Variations in Physico-Mechanical Properties of *Lonchocarpus sericeus* (Poir), a Lesser-Used Species in West Africa

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Abstract

This study investigates the properties of *Lonchocarpus sericeus* to determine its potential use for timber. Three matured trees of *L. sericeus* were selected from a forest located in Longe Village, Oluyole Local Government Area in Oyo State, Nigeria. Discs from the harvested trees were collected at the base (10%), middle (50%), and top (90%) and further partitioned into inner wood, center wood, and outer wood. An investigation was carried out to characterize the wood age, density, shrinkage, impact strength, modulus of elasticity, modulus of rupture, compressive, and shear strength. The ages were 28, 29 and 32 years. The mean wood density at 12 percent moisture content was 836.63 kg/m^3, which shows that it belongs to the high-density wood category. The mean shrinkage values in the radial, tangential, and longitudinal directions were 2.50, 3.99, and 0.78 percent respectively; the volumetric shrinkage was 6.36 percent. These shrinkage values were indicative of good dimensional stability. The mean impact bending strength, modulus of rupture, modulus of elasticity, maximum shear strength parallel to grain, and maximum compression strength parallel to the grain were 24.14, 114.18, 11,276, 12.76, and 47.16 N/mm^2, respectively. End-use assessments suggest that the wood species can be used in similar applications as well-known timbers. The study found *L. sericeus* to be very dense with high strength in comparison to well-known timbers. It was observed that the mechanical properties of the species decrease from the base to the top and also increase from the outer wood to the core wood.

The Nigerian forest contains a vast stock of tree species out of which over hundreds are suitable for sawing and commercial use (Ogunsanwo et al. 2006). Unfortunately, very few of these species are used for construction purposes (Adedeji 2016); these include *Milicia excelsa, Triplochiton scleroxylon, Nauclea diderrichii, Afzelia africana, Etandrophragma cylindrium, Afzelia pachyloba, Albizia zygia, Celtis zenkeri, Daniellia ogea, Daniellia oliveri, Diospyros mespiliformis, Distemonanathus benthamianus*, and *Entandrophragma candollei*.

An increase in Nigeria's population has resulted in new pressure to find alternative timber species for building and construction purposes while also ensuring a steady supply of fuelwood. This situation has led to a rapid shrinking of natural forests (Sadiku 2016). The demand for good quality timber has been increasing, along with pressure to decrease logging, resulting in tighter government regulations and environmental restrictions (Cherdchim et al. 2004). Modern forest management approaches are being explored to search for alternative substitute timber species to reduce pressure

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on those most exploited in the timber sectors in Africa. Remarkable progress in finding substitute species have been reported in Nigeria and other African countries. Several studies on lesser-used species have also been carried out across Africa with the goal of reducing pressure on limited species (Poku et al. 2001).

Ten lesser-used species from Nigeria were considered for this study and then *Lonchocarpus sericeus* was selected. Specifically, the selection of these species was based on a plank market survey conducted by the Timber Engineering section of the Forest Products Development and Utilization Department at the Forestry Research Institute of Nigeria. The survey showed the availability of the species in the timber market and little was known about their properties. These lesser-used species are currently in use for various purposes as a result of the scarcity of the economic species whose properties had been evaluated. It is therefore very important to determine the physical and mechanical properties of these species before their use so that we can avoid building-structure collapse or other similar problems to the end user (Adetogun et al. 2010).

Materials and Methods

The study area

The study area was a free forest area called Longe Village, Busogbooro, along Ibadan/Ijebu Ode Road in the Oluyole Local Government Area in Ibadan, Oyo State, Nigeria. It is surrounded by many other villages, which include Onigambari, Adebayo, Aba-Dalley, Mamu, Aba-Igbagbo, Idi-Ayunre, Ajibode, Lagunju, Gbale-Asun, Akintola, and Onipade. Longe Village is located at latitude 7°9.715′N and longitude 3°53.235′E. It is 122 meters above sea level with an average annual rainfall of 1,421 mm. The relative humidity ranges from 84.5 percent from June to September to 78.8 percent from December to January (WAHIP 1997).

Materials selection

Sampling selection and preparation.—The trees were felled and their merchantable heights were measured. Bolts 91.44 cm long were cut from each tree at the base (10%), middle (50%), and top (90%) of the merchantable length, as shown in Figure 1. Nine bolts were then transported to the sawmilling facility of the Department of Forest Products Development and Utilization, Forestry Research Institute of Nigeria, in Ibadan, for conversion. Planks were obtained from all the bolts, and they were taken to the wood workshop section for further conversion to test samples. The planks were sectioned into six equal portions, labeled 1 to 6 from bark to bark. Sections 1 and 6 formed the outer wood portion, 2 and 5 formed the middle wood, and 3 and 4 formed the inner wood portion, as shown in Figure 1.

Wood properties evaluation

The physical properties tested and recorded were tree age, wood density, and wood shrinkage.

Tree age.—Disks 0.05 mm in diameter were taken from breast height and sanded with sandpaper until the rings could be distinctly seen for counting. This was repeated for all bolts at their respective positions along the tree. Clarke (2000) stated that the number of growth rings can be used at a reasonable level to determine the age of the tree.

