Anatomy and Specific Gravity of Wood Samples from Six Nigerian Tree Species in Relation to their Diagnostic X-ray Shielding Capabilities

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Abstract

The basic principle of protection against nuclear radiation is to keep radiation exposure as much as possible below the maximum permissible dose equivalent (MPD). In order to redress the dependence on costly shielding materials such as lead, steel, glass and gypsum, cheaper and readily available materials such as wood have been brought under focus as potential resources for shielding hazardous radiations. Making use of the relative transmission of 60 kVp X-rays by the wood of six Nigerian tree species as reference data, this study examined the wood anatomy of the tree species (i.e *Syzygium guinense* (Willd.) DC., *Tectona grandis* L., *Afzelia pachyloba* Harms., *A. africana* Pers., *Gmelina arborea* Roxb. *and Daniellia oliveri* (Rolfe) Hutch. & Dalziel with a view to providing information on the wood anatomical basis for their X-ray shielding capabilities. *T. grandis* and *G. arborea* were the two most fibrous of the six species studied, with their fibre-to-non-fibrous tissue ratios (F/NF) being 1.24 and 1.01 respectively. Incidentally, these two species transmitted the least amounts of radiation at an average wood thickness of 5 cm. Tyloses were observed in the wood of all but *G. arborea* and *D. oliveri,* and the % of vessels with tylose ranged from 20.64 to 50.36. At 0.05 level of probability, the reference data on relative X-ray transmission showed significant positive correlation with % axial parenchyma content (r = 0.754), but significant negative correlations with % fibre content (-0.734), % of vessels with tylose (-0.864), vessel diameter (-0.757), vessel lumen width (-0.753) and F/NF (-0.742). The diagnostic X-ray attenuation capability of the wood samples examined can therefore be anatomically explained by these six parameters, and their evaluation in prospective wood samples for shielding hazardous radiations can be useful.

Key words: *Gmelina arborea*, hardwood, hazardous radiation, *Tectona grandis*, tylose, wood anatomy, X-ray.

1. Introduction

Widespread applications of nuclear radiation have been discovered and embraced. In order to reduce the hazards associated with the application of these radiations, the United States National Council on Radiation Protection in its Report Number 49 (NCRP, 1976) has enumerated ways of keeping radiation exposure as low as reasonably achievable, with the identification of shielding as a more practicable way. Radiation shielding by different materials has been examined (Mc Gure, 1986; Okunade and Hussain,1989; Rossi *et al.*, 1991; Archer *et al.*, 1994 and Okunade, 1996), the diagnostic X-ray shielding materials widely in use being lead, steel, glass, gypsum, wall board, lead acrylic and plywood (Archer *et al.*, 1994). These materials with the exception of plywood are however, costly and are not readily available for use.

In realization of the need to redress the dependence on these costly materials, other natural resources have been brought under focus for more serious survey with a view to actualizing their full potentials as resources for shielding hazardous radiations. Of all the natural resources on earth, wood is among the most ubiquitous and perhaps the cheapest structural material (Walton, 1981; Nwoboshi, 1982). Although the NCRP Report N0 49 warned that " it is impracticable to use wood products for shielding purposes due to the great thickness required', some recent developments have suggested that wood products of average thickness could be potentially useful in shielding hazardous emissions: Certain chemical compounds and mixtures have been identified to be of radiological importance. For these substances and all the naturally occurring elements with atomic number (i.e. Z) from 1 to 92, the X- ray mass attenuation coefficients and mass-energy-absorption coefficients have been documented by Hubbell and Seltzer (1989-1996). With the nature of wood as a structural material that is comparatively less suitable than the widely acknowledged shielding materials earlier enumerated in attenuating ionizing radiations (HMSO, 1971; NCRP, 1976; Rossi *et al.*, 1991; *Archer et al.*, 1994), enhancement of its capability in this direction can possibly be achieved by incorporation of appropriate chemical substances in its fabric. Wood of average thickness that has been fortified in this manner may be found suitable in the construction of X-ray shielding facilities with the added advantage of easy workability and light weight.

