EFFECT OF GROWTH RING WIDTH AND FIBER DIMENSIONS ON THE COMPRESSIVE STRENGTH OF SOME MEMBERS OF THE MORACEAE FAMILY

G. C. Ajuziogu

Senior Lecturer
E-mail: godswill.ajuziogu@unn.edu.ng

C. C. Onyeke

Senior Lecturer
E-mail: christopher.onyeke@unn.edu.ng

*E. O. Ojua**

Research Student
E-mail: eugene.ojua.pg78127@unn.edu.ng

A. N. Amujiri

Lecturer
E-mail: angela.amujiri@unn.edu.ng

C. C. Ibeawuchi

Research Student
Department of Plant Science and Biotechnology
University of Nigeria, Nsukka
Enugu State, Nigeria
E-mail: chiamakaibeawuchi231@gmail.com

(Received April 2019)

Abstract. Investigations were carried out on the effect of growth ring width, fiber morphometrics, and wood type on the compressive strength of three members of the Moraceae family namely: *Milicia excelsa*, *Treculia africana*, and *Antiaris toxicaria*. Fiber diameter (D), fiber length (L), fiber lumen diameter (l), cell wall thickness (c), derived fiber values, and growth ring width were measured and correlated with compressive strength. Results obtained revealed significant relationships: negative between growth ring width and compression strength and positive between wood type and compression strength at $p = 0.05$ and $p < 0.01$ levels. *A. Toxicaria* had the highest compression strength which differed significantly ($p = 0.05$) when compared with *T. africana* and *M. excelsa*. On the other hand, *T. africana* was observed to have the smallest growth ring width and shorter fibers. It is evident from the results that species with narrower growth ring widths have higher compression strength, although some factors other than this, which may depend on the wood type, could equally influence the compression strength positively.

Keywords: Compression strength, coefficient of flexibility, Runkel ratio, slenderness ratio, morphometrics, wood maceration.

INTRODUCTION

Wood has evolved over a period of millions of years to meet the mechanical and physiological needs of the tree. Doubtless, wood has been the most remarkable structural material on earth throughout history and has maintained the first position as the most important renewable natural resource available to man (Redhead 1971). The unique physical characteristics and engineering properties associated with timber (wood) have made it a constructional material of diverse

* Corresponding author

Wood and Fiber Science, 51(4), 2019, pp. 416-423
https://doi.org/10.22382/wfs-2019-039

applications. Evolutionary wise, trees have attained great diversity: it is estimated that there are about 20,000 forms of trees that potentially yield various grades of timber (Evert 2006). Although those of commercial importance are few, they however, exhibit a range of anatomical, chemical, mechanical, and physical properties that make them useful for a specific purpose (Ali 2011).

Growth ring is a layer of wood formed in a tree during a single period of growth. Growth rings are visible as concentric circles of varying width when trees are cut transversely (Hoadley 2000). They represent layers of cells produced by the vascular cambium. Most growth rings reflect a full year's growth and are called annual rings, but abrupt changes in the environment, especially in the availability of water, can cause a plant to produce more than one growth ring in a year (Cutler et al 2007). Annual ring is also another name for growth ring when its formation is in line with seasons of the year. The earliest rings are proximal to the center of the stem, although the most recent is distal to the center and adjacent to the vascular cambium. The rings are evident because of the periodic (commonly seasonal) activity of the cambium and a more or less sharp boundary between wood produced during slowing down of cambial activity (latewood) and that deposited after cambial reactivation (early wood). Growth ring latewood lies outside early wood. The age of the woody stem could be determined by counting the growth rings. The cells of the early wood (also called springwood) are generally larger in diameter, but thinner in wall substance than those of latewood (summer wood). The width of the growth ring and the relative amount of early and latewood are largely dependent on the prevailing environmental conditions during their formation. Adverse growth conditions tend to decrease ring width primarily because of the decrease in early wood formation (Briffa and White 2008).