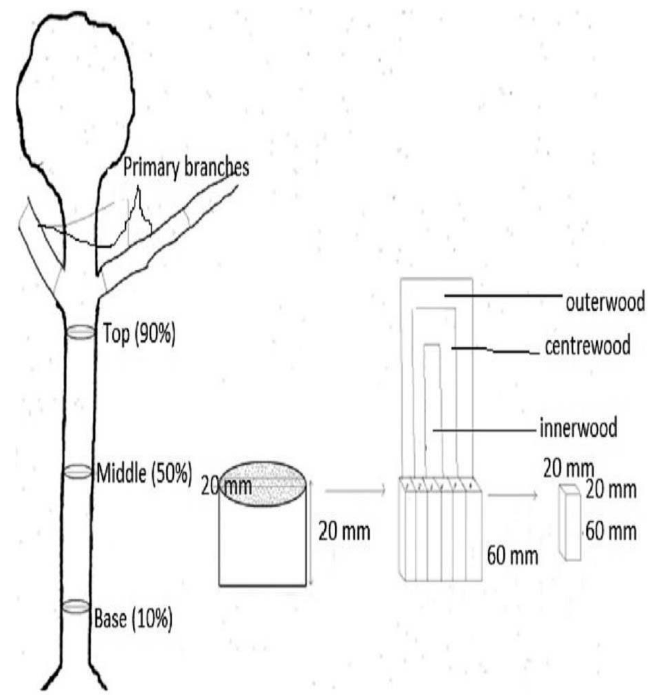

Figure 1.—Parts of sample selection.

Determination of wood density.—Test samples of 20 × 20 × 60 mm were taken using the circular bench saw based on ASTM D 2395-83 (ASTM 1983). Five samples each were taken from the inner wood, center wood, and outer wood at the base (10%), middle (50%), and top (90%), making a total of 270 test samples for all six trees. The test samples were oven-dried to a constant weight at 103°C ± 2°C and the weights along and across the boles were determined and recorded using the moisture analyser shown in Figure 2.

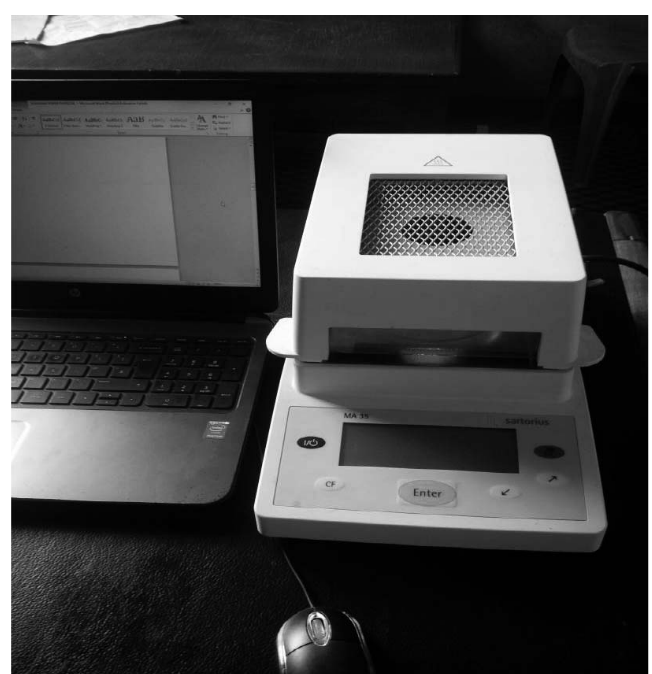

Figure 2.—Satorium moisture analyzer.

The formula used for the calculation of wood density (kg/m^3) is according to ASTM D 2395 (1983):

$$\text{Density} = \frac{\text{oven-dried weight}}{\text{oven-dried volume}}. \quad (1)$$

Shrinkage characteristics.—The standard method of testing small, clear specimens of timber, ASTM D 143-94 (ASTM, 1994), was used for this test. Five test samples of $20 \times 20 \times 60$ mm were obtained and soaked in water for 48 hours to condition them above the fiber saturation point. The test samples were removed and their dimensions measured from the three orthogonal directions (radial, tangential, and longitudinal). The samples were then oven-dried to a constant weight at 103°C ± 2°C and their dimensions were again measured in the three orthogonal directions. The following formulas were used to calculate various dimensional changes in accordance with Dinwoodie (1965).

For radial variation (percent),

$$\text{Rt} = \frac{\text{rt} - \text{ro}}{\text{ro}} \times 100 \quad (2)$$

where Rt is the radial shrinkage, ro is the initial radial dimension, and rt is the final radial dimension.

For tangential variation (percent),

$$\text{Tt} = \frac{\text{tt} - \text{to}}{\text{to}} \times 100 \quad (3)$$

where Tt is the tangential variation, to is the initial tangential thickness, and tt is the final tangential thickness at the moment of measurement.

For longitudinal variation (percent),

$$\text{Lt} = \frac{\text{tt} - \text{lo}}{\text{lo}} \times 100 \quad (4)$$

where Lt is the longitudinal variation, lo is the initial longitudinal dimension, and tt is the final longitudinal dimension.

For volumetric variation,

$$\text{Vs} = \text{Vr} + \text{Vt} \quad (5)$$

where Vs is volumetric shrinkage, Vr is shrinkage in the radial direction, and Vt is shrinkage in the tangential direction.

The volumetric shrinkage was calculated from the data obtained from the shrinkage determination. Volumetric shrinkage (%) was calculated from the summation of radial and tangential shrinkage as stated by Kollmann and Cote (1968) and Dinwoodie (1965):

Mechanical properties.—The mechanical properties tested in this study included the modulus of rupture (MOR), modulus of elasticity (MOE), maximum compressive strength parallel to grain (MCS), maximum shear strength parallel to grain (MSS), and impact bending strength (IBS) using a computer-controlled electronic universal testing machine (WDW-50, Jinan Hensgrand Instrument Co., Ltd., Jinan, China) for the mechanical-properties determination using a three-point bending test method at a loading rate of 20 mm/min as shown in Figure 3.

