustic properties of wood and its aesthetic appeal still make wood the material of choice for musical instruments. Worldwide, several hundred species are available for making wind, string and percussion instruments. Over generations, first by trial and error, and more recently by scientific approach, the most appropriate species were found for each instrument and application using material property charts which have been designed for acoustic properties such as frequency, speed of sound, wavelength, impendence, and pitch, as well as for physical and mechanical properties [8].

Wood has been used for the construction of such musical instruments as guitar, violin, piano, xylophone, and percussion instruments. Percussion instrument is any object which produces sound when hit with an implement or when it is shaken, rubbed, scraped, or otherwise acted upon in a way that sets the object into vibration [9]. Percussion instrument may play rhythm, but also melody and harmony. It is commonly referred to as the back bone or the heart beat of a musical ensemble, often working in close collaboration with base instrument. When present in jazz and other popular music ensembles, the pianist, bassist, and the drummer are often referred to as the rhythm sector. One of the known examples of percussion instrument is talking drum. Talking drum is classified under tuned or pitched drum; it is an hourglass shaped instrument from West Africa, whose pitch can be regulated to mimic the tone and prosody of human speech. It is a membranophonic drum made of membrane and covered shell, capable of producing sound only when struck or beaten [10].

MATERIALS AND METHODS

A stand each of *Brachystegia eurycoma* and *Gmelina arborea* purposively selected was felled and cut into merchantable height. Billets of 50 cm long from the bole of each wood species were taken at the base, middle and top portions to determine selected physical and mechanical properties of the wood species.

Based on the growth rings, the wood was partitioned into three zones relative to their distance from pitch to bark, as core wood, middle wood and outer wood respectively, in line with “unpublished” [11]. The wood samples were processed with the help of circular machine and planning machine to dimensions of 2×2×30 cm for determination of modulus of elasticity (mechanical property) and 2×2×6 cm and 2×2×2 cm respectively for density and moisture content (physical properties).

Procedure for Talking Drum Production

For building of the talking drum, a billet of 30cm long was collected from the wood of *Brachystegia eurycoma* and *Gmelina arborea* respectively. The wood from both species was each carved and shaped into an hourglass shell measuring 28 cm in length and 16 cm in diameter, with both ends opened. Goat skin soaked in water for 45 minutes was afterwards rubbed and squeezed, before being laid on both ends of each shell as cover. The drum membrane was firmly held in place with leather string by sewing the tension robe and the membrane together. Top bond was used as adhesive to hold the tension robe against the shell frame using membrane pegs to facilitate tuning of the drum during construction. The drum was thereafter sun dried for a day, followed by pegs removal and straightening of the tension robes in readiness for drum testing.

Acoustic Tests

The two talking drums produced were tested at a dynamic sound studio to determine the sound frequency, wavelength and time taken to produce the sound effects from the drums. In this wise, a microphone on a stand was connected to a sound mixer and computer system. The talking drum was positioned at a short distance of 10 cm from the microphone and several strikes on the drum at low, mid and high pitches were made. The sound effects were recorded with the aid of a spectrum analyzer while appropriate formulas were used to calculate derived parameters like sound velocity, impedance and speed of sound.

Determination of Sound Velocity

Velocity, v is the distance moved per unit time in a given direction. The velocity of sound, v is calculated using the formula:

Where,

$$V = f\lambda \text{ (m/s)} \quad (1)$$

V = velocity of sound

f, is frequency

λ, is wavelength

Determination of Speed of Sound

The speed of sound, *c* with which sound travels through a material, is defined as the root of the material's young modulus, *E*, divided by the material's density,

Mathematically,

Where,

$C = \sqrt{E}/p$ (m/s) (2)

E, is the modulus of elasticity

p is density

Determination of Impedance

The impedance, *z* of a material is defined as the product of material's speed of sound, *c* and its density,.