The foregoing submissions point to the necessity for evaluating the structural properties of wood of available tree species alongside their natural capabilities in shielding hazardous radiations with a view to documenting their radiation shielding potentials. Oni *et al.*, (2001) have examined the attenuation of diagnostic X- rays (at 60 kVp) by the wood of six tree species in Nigeria, and observed a relative mean absorption of between 0.951 and 0.967 at the maximum wood thickness of 10 cm. The present study was intended to elucidate the wood structure of these hardwood species with a view to providing possible explanations of the anatomical basis for their x-ray shielding capabilities. The procedure and results of this study may subsequently be found helpful in the screening and selection of hardwood species for attenuating hazardous radiations.

2. Materials and Methods

2.1. *Reference Data and Plant Material*

This study enjoyed, with permission the privilege of making use of the values of relative transmission of the diagnostic X- rays (60 kVp) obtained by Oni *et al.* (2001) for the wood of the six tree species under consideration. These were the reference data adopted for comparative purpose in the present study. Wood samples of the six timber species were also obtained from the collections made by these authors in Ogbomoso, southwestern Nigeria (Table 1).

2.2. *Wood Anatomy Investigation*

Each dry wood was rehydrated by boiling in water for 10 minutes. Thin transverse sections of the wood were then prepared using a freezing stage microtome. The sections were stained in safranin for 20 minutes, washed clean of excess stain in running water and dehydrated for 2 minutes each in 30%, 50%, 70% and 90% ethanol. The dehydrated sections were then cleared in pure xylene for about 2 minutes and mounted in Canada balsam.

A small block, the size of about half the length of a matchstick obtained from each of the wood samples was cut into a boiling tube containing some concentrated nitric acid to which a few crystals of Potassium Chlorate was added (Jane, 1970). Each wood block was softened by boiling in the mixture for about 5 minutes. It was then thoroughly washed with water and macerated gently on a glass slide using the bottom of a clean pair of forceps. The macerated wood tissue was teased into a thin layer using two long needles, stained in safranin, washed of excess stain in water and mounted in a few drops of glycerin. Observations and data collection were carried out on a CARTON monocular light microscope. The qualitative observations made on the wood transections were the general shape of the vessels, the presence or absence of tylose in the vessels, types of rays and the type of axial parenchyma, all of which were recorded in photographs. The quantitative fibre characteristics determined included length, diameter, lumen width and wall thickness which were obtained from the macerated wood tissues. Vessel characteristics such as diameter, lumen width and wall thickness were also obtained from the wood TS. Each of these wood parameters was measured in replicates of 30 using a caliberated micrometer eyepiece fitted to the microscope.

Table1 Relative transmission of 60 kvp X-rays by the wood of some tree species at a distance of 1m from the source*

	Species name	Local (Yoruba) name	Thickness of wood					Mean ±SE
			1cm	2cm	5cm	7cm	10cm	
1	*Syzygium guinense* (Willd.) DC.	Adere	0.944	0.524	0.213	0.112	0.049	0.368^a ±0.165
2	*Tectona grandis* L.	Gedu	0.735	0.406	0.166	0.092	0.037	0.287^a ±0.128
3	*Afzelia pachyloba* Harms.	Apa babo	0.928	0.512	0.209	0.116	0.047	0.362^a ±0.162
4	*Afzelia Africana* Pers.	Apadan	0.865	0.477	0.193	0.102	0.043	0.336^a ±0.151
5	*Gmelina arborea* Roxb.	Melaea	0.664	0.366	0.130	0.086	0.033	0.256^a ±0.117
6	*Daniellia oliveri* (Rolfe) Hutch. & Dalziel	Iya	0.839	0.463	0.190	0.104	0.042	0.328^a ±0.147
	Mean ±SE		0.829^a ±0.045	0.458^b ±0.025	0.184^c ±0.013	0.102^d ±0.005	0.042^d ±0.002	

*Constructed based on the results obtained by Oni *et al.* (2001); mean wood thickness being 5 cm. Means in the last column (i.e. across the tree species) which carry the same superscripts are not significantly different at P=

0.05. The means in the last row (i.e. across the different wood thickness) which carry different superscripts are significantly different at P= 0.001, while those with the same superscripts are not significantly different at P= 0.001.