Determination of MOR and MOE.—Panshin and DeZeeuw (1980) described MOR as the magnitude of the load required to cause failure in bending stresses. This test required clear samples of dimensions $20 \times 20 \times 300$ mm. The MOR (N/mm^2) was calculated using the equation below:

Figure 3.—Computerized universal testing machine.

$$\text{MOR} = \frac{3\text{PL}}{2\text{bd}^2} \quad (6)$$

where P is the load at some point below the proportional limit (N), L is the distance between supports for the beam (mm), b is the beam width (mm), and d is the thickness (depth) of the beam (mm).

MOE (N/mm^2) is a measure of the resistance to bending, or stiffness of a beam or other wood member. Pansin and Sezeeuw (1980) describe it as the ability of a material to regain its original shape and size after being stressed. Desch (1988) stated that the ability of a wood member to bend freely and regain normal shape is called flexibility while the ability to resist bending is called stiffness. This was calculated using the following equation:

$$\text{MOE} = \frac{\text{PL}^3}{4\text{bd}^3\Delta} \quad (7)$$

where P is the load at some point below the proportional limit (N), L is the distance between supports for the beam (mm), b is the beam width (mm), d is the thickness (depth) of the beam (mm), and Δ is deflection.

Determination of MCS parallel to the grain.—MCS (N/mm^2) is the ability of a material to resist a crushing force or stress applied to the body. The test of compressive strength parallel to the grain was carried out using wood samples of 20 $\times$ 20 $\times$ 60 mm. The values obtained were used to calculate the compressive strength using the equation below:

$$\text{MCS} = \frac{P}{\text{bd}} \tag{8}$$

where b is board width (mm), d is board depth (mm), and P is the load (N).

Determination of IBS (impact work).—IBS is the ability of wood samples to resist a load that was suddenly applied and is one of the criteria for measuring toughness (Desch, 1988). Impact bending is generally or widely used as an indication of the toughness of the wood material. This test was carried out using a sample of 20 $\times$ 20 $\times$ 300 mm. The maximum distance of the hammer drop was read and recorded directly from the impact bending machine in meters and the work done during this process was also determined and recorded. The impact work was calculated using the equation below:

$$\text{IBS} = \frac{W}{A} = \frac{\text{F} \times \text{d}}{\text{b} \times \text{w}} \tag{9}$$

where IBS is impact work (N/mm^2), W (Nm) is work done, A (mm) is the area of the samples, F (N) is the weight of the hammer, d (mm) is the distance of the hammer drop, b (mm) is the width of the sample (mm), and w is the depth of sample (mm).

Determination of MSS parallel to the grain.—MSS (N/mm^2) is the ability of the wood to resist internal slipping between adjacent fibers along the grain. Samples of 20 $\times$ 20 $\times$ 20 mm were used and tested parallel to the grain. The MSS parallel to grain was calculated using the equation below:

$$\text{Shear} = \frac{P}{\text{bd}} \tag{10}$$

where P is the load (N), b is the sample width (mm), and d is the sample depth (mm).

Statistical analysis

An analysis of variance (ANOVA) was conducted using IBM SPSS software, version 20.0 (Armonk, NY, USA). All statistical analyses were conducted as a factorial experiment in a completely randomized design via a one-way ANOVA to determine significant differences among treatment means. Separation of treatment means was carried out using Duncan multiple-range tests. This was completed to know the differences between means and to choose the best treatment combination from the factors considered.

Results and Discussion

Age

As per Table 1, the estimated ages for the three stands of *Lonchocarpus sericeus* were 28, 29, and 32 years. At this age range, the wood was considered to be mature timber with good wood quality. Wood maturity enhances the complete formation of all the wood properties (Adejoba and Onilude 2010). Age is one of the most important factors that affect and determine wood properties. Mature trees generally perform better than juvenile trees. The merchantable heights ranged from 8.32 to 9.71 m, which indicated that three to four logs could be obtained from the standing trees, making them suitable to produce a good number of logs. Also, the diameter ranged from 1.59 to 1.92 m. Hence, the species could potentially produce a large number of planks. The total height of *L. sericeus* ranged from 12.26 to 15.90 m.

Table 1.—Mean values for age determination of Lonchocarpus sericeus.

Tree no.	Age estimation (yr)	Merchantable height (m)	Diameter (m)	Total height (m)
1	32	9.71	1.92	14.72
2	28	8.32	1.72	12.26
3	29	8.95	1.59	15.90

Density

The average mean density of *Lonchocarpus sericeus* wood was 836.63 kg/m^3 as shown in Table 2. According to the Food and Agriculture Organization of the United Nations (FAO 1985), the timber should be graded hard, intermediate, or soft, corresponding to high, medium, and low densities. These technical limits determine the grades: high density is above 500 kg/m^3, medium density is between 500 and 350 kg/m^3, and low density is less than 350kg/m^3. Furthermore, only high-density timbers are allowed for structural purposes. These values showed that *Lonchocarpus sericeus* wood belongs to the high-density wood category and can be graded as hardwood. Economic wood species such as *Lophira lanceolata, Vitellaria paradoxa, Bridelia ferruginea, Anogeissus leiocarpus, Parkia biglobosa, Gardenia ternifolia, Hymenocardia acida*, *Lophira alata*, *Milicia excelsa*, *Erythropleum* spp., and *Afzelia africana*, etc. are of the same grade as the species under study. The results in Table 2 showed a decrease in wood density of *L. sericeus* from the base to the top along with the sampling height and also a decrease from the inner wood to the outer wood across the radial direction. A decrease in wood density of *L. sericeus* agreed with the findings of Hashemi and Kord (2011) who found that wood density of *Cupressus sempervirens* decreases from the base to the top and also the findings of Harvald and Olesen (1987) on the variation of density within juvenile wood of *Sitka spruce*. The decrease of wood density of *Lonchocarpus sericeus* from the base to the top was also in accordance with the findings of Fuwape and Fabiyi (2003) on the variation of wood density of *Nauclea diderrichii* grown on a plantation. Similar findings were reported by Izekor (2010), Ogunleye (2014), and Ojo (2016) on *Tectona grandis, Ricinodendron heudelotii*, and *Borassus aethiopum* respectively. Akachuku (1982) reported that variation in density within trees occurs as a result of changes in cell size and cell wall thickness that are associated with annual and periodic growth cycles and the increasing age of the cambium. The decrease in wood density axially agrees with the auxin gradient theory