Mathematically,

$Z = cp$ [8] (3)

Determination of Wood Density

Wood samples taken from all the discs were cut with circular saw into 2×2×6 cm dimensions based on [12], and coded according to their sources. The wood samples were oven dried to a constant weight at 103℃ The length, breath and thickness of the samples in oven-dried state were also taken to calculate their oven-dried volume, with a view to determining the wood density using the formula below:

$Density = \frac{Oven-dry\ weight}{Oven-dry\ volume}$ kg/m^3 (4)

Determination of Moisture Content

The sample was weighed when wet (original weight), and the loss in weight of the test piece on drying to constant weight was noted and calculated as a percentage using the formula:

$\textbf{Moisture content} = \frac{\textbf{Original weight}-\textbf{Oven dry weight}}{\textbf{Oven-dry weight}} \textbf{x100}(\%)$ (5)

Determination of Modulus of Rupture

Standard wood test specimens (20mm x 20mm x 300mm) were placed in a Hounsfield Tensiometer and load applied at the rate of 0.1mm/sec, with the growth rings parallel to the direction of loading (specimens loaded on the radial face). The bending strength of wood usually expressed as modulus of rupture (MOR) - the equivalent fibre stress in the extreme fibres of the specimen at the point of failure- was then calculated.

Determination of Modulus of Elasticity

The modulus of elasticity (MOE) was calculated from the value obtained at the point of failure recorded during the test for MOR. However, while the MOR test was being carried out, a load-deflection graph was also plotted on the testing machine simultaneously. This provided for the calculation of delta 'Δ', an addition to the parameters that were earlier defined in MOR. The MOE was then calculated using the formula below:

$MOE = \frac{PL^3}{4\Delta bd^3}$ (N/mm^2 (6)

Where:

P = Load in Newton (N)
L = Span/Length in (mm)
b = Width (mm)
d = Depth (mm)
Δ = The deflection at beam centre at proportional

Delta (Δ) which is the deflection of beam centre of proportional limit on the deflection curve, was calculated using the Pythagoras rule $c^2 = a^2 + b^2$, as the distance from the start of experiment to a perpendicular line drawn from the proportional limit to the absica of the graph obtained during the modulus of rupture test.

Experiment Design

For determination of the selected physical and mechanical properties of the wood species used, the experimental design adopted was a 2 x 3 x 3 factorial in a completely randomized design (CRD). The mathematical model for the factorial experiment is given as:

$$\gamma_{ijk} = \mu + A_i + B_j + C_k + AB_{ij} + AC_{ik} + BC_{jk} + ABC_{ijk} + E_{ijk} \quad (7)$$

Where,

γ_{ijk}=Individual observation

μ =General mean
A_i=Effect of factor A (sampling height)
B_j=Effect of factor B (Radial position)
C_k=Effect of factor C (Species)
AB_{ij}=Effect of interaction between A and B
AC_{ik}=Effect of interaction between A and C
BC_{jk}=Effect of interaction between B and C
ABC_{ijk}=Effect of interaction among A, B and C
E_{ijk}=Effect of interaction in Error term

Statistical Analysis

Analysis of variance (ANOVA) was conducted to estimate the relative importance of the various sources of variation on moisture content, wood density, and modulus of elasticity, sound frequency, wavelength and sound velocity. Other statistical tools like tables and graphical representation were also used to analyse the study.

RESULTS AND DISCUSSION

Table 1: Summary of selected mechanical and physical properties of wood of *Brachystegia eurycoma* and *Gmelina arborea* and acoustic properties of talking drums produced

Parameter	Brachystegia eurycoma	Gmelina arborea
Frequency (Hz)	170	159
Time (Sec)	4	4
Frequency Range (Hz)	87-1200	93-1300
Wavelength (m)	21.55	10.73
Velocity of sound (m/s)	3712.34	3068.66
Impedance (Kg/m2s)	5.08	4.84
Modulus of elasticity (N/mm2)	16609.33	11145.77
Moisture content (%)	40.31	30.79
Wood density (Kg/m3)	642.96	475.56

Table 1 shows the summary of selected physical and mechanical properties of wood of *Brachystegia eurycoma* and *Gmelina arborea*, and the acoustic properties of the talking drum produced from each wood species. From the table, it is observed that in density, moisture content and modulus of elasticity, *Brachystegia eurycoma* has higher values than *Gmelina arborea*. Similarly, the wavelength, velocity of sound, frequency and impedance of the talking drum produced from *B. eurycoma* wood are of higher values than those of the talking drum from *G. arborea* at all pitch levels.

Tables 2: Mean values of wood density (Kg/m^3) of *Brachystegia eurycoma* and *Gmelina arborea* in relation to their sampling height and radial position.