The cambial activity is influenced by some factors which could be internal or external (Barnet 1981). These internal and external factors are intertwined in their nature. Some of the external factors include temperature, photoperiod, moisture availability, etc. These factors influence the state of activity of the terminal and branch buds of the shoot. These external factors are not constant. Under favorable conditions, they cause the buds to open or flush, whereas under unfavorable conditions, they cause the buds to close or become dormant (Roberts 1982). Also, under favorable conditions, the buds of the shoots open, resulting in the growth of the apical meristems. This triggers off the synthesis of auxin and other growth regulators. Auxins produced at the shoot migrate downward, and on reaching the dormant cambium, activates it to start dividing. This alternation of favorable and unfavorable conditions brings about periodicity in the cambial activity. This is often reflected in the number of growth layers or rings of the wood (Amobi 1973). The internal factors that influence the cambial activity are the plant hormones. According to Roberts (1982), there are five "classical" groups of plant hormones. These include auxins, cytokinins, gibberellins, abscisic acid, and ethylene. The ideas about their functions have evolved from numerous experiments in which applications of the hormones have been shown to affect cell division in the vascular cambium, cell expansion, and control of differentiation into different types of cambial derivatives (Mellerowiez et al 2001). In the present work, an attempt has been made to show the effect of growth ring width and fiber morphometrics on the compression strength of three tropical hardwood species (*Milicia excelsa*, *Treculia africana*, and *Antiaris toxicaria*).

MATERIALS AND METHODS

Three timber species selected were *M. excelsa* (Welw.) Cl Berg., a well-known strong commercial timber, *A. toxicaria* Lesch., a nondurable species whose major application is in making formers for concrete casting in building constructions, and *T. africana* Decne., a large tree with furrowed trunk, planted mainly for its fruit but found its way into the Nigerian timber industry because of over logging and high prize of the popular timbers.

The wood samples of *M. excelsa*, *T. africana*, and *A. toxicaria* were supplied by the Forestry Department of Enugu, Nigeria. Preliminary identification of the samples was made following the guidelines of Titmuss and Richards (1971), Anon (1974), Jane (1962), Desch and Dinwoodie (1981), and Keay et al (1964). A confirmatory identification of the samples was made through the microscopic studies of their sections. The features observed were compared with those given by Titmuss and Richards (1971) and Desch and Dinwoodie (1981). Ajuziogu et al (2012) separated 17 hardwood timber species using wood microstructure.

Wood maceration was performed using 5% $KClO_3$ solution in concentrated nitric acid as described by Jane (1962). In this method, chips of wood about the size of half a matchstick from each of the test samples were placed differently in long test tubes labeled with the names of the various test samples. Two specimens of each sample were used and placed in separate test tubes. The test tubes were secured in test tube racks. Two grams of 5% $KClO_3$ crystals were added to each of the test tubes. This was followed by addition of 10 ml of concentrated nitric acid (conc. HNO_3), with the test tubes held in a slanting position. The setup was allowed to react in a fume cupboard until the chips were softened and bleached. $KClO_3$, being a strong oxidizing agent, causes an instant reaction with the nitric acid to effect maceration.

After maceration, excess solutions were decanted from the test tubes, and the soft and bleached chips were washed several times in distilled water to wash off the corrosive substances. The softened chips were then separately transferred into well-labeled specimen bottles—two bottles (A and B) for each sample. Two drops of phenol and glycerin were added into the bottles. The phenol protects the fibers from fungal decay, whereas the glycerin removes air bubbles from the bottles. The chips in the bottles were shaken with glass beads. This helps the fibers to tease out and fall apart. The fibers were then stained with brilliant crystal blue and safranin in bottles A and B, respectively, for each of the wood samples. The stained fibers and vessels were mounted on slides in 30% glycerin and covered with cover slips. This was examined microscopically using the ordinary light microscope. The fiber dimensions were measured using a Kyowa (Tokyo, Japan) monocular microscope to which an ocular micrometer was fitted. The ocular micrometer was calibrated using a stage micrometer of 2 mm range. Fifteen specimens were measured for each of the three timber species. The dimensions measured were as follows:

1. Fiber length (L)
2. Fiber diameter (D)
3. Fiber lumen diameter (l)
4. Fiber cell wall thickness (C)

From the dimensions observed, derived values were calculated using various formulas as follows:

1. Runkel ratio $(\mathrm{RR}) = 2C/l$
2. Coefficient of flexibility $(\mathrm{CF}) = l/D$
3. Slenderness ratio $(\mathrm{SR}) = L/D$

The various fiber morphometrics, the derived values, and growth ring widths of the timber species were analyzed and then compared with their compression strengths. The aim was to determine the effects of these parameters on the compression strengths of the plant species.

The compression strength test was based on the British Standard BS 373 (1957), which is currently used in most international timber research centers. The samples were cut using a BOSCH JIGSAW machine (model GST 85 PBE 580W, Germany). Fifteen small specimens were cut to the dimension 60 × 20 × 20 mm from the heartwood portion of each of the three timber species. The test samples were brought to a constant weight by storing them under controlled temperature and humidity conditions of 23°C and 66% RH, respectively. The samples were tested to know the maximum compressive strength (in N/mm^2) using a Hounsfield tensometer. These were indicated by the tensometer when the mercury meniscus

Table 1. Analysis of variance mean squares of compression strengths, fiber morphometrics, and growth ring width.

Traits	Mean square	*F*
CS (N/mm^2)	394.23	35.67[a]
GRW (mm)	0.04	4.46[c]
L (mm)	0.00	4.38[c]
D (mm)	0.01	1.51[c]
l (mm)	0.00	6.44[NS]
C (mm)	0.40	6.06[b]
RR	327,208.74	1.00[NS]
SR	77.91	3.47[c]
CF	0.06	123.89[NS]

NS, not significant; CS, compression strength; GRW, growth ring width; *L*, fiber length; *D*, fiber diameter; *l*, fiber lumen diameter; *C*, fiber cell wall thickness; RR, fiber Runkel ratio; SR, fiber slenderness ratio; CF, fiber coefficient of flexibility.
[a] Mean square significant at $p < 0.001$.
[b] Mean square significant at $p < 0.01$.
[c] Mean square significant at the 0.05 level.

drops sharply to deviate from the initial constant rising under continuous loading condition. Fifteen growth ring width measurements were made using a pair of dividers and a meter rule.

The data generated were subjected to a one-way analysis of variance (ANOVA) using IBM Statistical Package for Social Sciences (SPSS version 23, Armonk, NY) to test for significant difference between plant species. Significant means ($p < 0.05$) were then separated using the Duncan's new multiple range test. Correlation analysis was also carried out between the compression strength, growth ring width, plant species, and fiber morphometrics.

RESULTS

The result as presented in Table 1 shows that significant difference exists in compression strength, growth ring, fiber length, diameter, and slenderness ratio (SR) of the three wood species used at varied probability levels. The relationships between the growth ring width, fiber morphometrics (dimensions), and compression strengths of the wood species are shown in the correlation matrix in Table 2.

Graphical comparisons in Figs 1-3 show great variability in compression strengths, growth ring widths, and fiber lengths in the wood of the three species, respectively. Also, Fig 4 shows the photograph of a wood with a visible growth ring marks. Table 2 shows the mean values of fiber morphometrics. Figure 5 shows a scatter diagram giving the line of best fit in comparing compression strength with growth ring width.

A highly significant negative correlation exists between compression strengths and growth ring widths of the tree species. Although negative correlations exist between compression strength and the fiber morphometrics: fiber length, fiber diameter, and coefficient of flexibility, these relationships were not significant. Also, nonsignificant positive correlations exist between compression strengths, cell wall thickness, and slenderness ratio.

A significant positive correlation exists between the fiber lumen diameter and growth ring width,

Table 2. Correlation matrix showing the relationship between growth ring width, compression strengths, and fiber morphometrics.