Table 2.—Summary of mean values of selected physical properties of Lonchocarpus sericeus *at 12 percent moisture content.*

Property and radial position	Sampling height			
	Base (10%)	Middle (50%)	Top (90%)	Pooled mean
Density (kg/m^3)				
Inner wood	864.00 ± 53.33	871.67 ± 39.67	823.33 ± 54.02	851.67 ± 49.01 A[a]
Center wood	861.33 ± 41.33	863.67 ± 42.67	783.67 ± 68.23	836.22 ± 50.74 B
Outer wood	854.67 ± 35.67	831.67 ± 59.33	775.67 ± 73.19	820.67 ± 56.06 B
Pooled mean	860.00 ± 43.44 A	855.67 ± 47.22 A	794.22 ± 65.15 B	836.63 ± 51.94
Radial shrinkage (%)				
Inner wood	2.56 ± 0.70	1.92 ± 0.88	2.01 ± 0.94	2.16 ± 0.84 C
Center wood	2.81 ± 0.60	2.56 ± 1.19	2.20 ± 1.03	2.53 ± 0.98 B
Outer wood	3.31 ± 1.67	2.64 ± 0.94	2.47 ± 0.95	2.81 ± 1.26 A
Pooled mean	2.89 ± 1.12 A	2.37 ± 1.04 B	2.23 ± 0.94 B	2.50 ± 1.07
Tangential shrinkage (%)				
Inner wood	2.98 ± 1.36	3.99 ± 3.00	3.94 ± 1.60	3.64 ± 1.99 B
Center wood	3.38 ± 0.71	4.24 ± 1.49	4.11 ± 2.37	3.91 ± 1.52 B
Outer wood	4.20 ± 1.40	4.60 ± 1.25	4.43 ± 1.60	4.41 ± 1.42 A
Pooled mean	3.52 ± 1.16[b]	4.28 ± 1.91[a]	4.16 ± 1.86[a]	3.99 ± 1.64
Longitudinal shrinkage (%)				
Inner wood	0.58 ± 0.32	0.50 ± 0.35	0.81 ± 0.41	0.62 ± 0.36 B
Center wood	0.72 ± 0.31	0.71 ± 0.20	0.93 ± 0.41	0.79 ± 0.31 B
Outer wood	0.78 ± 0.38	0.91 ± 0.35	1.08 ± 0.30	0.92 ± 0.34 A
Pooled mean	0.69 ± 0.34 B	0.71 ± 0.30 B	0.94 ± 0.37 A	0.78 ± 0.34
Volumetric shrinkage (%)				
Inner wood	4.98 ± 1.38	5.86 ± 1.60	5.59 ± 1.26	5.48 ± 1.41 C
Center wood	5.49 ± 1.67	6.59 ± 1.39	6.92 ± 1.84	6.33 ± 1.63 B
Outer wood	6.47 ± 1.28	7.24 ± 1.35	8.14 ± 2.63	7.28 ± 1.75 A
Pooled mean	5.65 ± 1.44 C	6.56 ± 1.45 B	6.88 ± 1.91 A	6.36 ± 1.60

[a] Means with the same letter within each column and row are not significant ($P < 0.05$).

(Larson 1973). The theory states that endogenous auxin arising in the apical regions of growing shoots stimulates cambial division and xylem differentiation and the formation of juvenile wood. Hence, the high production of early wood towards the tree crown results in low density. The increase in density of *L. sericeus* wood from the outer wood to the inner wood or core wood was in accordance with the findings of Adedeji (2016) on *Borassus*. The decrease in wood density of *L. sericeus* from the inner wood to the outer wood negates the findings of Ogunsanwo (2000) on *Triplochiton scleroxylon*, Izekor and Fuwape (2011) on *Tectona grandis*, Ogunleye (2014) on *Ricinodendron heudelotii*, and Adedeji (2016) on *Borassus aethiopum*.

Radial shrinkage

Radial shrinkage decreased from the base (10%) through the middle (50%) to the top (90%) and increased from the inner wood to the outer wood as shown in Table 2. This pattern of variation was in line with Ogunsanwo (2000), Aguda (2007), Adejoba (2008b), and Izekor (2010) on *Triplochiton scleroxylon, Terminalia superba, Ficus mucuso,* and *Tectona grandis* respectively. The increase in radial shrinkage of *L. sericeus* wood from the inner wood through the center wood and to the outer wood was also reported by Ogunsanwo (2000) on *Triplochiton scleroxylon* and this negated the report of Ojo (2016) on *Borassus aethiopum*. The ANOVA in Table 4 showed that there were significant differences in radial shrinkage among the tree stands, sampling height, and the radial position (5% level of significance). Similarly, the interaction of tree stands and sapling height was also significant. However, the interaction of the tree stands, radial position, sampling height, and radial position and interaction among the tree stand, sampling height, and radial position were not significantly different.