	Brachystegia eurycoma				Gmelina arborea			
	Core	Middle	Outer	Mean	Core	Middle	Outer	Mean
Base	690.54	632.73	543.74	622.34	535	515	470	506.67
Middle	648.19	623.64	665.59	645.8	500	475	450	475
Top	709.5	656.3	616.4	660.73	470	450	415	445
Mean	682.74	637.56	608.58	642.96	501.67	480	445	475.56

From Table 2, it is shown that the mean values for density of *Brachystegia eurycoma* and *Gmelina arborea* are 642.96 Kgm^{-3} and 475.56 Kgm^{-3} respectively. According to [6], species with high density and modulus of elasticity will produce high sound pitch. This result shows that talking drum produced from *B. eurycoma* wood will have higher sound pitch than the *G. arborea* drum based on their density values. A decreasing pattern of variation in wood density was observed for both *Gmelina arborea* (501.67, 480.00 and 445.00) Kgm^{-3} and *Brachystegia eurycoma* (682.74, 637.56 and 608.58) kg/m^3 across the radial positions respectively.

However, the variation pattern along the sampling height for *Brachystegia eurycoma* shows an increase from base to the top (622.34, 645.80 and 660.73) kg/m^3.This pattern of variation is in agreement with [13] and [14] in their works on eucalyptus species. On the other hand, the axial variation for *Gmelina arborea* shows a decreasing pattern from base to top (506.67, 475.00 and 445.00) Kg/m^3. These findings are in accordance with the works of [15] on wood density of Nigeria grown *Gmelina arborea*. Reference [16] also reported similar observations for wood density of plantation grown *Nauclea diderrichii* wood. The observed decrease in wood density from base to top agrees with the auxin gradient theory of [17], which posits that the endogenous auxin arising in the apical region of growing shoot stimulates cambial division and xylem differentiation. Therefore, high production of early wood near the crown contributes significantly to low wood density at the top. Regional factors, particularly altitude, soil and climatic conditions, also affect the growing characteristics and properties of the wood species.

Table 3: Mean values of wood moisture content (%) of *Brachystegia eurycoma* and *Gmelina arborea* in relation to their sampling height and radial position

	Brachystegia eurycoma				Gmelina arborea			
	Core	Middle	Outer	Mean	Core	Middle	Outer	Mean
Base	30.59	37.64	42.72	38.65	27.38	33.78	27.59	29.58
Middle	40.29	39.11	39.5	39.63	33.78	33.18	31.96	32.97
Top	40.31	46.6	40.99	42.66	27.59	42.42	20.82	30.31
Mean	38.73	41.14	41.07	40.31	29.58	35	27.79	30.79

Table 3 shows that the mean values for the moisture content of *Gmelina arborea* and *Brachystegia eurycoma* are 30.79% and 40.31% respectively; thus implying that *B. eurycoma* has higher moisture content than *G. arborea*. The axial pattern of variation in moisture content of *Brachystegia eurycoma* indicates an increase from base to top (38.65, 39.63 and 42.66) % respectively. The variation may be due to upper logs with higher percentage content of sapwood of high moisture content [18]. Inconsistency in moisture content was however observed along the sampling height for *Gmelina arborea*, in line with [19].

Tables 4: Mean values of modulus of elasticity (N/mm^2) for *Brachystegia eurycoma* and *Gmelina arborea* wood in relation to their sampling height and radial position.

	Brachystegia eurycoma				Gmelina arborea			
	Core	Middle	Outer	Mean	Core	Middle	Outer	Mean
Base	16609.53	16604.88	16609.9	16609.1	11479.61	12603.66	12855.04	12312.77
Middle	16606.16	16604.85	16609.58	16606.86	10878.82	11983.09	12500.19	11787.7
Top	16614.54	16612.04	16609.51	16612.03	9647.38	9647.44	10575.69	9336.84
Mean	16610.08	16607.26	16610.66	16609.33	10048.76	11495.17	11893.18	11145.77

