International Journal of Applied and Natural Sciences (IJANS)
ISSN(P): 2319-4014; ISSN(E): 2319-4022
Vol. 3, Issue 2, Mar 2014, 97-106

International Academy of Science, Engineering and Technology
Connecting Researchers; Nurturing Innovations

DIMENSIONAL VARIATION IN FIBRES OF *GMELINA ARBOREA* ROXB (VERBANACEAE) ALONG AND ACROSS THE STEM

AJUZIOGU, G. C[1], ONYEKE, C. C[2], ABAIYAGUA, S. T[3], NZEKWE, U[4] & ONYEONAGU, C. C[5]

[1,2,3,4]Department of Plant Science and Biotechnology, University of Nigeria, Nsukka, Nigeria

[5]Department of Crop Science, University of Nigeria, Nsukka, Nigeria

ABSTRACT

Investigations were carried out on the nature of variations in fibre dimensions on both vertical and horizontal axis of a thirty year old *Gmelina arborea* Roxb tree. Mean values of fibre length (L), fibre diameter (D), fibre lumen diameter (l) and cell wall thickness (C), were determined. Values obtained for fibre length ranged from 0.616 mm to 0.828 mm, fibre diameter from 0.019 mm to 0.022 mm, fibre lumen diameter from 0.014 mm to 0.016 mm, and cell wall thickness ranges from 0.0028 mm to 0.0029 mm .There were no significant differences (P = 0.05) in fibre diameter, fibre lumen diameter, and cell wall thickness along the horizontal and vertical axis of the tree. Fibre length progressively increased significantly (P = 0.05) with increase in the vertical axis, but there was no significant difference in fibre length across the horizontal axis (from pith to the periphery).

KEYWORDS: *Gmelina arborea*, Horizontal and Vertical Variations, Wood Fibre Dimensions

Running Title: Fibre variation in the stem of *Gmelina arborea*

INTRODUCTION

Gmelina arborea Roxb is reported to have originated from the South and Southeast Asia (India, Pakistan and Sri Lanka to Myanmar). It has been widely introduced in Southeast Asian countries including Bangladesh, Thailand, southern China, Vietnam, Indonesia and the Philippines (Jensen 1995). It has been planted less widely in tropical and Latin American countries (Evans 1982). The wood is very useful for planking, panelling, carriages, furniture and carpentry of all kinds (Alam *et al*. 1996). It is easily worked, readily takes paint or varnish, and is very durable under water (Gamble 1922), hence the wood is used for light construction, pulp, fuel wood and charcoal. The wood is the material of popular choice for musical instruments because of its light nature. *G. arborea* (Melina) was introduced in tropical Africa due to the well known silvicultural techniques and wood quality produced by fast growing trees that were managed in short rotation system (Dvorak 2004). The species is considered a multi-purpose, hence the wood is used as raw material for cellulose, including pulp for paper making, pole wood (Moya 2004), particleboard (Chew and Ong 1989), veneer (Sicad 1987) and structural uses (Gonzalez, *et al*. 2004).

Studies of chemical and semi-chemical pulping processes show that *Gmelina* has high yield compared with other hardwoods; it pulps easily and the pulp can be used to manufacture many types of paper and board (Lamb 1968; Ballon *et al*. 1971; Estudillo *et al*. 1972; Palmer 1973; Palmer and Gibbs 1974; Doat 1976). In Nigeria, *Gmelina* plantations have been established on a large scale, to supply raw material to various wood-using industries especially for pulp and paper, panel products, matches, poles and occasionally saw-timber.

The anatomical structure of the secondary xylem (wood) is composed of different types of woody cells (vessels, fibres, radial and axial parenchyma), whose origins are in vascular cambium (Plomion, *et al*. 2001). During their formation, these cells are affected by many factors such as site, ecological conditions, management, genetics, and age of trees growing in plantation conditions (Zobel and Van Buijtenen 1989). The anatomical features are modified within trees during their growth in order to adjust physiologically due water stress, and then to maintain the existence of the species (Baas 1973; Metcalfe, 1989).