Tangential shrinkage

The percentage of tangential shrinkage was 3.99 percent. Ogunsanwo and Ojo (2011) obtained 3.84 percent for *Borassus aethiopum*. Poku et al. (2001) recorded 4.4, 6.8, and 4.0 percent for *Alstonia boonei, Petersianthus macrocarpus*, and *Ricinodendrron heudelotii* respectively; Izekor (2010) recorded 7.24, 5.04, and 2.89 percent for 15-, 20-, and 25-year-old *Tectona grandis*, respectively. The percentage tangential shrinkage of *L. sericeus* wood increases from the base to the middle and decreases to the top, which showed no consistent pattern of variation. Radially, tangential shrinkage gradually increases from the inner wood to the outer wood. The inconsistent pattern of variation observed axially for tangential shrinkage of *L. sericeus* wood was in accordance with Lausberg et al. (1995), and Adejoba (2008) on *Pseudotsuga menziesii,* and *Ficus mucuso* respectively. Poku et al. (2001) also recorded a similar pattern of variation in *Petersianthus macrocarpus* from Ghana. They concluded that the inner wood shrinks less than the outer wood as a result of a greater amount of extractives in the inner wood. Ogunsanwo (2000) stated that the suitability of wood for end use has been linked with the ratio of tangential/radial shrinkage. The low value of tangential/radial shrinkage is synonymous with high suitability of wood for end uses (Panshin and DeZeeuw, 1980). The tangential/radial shrinkage ratio of 1.60 for *L. sericeus* indicates its suitability for use.

Longitudinal shrinkage

The longitudinal shrinkage of *Lonchocarpus sericeus* wood was 0.78 percent. The mean value of longitudinal shrinkage of *L. sericeus* wood increased from the base to the top and also increased from the inner wood to the outer wood. This consistent pattern of variation is in accordance with the findings of Ali (2011) on *Ncurri, Ntholo,* and *Metil* which are lesser-known wood species from Mozambique.

Volumetric shrinkage

The volumetric shrinkage was 6.36 percent. The mean increased along with the sampling height from the base to the top and also increased across the radial sampling direction from the inner wood to the outer wood as shown in Table 2. This pattern of variation of *L. sericeus* wood is in accordance with the report of Koubaa et al. (1998), Ogunsanwo (2000), Mottonen and Luostarinen (2006), Seralde (2006), Adejoba (2008), Izekor (2010), and Ojo (2016). Their studies revealed that inner wood shrinks less than the outer wood and they all concluded that this may be due to the presence of extractives in the inner wood region which tend to inhibit normal shrinkage by bulking of the amorphous regions in the cell wall.

Impact bending strength

The IBS of *Lonchocarpus sericeus* wood was 24.14 N/mm^2. This decreases from the base to the top along with the sampling height and decreases from the inner wood to the center wood across the radial sampling direction as shown in Table 3. This pattern of variation in *L. sericeus* along the sampling height agrees with the findings of Ogunsanwo (2000), Adedipe (2004), Aguda et al. (2012, 2015), Adejoba et al. (2016), and Ojo (2016) on *Triplochiton scleroxylon*, *Gmelina arborea*, *Chrysophyllum albidum*, *Staudtia stipitata*, *Elaeis guineensis*, and *Borassus aethiopum*, respectively. This finding is contrary to the reports of Ajala (2005) on *Aningeria robusta* which showed an inconsistent pattern of variation. Adejoba (2008) also reported the same value of IBS at the base, middle, and top on *Ficus mucuso* and Aguda et al. (2014) on *Funtumia elastica*. The decrease in the IBS of both species from the inner wood to the outer wood is in line with the report of Aguda et al. (2012) on *Chrysophyllum albidum*, Aguda et al. (2015) on *Staudtia stipitata*, and Ojo (2016) on *Borassus aethiopum*. The decrease in IBS of *L. sericeus* negates the reports of Ogunsanwo (2000) on *Triplochiton scleroxylon*, Adedipe (2004) on *Gmelina arborea*, Adejoba (2008) on *Ficus mucuso*, Aguda et al. (2014) on *Funtumia elastica*, Adejoba et al. (2016) on *Elaeis guineensis*. Green et al. (1999) concluded this pattern of variation is as a result of the fact that wood is a natural material and the tree is subjected to many changing influences, hence wood properties vary considerably.

Modulus of rupture

The MOR obtained for *Lonchocarpus sericeus* wood was 114.18 N/mm^2. Forest Product Research Laboratory (1966) recorded a mean value of 83.3 N/mm^2 for *Milicia excelsa*, 76.3 N/mm^2 for *Mitragyna* spp., 95.5 N/mm^2 for *Khaya senegalensis*, and 39.9 N/mm^2 for *Antiaris africana*. Izekor (2010) recorded mean values of 76.86, 103.95, and 134.69 N/mm^2 for 15-, 20-, and 25-year-old *Tectona grandis* wood, respectively. Aguda et al. (2012) recorded 154.3 N/mm^2 for *Staudtia stipitata* and Adejoba et al. (2016) reported 66.33 N/mm^2 for *Elaeis guineensis*. The MOR values obtained for *L. sericeus* compare well with the economic species already used for structural applications. The MOR of *L. sericeus* decreases from the base to the top along with the sampling height and also decreases from the inner wood to the outer wood. The decrease in MOR from the base to the top for both species is in agreement with the reports of Hughes and Esan (1969) on *Gmelina arborea*, Ogunsanwo (2000) on *Triplochiton scleroxylon*, Fuwape and Fabiyi (2003) on *Nauclea diderrichii*, Adedipe (2004) on *Gmelina arborea*, Adejoba (2008) on *Ficus mucuso*, Izekor (2010) on *Tectona grandis*, Aguda et al. (2014) on *Funtumia elastica*, Adejoba et al. (2016) on *Elaeis guineensis*, and Ojo (2016) on *Borassus aethiopum*. The decrease in MOR from the base to the top differs from the reports of Aguda et al. (2012) on *Chrysophyllum albidum* and Aguda et al. (2015) on *Staudtia stipitata*. The decrease in MOR of both species from the inner wood to the outer wood in this study disagrees with Ogunsanwo (2000) on *Triplochiton scleroxylon*, Fuwape and Fabiyi (2003) on *Nauclea diderrichii*, Adedipe (2004) on *Gmelina arborea*, Adejoba (2008) on *Ficus mucuso*, Izekor (2010) on *Tectona grandis*, Aguda et al. (2014) on *Funtumia elastica*, Adejoba et al. (2016) on *Elaeis guineensis*, and Ojo (2016) on *Borassus aethiopum*. The decrease in the MOR from the inner wood to the outer wood may be as a result of vessel distribution and the diameter of vessels within the wood, the diameter of vessels of the inner wood are smaller and closely compacted than the vessels in the outer wood. Also, the outer part of the wood contains primarily sapwood which is less dense when compared with the inner wood, which is mostly heartwood.