From Table 4 above, it is observed that the mean value of modulus of elasticity (MOE) for *Brachystegia eurycoma* is 16609.33 N/mm^2 while that for *Gmelina arborea* is 11145.77 N/mm^2. The pattern of variation was observed both across the radial position and along the sampling height. The variation along the sampling height for *G. arborea* shows a decreasing pattern, from base to top (12312.77, 11787.70 and 9336.84) N/mm^2, while that of *B. eurycoma* is inconsistent (16609.10, 16606.86 and 16612.03) N/mm^2. The variation across the radial position for *G. arborea* is that of an increasing pattern, from core to outer wood, while that of *B. eurycoma* is inconsistent. The general trend of variation in modulus of elasticity for *G. arborea* shows a decrease from base to top, and an increase from core to outer wood at particular height. These findings are in line with [20]. And based on the value of MOE, a determinant of the speed of sound, talking drum produced from *E. eurycoma* is favoured to have higher pitch than drum made from *G. arborea*.

Table 5: ANOVA for selected physical and mechanical properties of *Brachystegia eurycoma* and *Gmelina arborea* wood

Source of Variance	Degree of Freedom	Sum of Squares	Mean Square	F cal	sig.
Wood density (Kg/m3					
Species	1	257256.912	257256.912	53.594	0.000*
Specie X Sampling Height X Radial position	4	6437.28	1609.32	0.335	0.851ns
Wood moisture content (%)					
Species	1	815.578	815.578	29.747	0.000*
Specie X Sampling Height X Radial position	4	62.716	15.679	0.572	0.686ns
Modulus of elasticity (N/mm2)					
Species	1	268654500.1	268654500.1	2344.221	0.000*
Specie X Sampling Height X Radial position	4	833114.423	208278.606	1.817	0.169ns

*Significant at 0.05 level of probability
ns= Not significant at 0.05 level of probability

For wood density, wood moisture content and modulus of elasticity, at 0.05 level of probability, there is significant difference between wood species while no significant difference was observed in the interaction between species, sampling height and radial position.

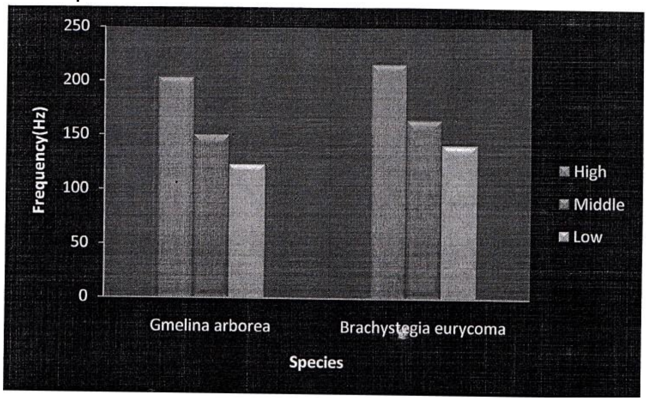

Fig. 1: Graph of sound frequency (Hz) of talking drums from wood of *Gmelina arborea* and *Brachystegia eurycoma*

The pitch of sound produced depends on the frequency of vibration. Wood sample with low frequencies tend to produce lower pitches while high frequencies will result in higher pitches. From the results, *B. eurycoma* drum has higher values for hi-frequency, mid-frequency, and low-frequency of 216,164 and 141 Hz, respectively. According to [21], MOE and density tend to increase with frequency. The values for hi-frequency of *B. eurycoma* and *G. arborea* made drums are 216 and 203 Hz, respectively. The mid-frequency and low-frequency values for *B. eurycoma* and *G. arborea* produced drums are 164 and 150 Hz; 141 and 123 Hz respectively.

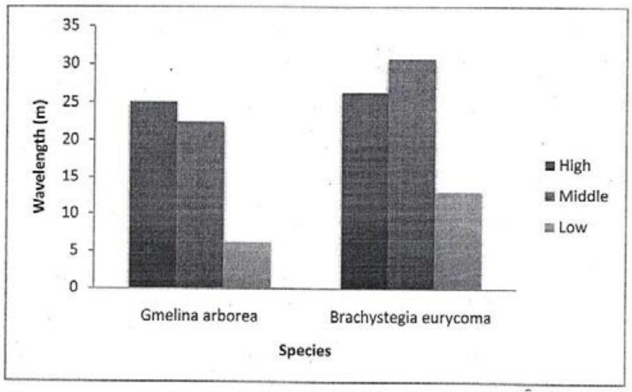

Fig. 2: Graph of sound wavelength (m) produced by drums of *Gmelina arborea* and *Brachystegia eurycoma* wood

According to [22], the frequency dependence on the modulus of elasticity of wood shows that higher frequencies become relatively stronger with increasing wavelength. Fig. 2 shows that at the respective pitch levels, *Brachystegia eurycoma* drum has higher wavelength values (26.25, 30.60 and12.91)m than *Gmelina arborea* talking drum with wavelength of 25.08, 22.37 and 6.20 m, respectively.