Many studies on *G.melina* indicated that the variation in the anatomy of secondary xylem occurred in relation to tree age (Akachuku and Burley 1979; Akachuku 1985; Nobuchi *et al*. 1997), growth conditions (Chowdhury 1947; 1953), growth rate (Esan 1966; Lamb 1968; Ohbayashi and Shiokura 1989), differences in site fertility (Ogbonnaya 1993), and availability of water (Ogbonnaya *et al*. 1992). Based on microscopic examination of two Indian samples, Pearson and Brown (1932) have described in detail *G. arborea*. Other studies have reported the anatomical variations. Chowdhury (1947, 1953) established three different porosities for different climatic conditions: diffuse, annular, and semi-annular. The anatomical elements presented significant variations. Philipson *et al*. (1971), reported that many trees pass through a grand period of growth when the actual rates of extension and radial growth are at maximum.

The fusiform initials laid down during this period are expected to be appreciably longer than those formed during the slower growth phase. Vessels percentage was negatively correlated with latitude, longitude, growth rate and tree height (Akachuku 1985; Akachuku and Burley 1979; Nobuchi, *et al*. 1997). The length and diameter of vessels increased with increased distance from the pith (Ohbayashi and Shiokura 1989), while vessel frequency decreased when pith distance or tree age increased (Frimpong-Mensah, 1992). Frimpong-Mensah (1992) observed that wall thickness was significantly correlated with cambial age. Hughes and Esan (1969) found strong correlations between fibre length and tree age with distance from pith in 9-year old trees in Nigeria. Also in Nigeria, for 7-years old trees, it was found that fibre length was different at four sites (Akachuku and Burley 1979). In contrast, Frimpong-Mensah (1992) reported no variation in fibre length with cambial age in 20-years old *G. arborea* trees in Ghana. Growth rate affects fibre dimension too. Ohbayashi and Shiokura (1989) carried out a study on fibre-length in 15-years old trees and reported that high growth rate was strongly correlated with short fibre length.

Histological variations affecting properties of wood are mainly those of proportion and arrangement of cells. Example, presence or absence of fibre, vessels, and their distribution, the diameter and thickness of the wall of fibre, straightness and abundance of rays etc, plays significant roles in variation of fibre dimensions.

The important dimensional characteristics in determining and predicting behaviour of derived pulps are fibre length, fibre diameter, lumen diameter and cell wall thickness. Clark (1965) observed that thick-walled fibres with relatively small lumen tend to remain rigid in pulps, resulting in stiff paper. The areas for fibre to fibre contact are small, consequently strength, other than resistance to tear may be lacking. On the other hand, fibres with large lumen and thin walls tend to flattened during paper making operations to ribbons with large areas of contact, resulting in good strength development. The thin ribbon-like cross-sections contribute to improved flexibility, however, they also account for losses in resistance to tear.

Pulp woods (woods used in pulping) are usually categorised into two namely: long fibre and short fibre plants, based on the length of the fibres (the ultimate fibres). The long-fibre plants are usually preferred, because they give tear-resistant, strong, and high quality papers. The dimensional characteristics may be determined from transverse and longitudinal sections of plant material (Esau 1977) or from isolated fibres using maceration techniques (Jane 1970). A transformation of some of these dimensions into ratios provides greater information about the fibres and the pulp and paper to be made from them (Ademiluyi and Okeke 1979). The ratios are termed Flexibility Coefficient (FC) = lumen/fibre diameter, Relative fibre length (RFL) = fibre length/fibre diameter, and Runkel Ratio (RR) = 2 x cell wall thickness/lumen diameter. The Flexibility Coefficient determines the tensile strength property of fibre, the higher the coefficient, the more flexible and tensile is the fibre. The relative fibre length is an expression of the slenderness of the fibre; the higher the value, the more slender and tear-resistant is the fibre. Runkel ratio of one (1) or less indicate fibre that are good for paper-making, while fibre with RR value greater than one (1) are poor for paper-making (Ademiluyi and Okeke 1979).

In the present work, the dimensional variations in fibres of *G. arborea* in different heights, and in relation to distance from the pith were assessed to ascertain the part of the tree with the best fibre quality.