	CS	*L*	*D*	*l*	*C*	RR	CF	SR	GR	WT
CS	1									
L	−0.129	1								
D	−0.029	0.188	1							
L	−0.138	0.236	0.131	1						
C	0.162	0.037	0.011	0.005	1					
RR	0.135	−0.160	−0.017	−0.232	0.161	1				
CF	−0.026	0.051	−0.255	0.191	−0.205	−0.492[a]	1			
SR	0.073	0.434[a]	−0.619[a]	−0.204	−0.044	0.076	0.065	1		
GR	−0.664[a]	0.281	−0.102	0.341[a]	−0.136	−0.347[b]	0.231	0.108	1	
WT	0.505[a]	−0.064	−0.394[a]	−0.145	−0.247	−0.113	0.308[b]	0.287	−0.267	1

CS, compression strength; *L*, fiber length; *D*, fiber diameter; *l*, fiber lumen diameter; *C*, fiber cell wall thickness; RR, fiber Runkel ratio; SR, fiber slenderness ratio; CF, fiber coefficient of flexibility; GR, growth ring width; WT, wood type.
[a] Correlation is significant at the 0.01 level (2-tailed).
[b] Correlation is significant at the 0.05 level (2-tailed).

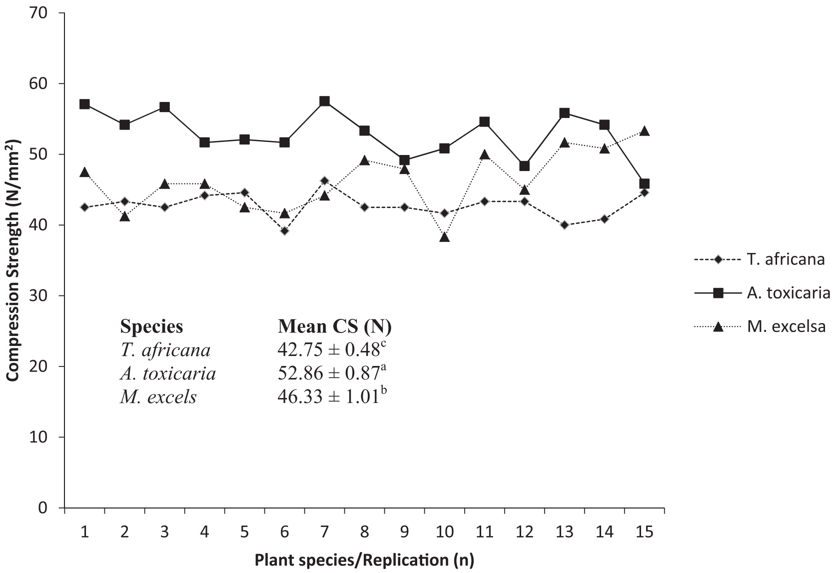

Figure 1. Variability in compression strengths among the plant species studied. Means with different alphabet represent significant differences ($p = 0.05$) using Duncan's new multiple range test.

although the relationship between the Runkel ratio (RR) and growth ring width was negatively significant. Positive correlations exist between growth ring width and fiber length, coefficient of flexibility and slenderness ratio, but these relationships were not significant. In the same vein, nonsignificant correlations exist between growth ring width, fiber diameter, and fiber cell wall thickness (Table 2).