Modulus of elasticity

The MOE obtained for *Lonchocarpus sericeus* was 11,276 N/mm^2. The MOE decreases from the base top the top and also decreases from the inner wood to the outer wood as shown in Table 3. The decrease in MOE from the base to the top recorded for *L. sericeus* wood is in line with the findings of Ogunsanwo (2000) on *Triplochiton scleroxylon*; Fuwape and Fabiyi (2003) on *Nauclea diderrichii*; Adedipe (2004) on *Gmelina arborea*; Adejoba (2008) on *Ficus mucuso,* Izekor (2010) on *Tectona grandis*; Aguda et al. (2012, 2014, 2015) on *Chrysophyllum albidum*, *Funtumia elastica,* and *Staudtia stipitata*; Adejoba et al. (2016) on *Elaeis guineensis*; and Ojo (2016) on *Borassus aethiopu*m. The decreases in MOE from the inner wood to the outer wood vary with the reports of Ogunsanwo (2000) on *Triplochiton scleroxylon*; Fuwape and Fabiyi (2003) on *Nauclea diderrichii*; Adedipe (2004) on *Gmelina arborea*; Adejoba (2008) on *Ficus mucuso*; Izekor (2010) on *Tectona grandis*; Aguda et al. (2012, 2014, 2015) on *Chrysophyllum albidum*, *Funtumia elastica,* and *Staudtia stipitata*; Adejoba et al. (2016) on *Elaeis guineensis*; and Ojo (2016) on *Borassus aethiopum*. This may be as a result of vessel distribution and diameter within the wood; the diameter of the vessels at the inner wood are smaller and more closely compacted than the vessel at the outer wood. It can also be as a result of cell wall thickness and number which also determine the density of any lignocellulosic material.

Table 3.—*Summary of mean values of selected mechanical properties of* Lonchocarpus sericeus.

Property and radial position	Sampling height Base (10%)	Middle (50%)	Top (90%)	Pooled mean
Impact bending (N/mm^2)				
Inner wood	33.50 ± 6.29	29.70 ± 6.22	22.42 ± 8.53	28.54 ± 8.35 A[a]
Center wood	28.04 ± 8.02	23.83 ± 5.07	20.04 ± 8.24	23.97 ± 7.82 B
Outer wood	23.69 ± 6.43	20.99 ± 5.97	15.06 ± 5.64	19.92 ± 6.92 C
Pooled mean	28.41 ± 7.92 A	24.84 ± 6.73 B	19.17 ± 8.03 C	24.14 ± 8.44
Modulus of rupture (N/mm^2)				
Inner wood	143.18 ± 26.61	125.63 ± 25.64	109.47 ± 24.81	126.09 ± 28.71 A
Center wood	127.65 ± 26.52	117.23 ± 25.44	100.35 ± 26.80	115.08 ± 28.07 B
Outer wood	122.55 ± 30.48	96.34 ± 23.37	85.28 ± 32.70	101.39 ± 32.55 C
Pooled mean	131.13 ± 28.70 A	113.06 ±27.27 B	98.36 ± 29.44 C	114.18 ± 31.31
Modulus of elasticity (N/mm^2)				
Inner wood	13,062 ± 4,015	13,210 ± 5,732	11,191 ± 3,453	12,488 ± 4,499 A
Center wood	12,566 ± 4,742	11,270 ± 3,070	9,744 ± 2,415	11,193 ± 3,656 B
Outer wood	11,671 ± 4,063	10,117 ± 3,122	8,651 ± 3,524	10,146 ± 3,723 C
Pooled mean	12,433 ± 4,228 A	11,533 ± 4,269 B	9,862 ± 3,272 C	11,276 ± 4,063
Maximum shear strength (N/mm^2)				
Inner wood	16.07 ± 0.90	13.78 ± 2.65	11.67 ± 1.26	13.84 ± 2.51 A
Center wood	14.50 ± 1.24	12.67 ± 1.23	11.12 ± 0.78	12.76 ± 1.77 B
Outer wood	13.32 ± 0.54	11.72 ± 0.97	10.02 ± 1.05	11.68 ± 1.61 C
Pooled mean	14.63 ± 1.46 A	12.72 ± 1.93 B	10.93 ± 1.24 C	12.76 ± 2.17
Maximum compression strength parallel to grain (N/mm^2)				
Inner wood	51.75 ± 2.17	49.67 ± 2.49	47.02 ± 4.28	49.48 ± 3.62 A
Center wood	49.80 ± 2.82	48.17 ± 4.13	43.82 ± 4.53	47.27 ± 4.58 B
Outer wood	47.21 ± 2.76	44.62 ± 4.90	42.35 ± 6.01	44.73 ± 5.06 C
Pooled mean	49.59 ± 3.16 A	47.49 ± 4.43 B	44.40 ± 5.27 C	47.16 ± 4.84

[a] Means with the same letter within each column and row are not significant ($P < 0.05$).