MATERIALS AND METHODS

Three transverse discs of about 5cm thick were cut at three heights/levels of 1, 3, and 6 metres along the axial direction of a thirty year old *G. arborea* tree trunk. These are shown in figures 1 to 3. Transradial longitudinal sections were cut out of the three discs from the pith. Thin slivers of wood were obtained at various distances of 2 cm, 6 cm and 10 cm from the pith in each of the three transradial longitudinal sections. These slivers were reduced to the size of match sticks and placed into nine boiling test-tubes labelled 1m-2cm, 1m-6cm, 1 m-10 cm; 3 m-2 cm, 3 m-6 cm, 3 m-10 cm; 6 m-2 cm, 6 m-6 cm, 6 m- 10 cm, respectively.

Two grammes of Potassium Chlorate crystal ($KClO_3$) were added into the respective boiling test-tubes followed by the addition of 10 ml concentrated Nitric acid (HNO_3) and allowed to react in a fume cupboard air till maceration occurred. After the reaction they were removed and washed several times with distilled water to wash off the maceration chemicals.

The washed samples were allowed to stand for about 12 hr to observe for further reaction. Excess water was decanted and the softened bleached fibres were transferred into specimen bottles and labelled properly. The fibres inside the specimen bottles were then stained with two drops of “Safranin” solution which stains the fibres red.

Measurements of fibre dimension were obtained using the light microscope, fitted with a calibrated ocular micrometer. The calibration was achieved by mounting the stage micrometer on the stage of the microscope and aligning its zero-mark with that of the ocular. The number of units of the ocular which aligned with a given unit of the stage micrometer at a given magnification was noted as the conversion factor in the subsequent measurements.

The conversion factors were worked out as follows:

At x 100 magnifications;

70 units of ocular = 0.8 mm of the stage micrometer

$\therefore$ 1 unit of ocular = $\frac{0.8}{70}$

= 0.0114 mm

The conversion factor at x100 = 0.0114 mm

Fibre length measurement was achieved using this magnification.

At x 400 magnifications

50 units of ocular = 0.14 mm of the stage micrometer

$\therefore$ 1 Unit of ocular = $\frac{0.14}{50}$

= 0.0028 mm

The conversion factor at x400 = 0.0028 mm

This magnification was used to measure fibre diameter, fibre lumen diameter and fibre cell wall thickness.

In all, twenty five fibres were measured for each height and transradial–longitudinal section and mean values were calculated.

The dimensions measured include:

- Fibre length (L)
- Fibre diameter (D)
- Fibre lumen diameter (l)
- Fibre cell wall thickness (C)

Twenty five readings were taken in each of the distances from pith and plant heights ten measurements were randomly taken out of the twenty five replications for the means and ANOVA analysis.

The experimental design employed was a 3 x 3 factorial in complete randomised design (CRD). The ANOVA for the various dimensions were obtained using the Gentstat statistical analysis software.

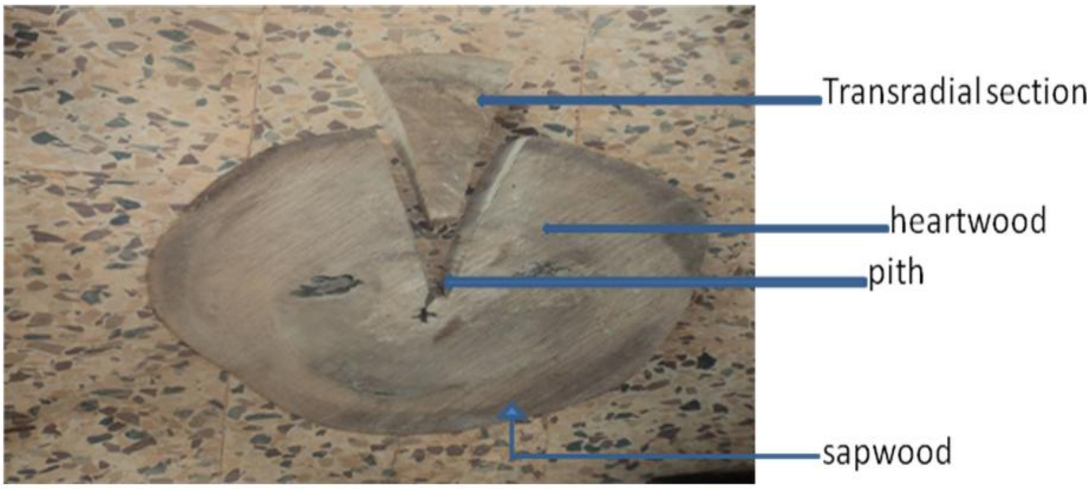

Figure 1: Transverse Disc of *Gmelina* Tree at 1m (Breast Height)