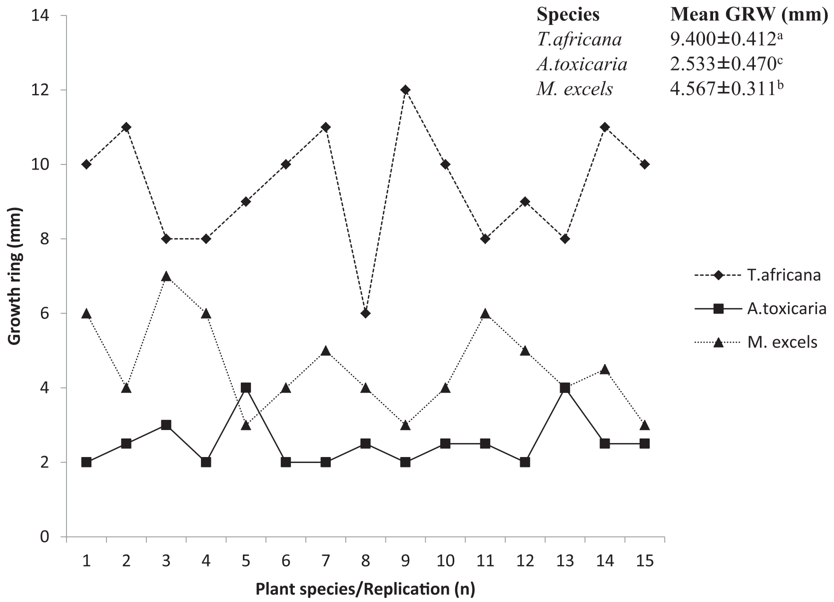

Figure 2. Variability in growth ring width among the plant species studied. Means with different alphabet represent significant differences ($p = 0.05$) using Duncan's new multiple range test.

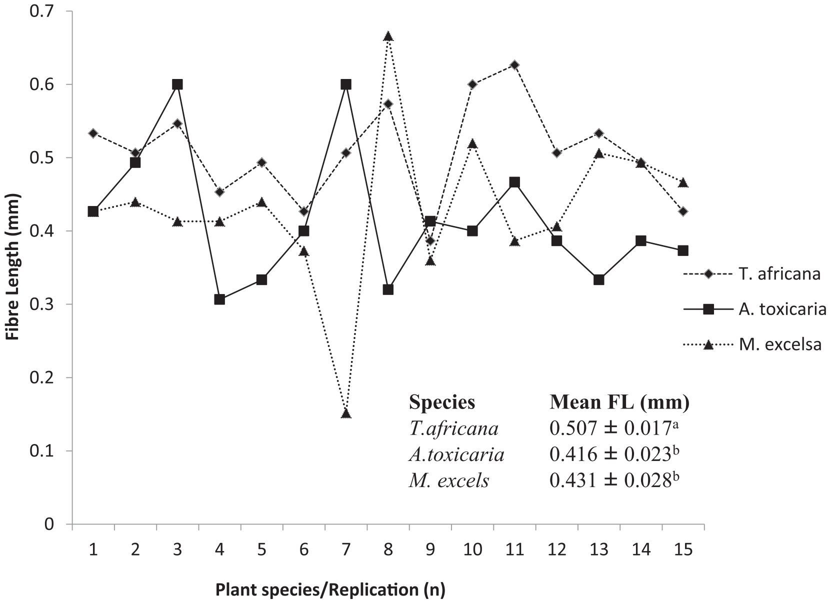

Figure 3. Variability in fiber lengths among the plant species studied. Means with different alphabet represent significant differences ($p = 0.05$) using Duncan's new multiple range test.

A. toxicaria had significantly ($p < 0.05$) the highest compression strength as compared with *T. africana* and *M. excels* (Fig 1). On the other hand, *A. toxicaria* was observed to have smaller growth ring (Fig 2) and shorter fibers (Fig 3). In comparison, *T. africana* that had significantly the longest fiber and widest growth ring tend to possess lower compression strength. They ranged from 0.024 to 0.043 mm across the three species, with *T. africana* having the widest fiber. The range of 0.359-0.675, 14.220-18.557, and 0.503-0.699 were recorded for Runkel ratio, coefficient of flexibility and slenderness ratio, respectively (Table 3).

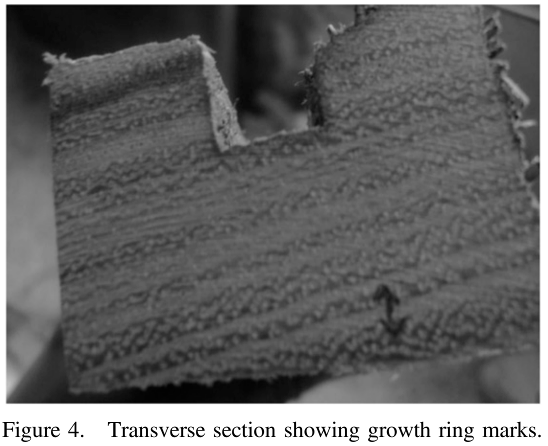

Figure 4. Transverse section showing growth ring marks.