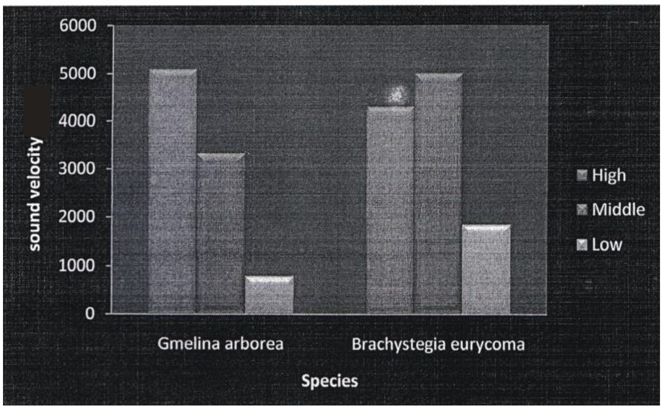

Fig. 3: Graph of sound velocity from talking drums of *Gmelina arborea* and *Brachystegia eurycoma* wood

Fig. 3 above shows that at hi-pitch, *Gmelina arborea* drum has higher value of sound velocity than *Brachystegia eurycoma* drum (5095 and 4303 m/s), respectively. However, at mid-pitch, the value of sound velocity for *Brachystegia eurycoma* drum (5005 m/s) is higher than that of *Gmelina arborea* drum (3327 m/s). Similar trend is also observed at low pitch, with *Brachystegia eurycoma* drum recording higher value of sound velocity (1829 m/s) than *Gmelina arborea* drum with 784 m/s.

Table 6: ANOVA for selected acoustic properties of talking drums produced from wood of *Brachystegia eurycoma* and *Gmelina arborea*

Source of Variance	Degree of Freedom	Sum of Squares	Mean Square	F cal	sig.
Sound frequency (Hz)					
Species	1	896.533	896.533	3.339	0.080ns
Pitch	2	26267.4	13133.7	48.909	0.000*
Specie X Pitch	2	388.067	194.033	0.723	0.496ns
Sound wavelength (m)					
Species	1	101.021	101.021	23.013	0.000*
Pitch	2	1605.974	802.987	182.927	0.000*
Specie X Pitch	2	219.602	109.801		
Sound velocity (m/s)					
Species	1	31111763.04	31111763.04	21.623	0.080ns
Pitch	2	66586693.2	33293346.59	231.347	0.000*
Specie X Pitch	2	8224452.213	4112226.106	28.575	0.000*

*Significant at 0.05 level of probability
ns= Not significant at 0.05 level of probability

As shown in Table 6, for sound frequency and sound velocity, there is no significant difference between species, while significant difference between species is observed for sound wavelength at 0.05 level of probability. However, there is significant difference between pitch for sound frequency, sound wavelength and sound velocity at 0.05 level of probability. Equally, for sound wavelength and sound velocity, there is significant difference in the interaction between wood species and pitch, though for sound frequency, there is no significant difference in the interaction between wood species and pitch at the same level of probability

CONCLUSION AND RECOMMENDATIONS

The study has provided some basic information on mechanical and physical properties of *Brachystegia eurycoma* and *Gmelina arborea* wood. Similarly, the acoustic properties of the talking drums produced from both species, have also been brought to the fore. From the study, *B. eurycoma* drum recorded higher values of sound frequency; wavelength, sound velocity and impedance than *G. arborea* drum at all the pitch levels. In addition, the mean values of density, moisture content and modulus of elasticity are higher in *B. eurycoma* than in *G. arborea,* although the patterns of variation of these values were inconsistent in axial and radial positions in both species. In conclusion, *Brachystegia eurycoma* has proven its potential as a good acoustic material and can therefore be recommended as a suitable substitute for *Gmelina arborea* in talking drum production.