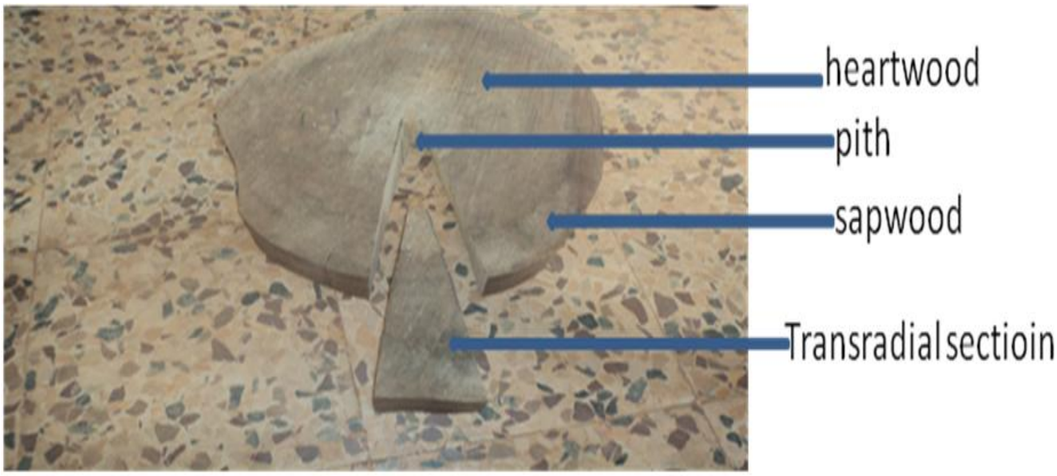

Figure 2: Transverse Disc 5 cm Thick of *Gmelina* Tree at 3m High

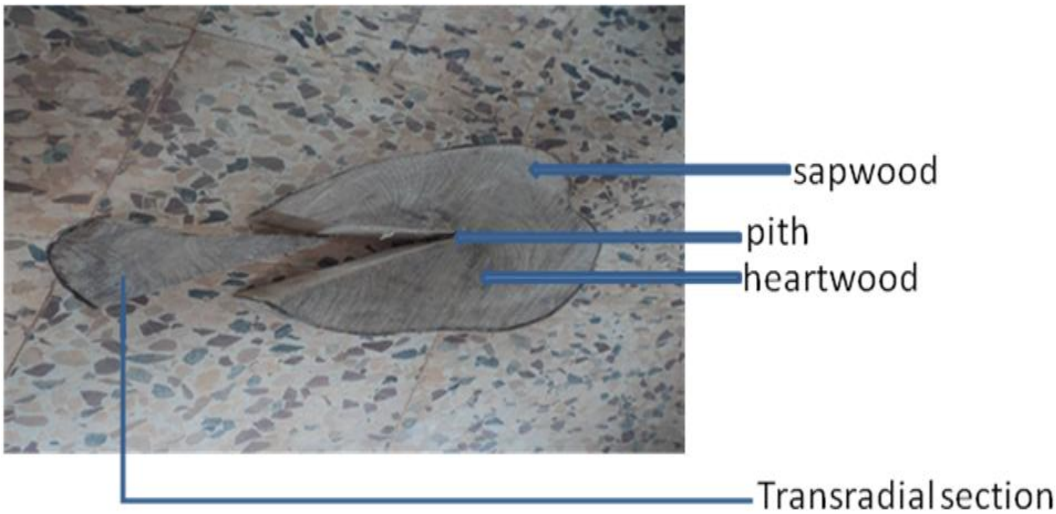

Figure 3: Transverse Disc of *Gmelina* Tree at 6m High

RESULTS

The main effect of distance from pith (DF-PITH) and plant height (PLTHT) on the fibre dimensions are shown in Tables 2, 5. The study shows that there was no significant effect of distance from pith and plant height on fibre diameter (D), lumen diameter (l), and cell wall thickness (C).