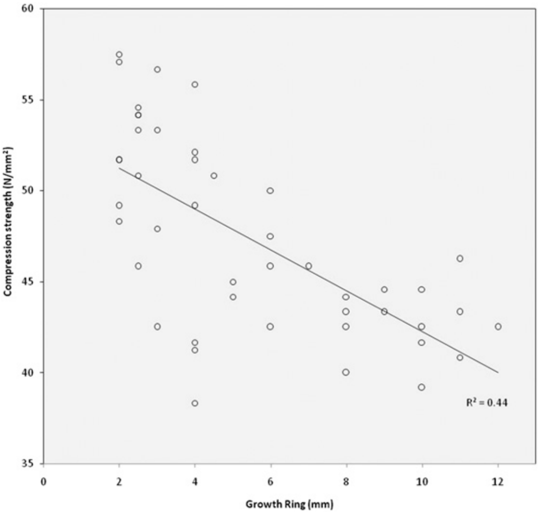

Figure 5. Scatter diagram showing the line of best fit for compression force against growth ring width.

Table 3. Mean values of the parameters measured.

Species	*Treculia africana*	*Antiaris toxicaria*	*Milicia excelsa*
D (mm)	0.043 ± 0.008^{a}	0.028 ± 0.001^{b}	0.024 ± 0.001^{b}
l (mm)	0.017 ± 0.002^{a}	0.020 ± 0.001^{a}	0.015 ± 0.001^{a}
C (mm)	0.007 ± 0.002^{a}	0.003 ± 0.000^{b}	0.004 ± 0.000^{ab}
RR	0.675 ± 0.099^{a}	0.359 ± 0.025^{b}	0.597 ± 0.054^{a}
SR	14.220 ± 1.441^{b}	18.557 ± 0.990^{a}	17.695 ± 1.192^{ab}
CF	0.503 ± 0.060^{a}	0.699 ± 0.011^{a}	0.625 ± 0.022^{a}

Means with different alphabet on each horizontal array represent significant differences ($p = 0.05$) using Duncan' s new multiple range test (DNMRT). D, fiber diameter; *l*, fiber lumen diameter; *C*, fiber cell wall thickness; RR, fiber Runkel ratio; SR, fiber slenderness ratio; CF, fiber coefficient of flexibility.

DISCUSSION

In the present work, the anatomical characteristics of the species showed variations in fiber length; fiber diameter; fiber lumen diameter; fiber cell wall thickness; and in the derived fiber values, such as RR, SR, and CF. Variations occurred also among the species in their compression strength. This conforms to the report of Wilson and White (1986), who informed that no two pieces of wood, even if cut from the same tree, are exactly alike.

The correlation analysis showed that the wider the growth ring width, the lower the compression strength. According to Esau (1965) and Plomion et al (2000), the activities of the vascular cambium is more vigorous during the favorable seasons, spring and summer, resulting in xylem with wider radial cell diameter with a corresponding thin wall. These cells are shorter in length and low in density. These contrast with the xylem cells of the late summer and autumn wood, whose cells have a narrower diameter, thicker wall, and higher density. In Nigeria, where these species grow, there are no well spelt seasons of the year. According to Amobi (1973), this is responsible for the great variability in the size and nature of the growth rings. *A. toxicaria* with the lowest mean growth ring width of 2.533 ± 0.470 mm had correspondingly the highest compression strength of 52.86 ± 0.87 N/mm^2. *T. africana* with the highest mean growth ring width of 9.400 ± 0.412 mm gave the lowest compression strength of 42.75 ± 0.48 N/mm^2.