Maximum shear strength parallel to grain

The MSS parallel to the grain of *Lonchocarpus sericeus* wood was 12.76 N/mm^2. The shear strength decreases from the base to the top along with the sampling height and also decreases from the inner wood to the outer wood across the radial sampling direction. The decrease in the MSS parallel to the grain from the base to the top and also from the inner wood to the outer wood conforms with the findings of Ogunsanwo (2000) on *Triplochiton scleroxylon*, Fuwape and Fabiyi (2003) on *Nauclea diderrichii*, Adedipe (2004) on *Gmelina arborea*, Adejoba (2008) on *Ficus mucuso*, and Aguda et al. (2014, 2015) on *Funtumia elastica* and *Staudtia stipitata*. The decrease in the MSS parallel to the grain from the inner wood to the outer wood for *Lonchocarpus sericeus* is in line with the findings Fuwape and Fabiyi (2003) on *Nauclea diderrichii,* Adejoba (2008b) on *Ficus mucuso*, and Aguda et al. (2014, 2015) on *Funtumia elastica* and *Staudtia stipitata*. This pattern of variation across the radial sampling direction disagrees with the reports of Ogunsanwo (2000) on *Triplochiton scleroxylon*, Adedipe (2004) on *Gmelina arborea*, and Adejoba (2008) on *Ficus mucuso*. The ANOVA in Table 4 shows that there were significant differences among the tree stands, sampling height, and the radial position at the 5 percent probability level. Similarly, there were significant differences in the interaction between the tree stands and the sampling height, tree stands, and the radial position, and also among the tree stands, sampling height, and the radial position at the 5 percent probability level.

Maximum compression strength parallel to grain

The MCS parallel to the grain was 47.16 N/mm^2. The MCS strength parallel to the grain of *Lonchocarpus sericeus* wood decreases from the base to the top along the sampling height and decreases from the inner wood to the outer wood across the radial sampling positions. EPRL (1966) recorded 16.94 N/mm^2 for *Haematostaphis barteri*, 30.45 N/mm^2 for *Afzelia africana*, and 34.44 N/mm^2 for *Daniellia oliveri*; Akira (1978) reported 16 N/mm^2 for a *Borassus aethiopum* sample in Ghana; Adejoba (2008) reported 13.7 N/mm^2 for *Ficus mucuso*; Izekor (2010) reported 43.74, 58.47, and 75.36 N/mm^2 for 15, 20, and 25 year-old *Tectona grandis*; and Aguda et al. (2012, 2014, 2015) recorded 45.55, 20.41, and 45.87 N/mm^2 for *Chrysophyllum albidum*, *Funtumia elastica*, and *Staudtia stipitata*, respectively. This shows that the values obtained from this study are in line with range values obtained for economic wood species that are already popular in structural applications. The decrease in MCS parallel to the grain from the base to the top recorded for *L. sericeus* wood is in line with the findings of Ogunsanwo (2000) on *Triplochiton scleroxylon*; Fuwape and Fabiyi (2003) on *Nauclea diderrichii*; Adedipe (2004) on *Gmelina arborea*; Adejoba (2008) on *Ficus mucuso*; Izekor (2010) on *Tectona grandis*; Aguda et al. (2012, 2014, 2015) on *Chrysophyllum albidum*, *Funtumia elastica* and *Staudtia stipitata*; Adejoba et al. (2016) on *Elaeis guineensis*; and Ojo (2016) on *Borassus aethiopum*. The decrease in MCS parallel to the grain from the inner wood to the outer wood

Table 4.—Analysis of variance for density, radial shrinkage, tangential shrinkage, longitudinal shrinkage, volumetric shrinkage, impact bending strength, modulus of rupture, modulus of elasticity, maximum shear strength parallel to grain, and maximum compressive strength parallel to grain.

Source of variation[a]	df	Sum of squares	Mean squares	F
D				
Trees	2	5,948.20	2,974.10	0.95*
SH	2	121,661.47	60,830.73	19.36*
RP	2	23,279.10	11,639.55	3.70*
Trees × SH	4	17,324.72	4,331.18	1.38*
Trees × RP	4	18,863.87	4,715.97	1.50
SH × RP	4	10,114.32	2,528.58	0.80
Trees × SH × RP	8	12,221.14	1,527.64	0.49
Error	108	339,390.76	3,142.51	
Total	134	548,803.58		
RS				
Trees	2	38.68	19.34	23.23*
SH	2	11.10	5.55	6.67*
RP	2	9.50	4.75	5.71*
Trees × SH	4	1.92	0.50	0.58
Trees × RP	4	0.45	0.11	0.14
SH × RP	4	1.30	0.32	0.39
Trees × SH × RP	8	0.32	0.04	0.05
Error	108	89.91	0.83	
Total	134	153.18		
TS				
Trees	2	2.02	1.01	0.41
SH	2	18.97	9.49	3.82*
RP	2	19.83	9.92	3.99*
Trees × SH	4	31.48	7.87	3.17*
Trees × RP	4	1.50	0.38	0.15
SH × RP	4	0.69	0.17	0.07
Trees × SH × RP	8	10.64	1.33	0.54
Error	108	268.23	2.48	
Total	134	353.37		
LS				
Trees	2	0.43	0.21	1.59*
SH	2	1.74	0.87	6.48*
RP	2	1.95	0.97	7.25*
Trees × SH	4	0.93	0.23	1.73
Trees × RP	4	0.15	0.04	0.29
SH × RP	4	0.20	0.05	0.37
Trees × SH × RP	8	0.21	0.03	0.20
Error	108	14.49	0.13	
Total	134	20.09		
VS				
Trees	2	28.39	14.20	4.66*
SH	2	50.51	25.25	8.29*
RP	2	55.18	27.59	9.06*
Trees × SH	4	31.72	7.93	2.60*
Trees × RP	4	0.77	0.19	0.06
SH × RP	4	1.38	0.35	0.11
Trees × SH × RP	8	11.77	1.47	0.48*
Error	108	329.06	3.05	
Total	134	508.77		
IBS				
Trees	2	2,561.47	1,280.73	50.33*
SH	2	1,954.19	977.09	38.40*
RP	2	1,676.00	838.00	32.93*
Trees × SH	4	297.48	74.37	2.92*
Trees × RP	4	120.73	30.18	1.19

Table 4.—Continued.