Plant fibre length progressively increased significantly (P= 0.05) with incremental increase in plant height (Table 2). There was no significant difference in fibre length across the horizontal axis of the plant. The interaction between plant height and distance from the pith showed no significant effect on the fibre length.

Table 1: Means for Fibre Dimensions in Relation to Distance from Pith and Plant Height

Fibre Dimension	Fibre Length L			Fibre Diameter D			Lumen Diameter L			Cell Wall Thickness C		
Distance from pith (cm)	2	6	10	2	6	10	2	6	10	2	6	10
Means (mm)	0.689	0.710	0.766	0.0197	0.0221	0.0204	0.0147	0.0166	0.0145	0.0029	0.0028	0.0029
Plant heights (m)	1	3	6	1	3	6	1	3	6	1	3	6
Means (mm)	0.616	0.721	0.828	0.0216	0.0214	0.0193	0.0159	0.0156	0.014	0.0029	0.0028	0.0028

Table 2: Main Effect of Distance from (DF-PITH) and Plant Height (PLTHT) on Fibre Lenght (L)

	Plant Height (M)			
Distance from Pith (cm)	**1**	**3**	**6**	**Mean**
2	0.565	0.693	0.808	0.689
6	0.646	0.708	0.776	0.710
10	0.637	0.760	0.899	0.766
MEAN	**0.616**	**0.721**	**0.828**	**0.722**

LSD (0.05) for 2 DF-PITH means (P) = ns
LSD (0.05) for 2 PLTHT means (H) = sig.
LSD (0.05) for 2 P×H means = ns

Table 3: Main Effect of Distance from Pith (DF-PITH) and Plant Height (PLTHT) on Fibre Diameter (D)

	Plant Height (M)			
Distance from Pith (cm)	**1**	**3**	**6**	**Mean**
2	0.01960	0.02156	0.01788	0.01968
6	0.02324	0.02256	0.02044	0.02208
10	0.02184	0.02002	0.01946	0.2044
MEAN	**0.02156**	**0.02138**	**0.01926**	**0.02073**

LSD (0.05) for 2 DF-PITH means (P) = ns
LSD (0.05) for 2 PLTHT means (H) = ns
LSD (0.05) for 2 P×H means = ns

Table 4: Main Effect of Distance from Pith (DF-PITH) and Plant Height (PLTHT) on Lumen Diameter (L)

	Plant Height (M)			
Distance from Pith (cm)	**1**	**3**	**6**	**Mean**
2	0.01400	0.01610	0.01400	0.01470
6	0.01972	0.01694	0.01484	0.01657
10	0.01596	0.01372	0.01372	0.01447
MEAN	**0.01596**	**0.01559**	**0.01419**	**0.01524**

LSD (0.05) for 2 DF-PITH means (P) = ns
LSD (0.05) for 2 PLTHT means (H) = ns
LSD (0.05) for 2 PXH means = ns

Table 5: Main Effect of Distance from Pith (DF-PITH) and Plant Height (PLTHT) on Cell Wall Thickness (C)

	Plant Height (M)			
Distance from Pith (cm)	**1**	**3**	**6**	**Mean**
2	0.003080	0.002800	0.002800	0.002893
6	0.002940	0.002800	0.002800	0.002847
10	0.002940	0.002940	0.002800	0.002893
MEAN	**0.002987**	**0.002847**	**0.002800**	**0.002878**

LSD (0.05) for 2 DF-PITH means (P) = ns
LSD (0.05) for 2 PLTHT means (H) = ns
LSD (0.05) for 2 P×H means = ns

DISCUSSIONS

In the four parameters studied (fibre length (L), fibre diameter (D), lumen diameter (l), and cell wall thickness (C)), along the vertical and horizontal axis, there was a significance difference in fibre length along the vertical axis (P = 0.05), while no significant difference was observed across the horizontal axis. The other three parameters showed no significant differences in both the horizontal and vertical axis at (P = 0.05).