REFERENCES

[1]M. Hickey and C. King. The Cambridge Illustrated Glossary of Botanical Terms, Cambridge, University Press, 2001, Pp 96.

[2]G. U. Ogbogu. The state of wood treatment technology, a paper presentation at FRIN seminar series, Forestry Research Institute of Nigeria, Ibadan, 1996, Pp 67-69.

[3]V. Bucur. Acoustics of Wood, CRC Press Inc., New York, 1995

[4]A.Z. Olagunade. Determination of acoustic properties of talking drums using three hardwood wood species, unpublished dissertation of the Department of Wood and Paper Technology, Federal College of Forestry, Ibadan, Nigeria, Pp 2-3, 2009.

[5]F. G. R. Olivera, M. Cadian, F. F. Lucchette, J. L. Salgor, A. Sales. Moisture content effect on ultrasonic velocity in

Goupia glabra, *Materials Research, vol. 8 no. 1*, Jan/March, 2005

[6]D. J. Albert, T. A. Clare, R. L. Dickson and J. C. F. Walker. Wood acoustics, *The International Forestry Review 4(1):* 12- 16, 2002

[7]L. O. Aguda, O. R. Adejoba, B. Ajayi and A. I. Adegoke. Evaluation of selected physical properties of *Chrysophyllum aibidum:* a lesser used wood species, proceedings of the 5th International Union of Forestry Research Organisations (IUFRO), Lisbon, Portugal, 8th- 13th July, 2012, Pp 240

[8]G. K. W. Ulrike. Wood for sound, *American Journal of Botany 93(10)*: *1439-1448,* 2006

[9]O.W. Tolu. The philosophy of traditional musical ensemble in Yoruba land, *Journal Polycom. Vol.5 Pp 4*8-50, 1995 [10]A. D. Abel. Factors for aesthetic evaluation of Yoruba traditional music, *Journal Polycom*, vol. 5, Pp 84-89, 1998.

[11]O.J. Alao. Evaluation of specific gravity and anatomical properties of *Gliricidia sepium* stand, unpublished dissertation of the Department of Forestry Technology, Federal College of Forestry, Ibadan, Nigeria. Pp 31-32, 2008

[12]British standard specification: standard testing procedure for evaluating properties of wood-based products,

BS323-399, 1989

[13]Q.Teresa and P. Helena. Within and between-tree variations of bark content and wood density of *Eucalyptus globulus* in commercial plantations, *Research gate.net*, 2014.

[14]N.S. Abassali and K. Majid. The within-tree variation in basic density and fiber length of *Eucalyptus camaldulensis*

wood, *Applied Science Journal 13(5):* 1042-1046, 2011.

[15]A. E. Akachuku. Variations in wood density of Nigeria grown *Gmelina arborea*, *Agric. Research Bulletin, volume 1 number 3,* University of Ibadan, Nigeria. Pp 5-6, 1980

[16]J.A. Fuwape and J.F. Fabiyi. Variation in strength properties of plantation grown *Nauclea diderrichii, Journal of Tropical Forest Products 9 (1&2)*: 45-53, 2003.

[17]P.R. Larson. Wood Formation and Concept of Wood Technology, Vol. 1 McGraw Hill Book Company, New York, 1969, Pp 79

[18]H.E. Desh and J.M. Dinwoodie. Timber: Its Structure, Property and Utilization. 6thedition, Macmillan Science and Education Publishers, UK, 1983, Pp 410.

[19]K. E. Okon. Variations in specific gravity and shrinkage in wood of 25-year-old *Gmelina arborea* in Oluwa forest reserve, south west Nigeria, *Archives of Applied Science Research 6(4): 271-276, 2014.*

[20]D. N. Izakor and J. A. Fuwape. Effect of density on variation in the mechanical properties of plantation grown

Tectona grandis wood, *African Journal of General Agriculture 5(3)*: 170-177, 2010

[21]J.D. Ferry. Viscoelastic properties of polymers. 3rd edition New York; Wiley, 1980, Pp 23

[22]D. Ouis. Frequency dependence on the modulus of elasticity of wood, *Wood Science and Technology* 36(6): 335- 346, 2002.