Source of variation[a]	df	Sum of squares	Mean squares	F
SH × RP	4	63.44	15.86	0.62
Trees × SH × RP	8	120.89	15.11	0.59
Error	108	2,748.26	25.45	
Total	134	9,542.46		
MOR				
Trees	2	47,727.03	23,863.51	60.55*
SH	2	24,234.82	12,117.41	30.75*
RP	2	13,781.72	6,890.86	17.49*
Trees × SH	4	1,125.12	281.28	0.71
Trees × RP	4	214.41	53.60	0.14
SH × RP	4	981.31	245.33	0.62
Trees × SH × RP	8	694.61	86.83	0.22
Error	108	42,563.99	394.11	
Total	134	131,323.09		
MOE				
Trees	2	2,024,148.40	1,012,074.20	0.06
SH	2	1.53	7.66	4.77*
RP	2	1.24	6.19	3.86*
Trees × SH	4	7.06	1.77	1.10
Trees × RP	4	7.13	1.78	1.11
SH × RP	4	1.31	3,276,366.29	0.20
Trees × SH × RP	8	4.57	5,717,962.26	0.36
Error	108	1.73	1.60	
Total	134	2.21		
MSS				
Trees	2	72.76	36.38	93.55*
SH	2	307.20	153.60	394.98*
RP	2	104.54	52.27	134.41*
Trees × SH	4	36.69	9.17	23.59*
Trees × RP	4	42.76	10.69	27.49*
SH × RP	4	5.82	1.46	3.74*
Trees × SH × RP	8	21.09	2.64	6.78*
Error	108	42.00	0.39	
Total	134	632.86		
MCS				
Trees	2	266.15	133.08	9.13*
SH	2	613.52	306.76	21.04*
RP	2	509.69	254.85	17.49*
Trees × SH	4	76.93	19.23	1.32
Trees × RP	4	25.42	6.36	0.44
SH × RP	4	19.32	4.83	0.33
Trees × SH × RP	8	52.31	6.54	0.45
Error	108	1,574.34	14.58	
Total	134	3,137.68		

[a] D = density, RS = radial shrinkage, SH = sampling height, RP = radial position, TS = tangential shrinkage, LS = longitudinal shrinkage, VS = volumetric shrinkage, IBS = impact bending strength, MOR = modulus of rupture, MOE = modulus of elasticity, MSS = maximum shear strength parallel to grain, MCS = maximum compressive strength parallel to grain.
* Significant at 5% probability level.

disagrees with the reports of Ogunsanwo (2000) on *Triplochiton scleroxylon*; Fuwape and Fabiyi (2003) on *Nauclea diderrichii*; Adedipe (2004) on *Gmelina arborea*; Adejoba (2008) on *Ficus mucuso*; Izekor (2010) on *Tectona grandis*; Aguda et al. (2012, 2014, 2015) on *Chrysophyllum albidum*, *Funtumia elastica*, and *Staudtia stipitata*; Adejoba et al. (2016) on *Elaeis guineensis*; and Ojo (2016) on *Borassus aethiopum*.

Conclusions

This research work has provided fundamental information on the physical and mechanical properties of *Lonchocarpus sericeus*, which is a lesser-used wood species found in Nigeria.

The density of *L. sericeus* was 836.63 kg/m^3 and it can be regarded as a high/very heavy density wood based on the classification of Brandon (2005).

The density of this species decreases from the base to the top and also decreases from the inner wood to the outer wood. The variation in wood density along and across the sampling direction does not affect its use, though, based on the pattern of variation, heavier and better wood would be acquired at the base and from the inner wood s. Based on the density results obtained for this species, it can be used for heavy construction, furniture making, and panel products, but the suitability of it in the pulp and paper industry is not guaranteed based on its high density, since the preferred range for wood density in pulp and paper industry is between 400 and 600 kg/m^3.

The radial, tangential, and volumetric shrinkage increases from the base to the top and also increases from the inner wood to the outer wood. The shrinkage values obtained indicate that *L. sericeus* is dimensionally stable.

The IBS, MOR, MOE, MSS parallel to the grain, and MCS parallel to the grain of *L. sericeus* all decrease from the base to the top and also decrease from the inner wood to the outer wood. Comparison of the strength values obtained with other economic tree species shows that *L. sericeus* compares well with *Albizia zygia, Anogeissus leiocarpus, Afrormosia laxiflora, Distemonanthus benthamianus, Piptadeniastrum africanum, Nesogordonia papaverifera, Guarea cedrata, Mansonia altissima*, with strength values higher than *Milicia excelsa, Gmelina arborea, Khaya ivorensis, Triplochiton scleroxylon, Terminalia ivorensis* and lower than *Celtis zenkeri, Lophira alata, Scottellia coriacea, Cylicodiscus gabunensis, Nauclea diderrichii*, and *Sterculia oblonga*. This shows that any part of the wood of *L. sericeus* can be used for heavy construction, structural work, and furniture. *Lonchocarpus sericeus* can serve as a substitute for other commercially important species that are already endangered.

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