The mean fibre lengths of the *G. arborea* studied in relation to distance from pith and plant height as presented in Table 1, were found to be short, being in the range; 0.689 – 0.766 mm. The other dimensions are 0.0197 – 0.0221 mm for fibre diameter and 0.0145 – 0.0166 mm for lumen diameter. Cell wall thickness was found to be 0.0028 – 0.0029 mm in relation to distance from the pith. Means of fibre dimensions in relation to plant height showed that fibre length had mean value, 0.166 – 0.828 mm that is, increasing from 1m at breast height to 6 m height. Fibre diameter had 0.0193 – 0.0216 mm, and lumen diameter has 0.014 – 0.0159 mm, while cell wall thickness has 0.0028 – 0.0029 mm.

The main effect of the study which is the distance from pith with plant height showed no significant effect on fibre diameter, lumen diameter, and cell wall thickness. However, plant height has significant effect on fibre length. There is the general trend of fibre length increasing from base up the trunk. Fibres of greater lengths are recorded at distance of 10 cm from pith at 6 m of plant height (Table 1). Fibre lengths ranged from 0.5770 – 1.1172 mm and a mean of 0.828 mm. This is in conformity with one of Sanio's laws as reported by Bailey and Shepard (1915) that fibre length increases from base to about one-third of stem height.

Fibres above 1.60mm in length are classified as long (Metcalfe and Chalk 1983). In similar observation, Anon (1951) reported that the average length of fibres in hardwoods is only 1mm, and in coniferous wood, about 3 mm. Results obtained from the measurements of fibre dimensions and their derived values have been used in making some inferences on timbers studied with regards to their suitability for pulp and paper making. Fibres with short lengths are considered not suitable for paper making (Chittenden and Rotibi 1970). In a similar report, Ademiluyi and Okeke (1979) indicated that as far as the fibres of wood are concerned, the longer the fibre the higher the tear resistance of the paper produced from them. This observation implied that papers produced from fibres of short lengths are likely to have low tear resistance. Ademiluyi and Okeke (1979) also reported that the collapsibility and the inter-fibre bonding qualities of fibres in papermaking are also dependent on the fibre lumen diameter. The wider the lumen diameter, the better the fibre for paper making, the significance of the various fibre dimensions in paper making is based more on the derived values than the absolute dimensions. A transformation of these dimensions into ratios provides greater information about the fibres and the pulp and paper to be made from them (Ademiluyi and Okeke 1979; Kpikpi and Olatunji 1990).

The derived values (Runkel ratio, coefficient of Flexibility and slenderness ratios) were not however considered in this study due to their well established values in *Gmelina arborea* as suitable for pulp and paper making. This was reported by (Uju and Obot 1990). Coefficient of flexibility (ratio of lumen to fibre diameter is 0.83± 0.006). This ratio is of importance in detecting suitability of wood for pulping. Slenderness ratio or relative fibre length values ranges from (43.91 ± 0.719), it is important in detecting tear property of pulp in paper production. Runkel ration expressed by the formula (2 x cell wall thickness/lumen diameter), is 0.21±0.009. Runkel ratio determines the suitability of fibre for paper production. For good paper characteristics this ratio will be equal or less than 1. For *G. arborea* it has been established to conform to these derived values for being suitable for paper making.

The study shows that *G. arborea* has short fibre lengths. However, the short fibre length of *G. arborea* can be improved by mixing with pulp of long fibre length to get a quality paper.

Although, wood fibre length has long been acknowledged as a factor for consideration in pulp and papermaking, Kpikpi and Olatunji (1990), were of the opinion that fibre morphology studies alone are inadequate for anatomical appraisal of a hardwood for paper making. They however advised that the knowledge of the entire wood structure is necessary because of certain tissues like parenchyma and vessel when in excessively large quantities, influence the paper making process and quality. Thus descriptions of the wood anatomy and various tissue proportions of the wood by volume should be considered. Vessels are of important not only for their primary roles but also for impregnation of wood with chemicals for preservation and pulping. Philipson, *el al.* (1971) noted that many trees pass through a grand period of growth when the actual rates of extension and radial growth are at maximum. The fusi form initials laid down during this period are expected to be appreciably longer than those formed during the slower growth phase. Thus occurrence of the elements at a particular level of the stem height could be partly due to the relative growth rate. The decrease of cell length towards the crown may be due to core defect such as genetic variability, sites, management, and ecological factors.