Datta and Basu (1983) reported that fiber wall volume and mean thickness of the individual fiber wall had a rough relation to strength. Some factors such as temperature and photoperiods affect the activities of the vascular cambium. These factors again are well defined in the temperate region but not so in the tropics (Amobi 1973; Uggla et al 2001). This contributes immensely to the great variability in the nature and size of growth rings in the species studied.

In conclusion, the size of the growth ring width seems inversely proportional to the compression strengths for these tree species. Although the fiber morphometrics showed some relationships with compression strength, these were not significant. *T. africana* and *M. excelsa*, with relatively wide growth ring widths, had low compression strengths; therefore, they should be avoided in construction works, where they will be exposed to high compression loads.

REFERENCES

Ajuziogu GC, Uju GC, Nzekwe U (2012) Identification of timbers using wood microstructures. Asian J Res Chem 5(3): 433-437.

Ali AC (2011) Physical–mechanical properties and natural durability of lesser used wood species from Mozambique. Doctoral thesis, Swedish University of Agricultural Sciences, Uppsala, Sweden. 60 pp.

Amobi CC (1973) Periodicity of wood formation in some trees of lowland rainforest in Nigeria. Ann Bot 37:211-218.

Anon (1974) African encyclopaedia for schools and colleges. Oxford University Press, England, UK. 55 pp.

Barnett JR (1981) Xylem cell development. Castel House Publication Ltd., England, UK. 307 pp.

Briffa KR, Shishov VV, Melvin TM, Vaganov EA, Grudd H, Hantemirov RM, Eronen M, Naurzbaev MM (2008) Trends in recent temperature and radial tree growth spanning 2000 years across northwest Eurasia. Philos Trans R Soc Lond B Biol Sci 363(1501):2271-2284.

Cutler DF, Botha T, Stevenson DW (2007) Plant anatomy an applied approach. Blackwell Publishing, Malden, MA. 302 pp.

Datta PC, Basu B (1983) Strength elements of wood structure and their biochemical control. Int Assoc Wood Anatomists 4(1):5-6 (Abstract).

Desch HE, Dinwoodie JM (1981) Timber, its structure and properties, 6^{th} edition. Macmillian Education, London, UK. 410 pp.

Esau, K (1965) Plant Anatomy, 2nd Edition. John Wiley, New York, NY. 550 pp.

Evert RF (2006) Esau's plant anatomy, 3nd edition. John Wiley and Sons, Inc., Hoboken, NJ. 601 pp.

Hoadley RB (2000) Understanding wood: A craftsman's guide to wood technology, 2nd edition. Taunton Press, London, UK. 215 pp.

Jane FW (1962) The structure of wood, 2nd edition. Revised by K Wilson and DJB White. Adam Charles Black. 427 pp.

Keay RWJ, Onochie CFA, Standfield DP (1964) Nigerian treesvol. II. Federal Department of Forest Research, Ibadan, Nigeria. 495 pp.

Mellerowiez EJ, Baucher M, Sundberg B, Boerjan W (2001) Unravelling cell wall formation in the woody dicot stem. Plant Mol Biol 47:239-274.

Plomion C, Pinnoeau C, Brach J, Costa P, Bailleries H (2000) Compression wood responsive protein in the development of xylem of maritime pine (*Pinus pinaster* Ait). Plant Physiol 123:959-969.

Redhead JF (1971) The timber resources of Nigeria. The Nigerian J Forestry 1:7-11.

Roberts MBV (1982) Biology-A functional approach, 3rd edition. Cengage Learning, Australia. 655 pp.

Titmuss FH, Richards CH (1971) Commercial timbers of the world, 4th edition. CRC Press, Cleveland, OH. 351 pp.

Tsoumis G (1991) Science and technology of wood structure, property, utilization. Chapman and Hall, London, UK. 494 pp.

Uggla C, Magel E, Moritz T, Sundberg B (2001) Function and dynamics of auxin and carbohydrates during earlywood/latewood transition in Scots pine. Plant Physiol 125:2029-2039.

Wilson K, White DJB (1986) The anatomy of wood: Its diversity and variability. Stobart and Sons Ltd., London, UK. 309 pp.