CONCLUSIONS

In conclusion, the study has shown that distance from pith has no effect on fibre dimensions. However, there was a significant effect of plant height on fibre length. Fibre length increases with height, with long fibre length at height of 6 m along and across the radius of stem. As reported by Philipson, *et al*. (1971); many trees pass through a grand period of growth when the actual rates of extension and radial growth are at maximum. The fusiform initials laid down during this period are expected to be appreciably longer than those formed during the slower growth phase. Thus occurrence of elements at a particular level of stem height could be partly due to the relative growth rate. Although the fibres at that height are still considered short (1.117 mm) as against 1.6 mm for long fibres, it could be improved by adding fibres of coniferous wood to give good quality paper.

REFERENCES

1. Ademiluyi EO and Okeke RE (1979). Studies on specific gravity and fibre Characteristics of *Gmelina arborea* in some Nigerian plantations. *Nigerian J. Sci.* **13**: 231 – 238.
2. Akachukwu AE (1985). Intra-annual variation in wood density in *Gmelina arborea* from X-ray densitometry and its relations with rainfall. *Tree Ring Bull.* **45** 43 – 55.
3. Akachukwu AE, and Burley J. (1979). Variation of wood anatomy of *Gmelina arborea* Roxb, in Nigerian plantations. *IAWA Bull.* **4** 94 -99.
4. Alam M K, Siddiqi NA and Das S (1996). Fodder trees of Bangladesh (Chittagong: Bangladesh Forest Research Institute).
5. Anon. (1951). The dictionary of paper. (New York: American paper and pulp Association).
6. Baas P (1973).The wood anatomical range in (Aqui-foliaceae) and its ecological and phylogenetic significance. *Blumea* **2** 193 – 258.
7. Bailey IW and Shepard HB (1915). Sanio’s Law for the variation in size of coniferous tracheids. *Bot. Gaz.* **60** 66 – 77.
8. Ballon CH, Escalano JO, Villanueva EP, Tadena OB, Visperas RV and Estudillo CP (1971). Prospects of Gmelina arborea for pulp and printing paper. *Philippine Forestry* **5** 23 – 15.
9. Chew LT and Ong CI (1989). Urea-formaldehyde particle board from Yamane (*Gmelina arborea*). J. Trop. Sci. **1**(1) 26 – 34.
10. Chowdhury KA (1953). Initial parenchyma cells in dicotyledons. *Nature* **160** 609.

11. Clark TF (1965). Plant Fibres in the Paper Industry. *Econ. Bot.* **9** 394 – 405.
12. Chittenden AE and Rotibi J O (1970). Studies on the suitability of nigerian raw materials for pulp making. *Gmelina arborea*. *Research Report* **17**.
13. Doat J (1976). The papermaking characteristics of a reforestation species: *Gmelina arborea*. *Bios for Trop.* **168** 47 – 63.
14. Dvorak WS (2004). Worldview of *Gmelina arborea*: Opportunities and Challenges. *New Forestry* **28(2-3)** 111-126.
15. Esan RF (1966). Study of variation in some structural features and properties of Gmelina arborea Roxb. PhD. Thesis, University of Oxford, England.
16. Esau K (1977). *Anatomy of seed plants* (New York: John Wiley).
17. Estudillo CP, Visperas RV, Ballon CH, Tadena OB and Villanueva EP (1972). Sulphate pulping studies on Yamane (*Gmelina arborea* Roxb). *Philippine Lumberm* **18 (14)** 18 – 23.
18. Evans J (1982). *Plantation Forestry in the Tropics*. (Oxford: Claredon Press).
19. Frimpong – Mensah K (1992). Wood quality variation in the tree of some endemic species, p.25 -26. *In Association pour la Reserche sur le bois en Larraine & International Union of Forestry Research Organization (eds). Working Session* ***Vol. 1****. All Division 5 Conference "Forest Products*", Nancy France.
20. Gamble JS (1922). *A Manual of Indian Timbers*: an account of the structure, growth, distribution, and qualities of Indian woods. Bibliobazaar.
21. Gonzalez G, Moya R, Nonge F, Cordoba R, Coto JC (2004). Evaluating the strength of finger-jointed lumber of *Gmelina arborea* in Costa Rica. *New Forestry* **28(2-3)** 319 – 323.
22. Jensen, M. (1995). Trees commonly cultivated in Southeast Asia; Illustrated field guide. (Bangkok*: RAP Publication*).
23. Kpikpi W M and Olatunji AO (1990). Wood Anatomy Consideration in Deciding the Suitability of Some Nigerian Hardwoods for Pulp and Paper Production. *Nigerian J. Bot.* **3** 137 – 150.
24. Lamb AFA (1968). Fast growing timber trees of the lowland tropics No. 1: *Gmelina arborea*. (Oxford*: University of Oxford and Commonwealth Forestry Institute*).
25. Metcalfe CR and Chalk L (1983). *Anatomy of the Dicotyledons Vol. II.* (Oxford: Oxford University Press).
26. Metcalfe CR (1989). Ecological anatomy and morphology general survey; *In Anatomy of the dicotyledons*. *Wood structural and conclusion of the general introduction*. (eds.) C R Metcalfe and L Chalk (England: Oxford Science) pp.126 – 152.
27. Moya, R. (2004). Wood of *Gmelina arborea* in Costa Rica. *New Forestry* **28** 299 – 307.
28. Nobuchi, T.C.K. and Fujita, M. (1997). Radial variation of vessel and fibre dimensions in some plantation grown tropical trees as it related to wood qualities, *In* International Tropical Wood "New Tropical Timber Crops:

Challenges in Processing and Utilization”. *Faculty of Forestry, University of Putra Malaysia*, Kuala Lumpar, Malaysia.

29. Ohbayashi, H. and Shiokura, T. (1989). Anatomical structure of fast-growing tropical species with differing growth rates. *IAWA Bull.* **10** 342 – 343.
30. Ogbonnaya, C.I., Nwalozie, M.C. and Nwaigro, L.C. (1992). Growth and wood properties of *Gmelina arborea* (Verbenaceae) seedlings grown under five soil moisture regimes. *American J. Bot.* **79** 128 – 132.
31. Ogbonnaya, C. I. (1993). Effects of nitrogen sources on the wood properties of *Gmelina arborea* relevant to pulp and paper production. *Forestry Ecol. Mgt.* **56** 211 – 223.
32. Palmer, E.R. (1973). *Gmelina arborea* as a potential source of hardwood pulp. *Trop. Sci*. **15** 243 – 260.
33. Palmer, E.R. and Gibbs, J.A.(1974). Pulping characteristics of *Gmelina arborea* and *Bursera simaruba* from Belize. Tropics. *Trop. Prod. Inst. Rep*. **No. L36**.
34. Pearson, R.S. and Brown, H. P. (1932). *Commercial timbers of India* (New Delhi : Calcutta Government of India, Central Publication Branch).
35. Philipson, W.R., Ward, J.M., and Butterfield, B. G. (1971). *The Vascular Cambium, its development and activity*. Chapman and Hall Ltd, London.
36. Plomion, C., Leprovot, G. and Stokes, A. (2001). Wood formation in Trees. *Physiol.* **127** 1513 – 1523.
37. Sicad, E.N. (1987). Rotary veneer cutting of four fast-growing plantation hardwood species. *FPRDI* **16(1-2)** 86 – 104.
38. Uju, G.C. and Obot, J.J. (1990). Fibre Characteristics of Ten Nigerian Hardwoods: Suitability for Paper Making. *Nigerian J. Bot*. **3** 63 – 67.
39. Zobel, B. and Van Buijtenen, B. (1989). Wood variation: its causes and control. *Springer* **89** 97 – 109.