Also from the wood TS, the units of occurrence of the vessels (i.e the number of them which frequently occured together) were noted for each tree species. Moreover, the % frequency of occurrence by volume of the constituent tissue types namely, fibres, vessels, rays and axial parenchyma was computed. Each of these four parameters was obtained from four different microscope fields of view using the eyepiece grid with 100 squares. With the ocular grid in place, the objective lens was set to appropriate magnification and on each microscope field of view considered, four squares of the grid were observed as a quadrat at a time. The occurrence of fibre, vessels, axial parenchyma and ray in each quadrat was scored with a tally and % composition of each tissue type was computed from a simple proportion of the number of occurrence of each cell type to a total of all the four (Kpikpi and Olatunji, 1990; Ogunkunle and Oladele, 2008). The mean tissue proportion was thereafter computed and reported from the four fields of view. Using the ocular grid of known dimension, the density (i.e. the number per, mm^2 of wood tissue) of fibres, vessels and axial parenchyma was determined in the wood TS. In doing this, prepared slides were made to pass under the grid and the number of cell types falling within the 100sq grid was counted. These values were then converted into number of such cells in one mm^2 area by direct proportion, the sample size being 30. Wood anatomical descriptions adopted followed those of international association of wood anatomists (IAWA Committee, 1989).

2.3. Wood Specific Gravity Determination

Four blocks of wood, each of about 4x2x2 cm were cut from each of the hardwood species studied. These were soaked in water for 24 hrs after which they were wiped with clean cloth and their green volumes determined in cm^3 by Archimedes principle. They were then dried to a constant weight at a temperature of about 100 ± 5^0C in an oven. The specific gravity for each block of wood was calculated as its dry weight divided by the green volume (Ademiluyi and Okeke, 1979). The mean for the four replicates was computed for each wood sample.

2.4. Statistical Analyses

Making use of the reference data, first, a one-way classification analysis of variance (ANOVA) was conducted to compare the mean transmission values of the wood samples (i.e the rows of data in Table 1) using the computer-based SPSS version 17.0. The same statistical test was conducted to compare the means of transmission values by the various wood thicknesses across the six tree species (i.e. the columns of data in Table 1). Thirdly, the replicated data values on each of the 16 wood structural features examined (Table 3) were subjected to a one-way analysis of variance. In those parameters that showed significant differences at $\alpha = 0.05$, Duncan’s multiple range test was conducted to classify the means for the tree species into homogenous groups (Table 3). From the means of some wood structural features, three ratios were derived as additional parameters, thus bringing the total of wood dimensional characteristics considered to 19. The derived ratios were those of fibre-to-vessel (F/V), fibre –to –non-fibrous tissue (F/NF) of type I (i.e mean % fibre divided by sum of mean % vessel, ray and axial parenchyma) and F/NF of type II (i.e. sum of % fibre and vessel divided by sum of % ray and axial parenchyma) (Table 3).

In order to determine the extent of the contribution of each of the 19 wood parameters to diagnostic X-ray transmission, the means and/or derived ratios of each parameter for the six hardwood species in Table 3 were subjected to a two–tail statistical correlation test with the mean X-ray transmissions (last column in Table 1). Having noted the direction (i.e. positive or negative) of the contribution of each wood parameter from the correlation tests, the level of significance of correlation coefficient obtained in each case was determined at P = 0.05 (one-tail) using the correlation significance calculator with directional probability (Lowry, 2001-2014), n being 6. By this calculation, all the correlation coefficients of ± 0.73 and above were considered significant.

3. Results

Figure 1 and Table 2 show the qualitative wood anatomical features observed on the six hardwood species studied. Table 3 on the other hand shows two categories of observations i.e. the quantitative results on the wood parameters and their results of correlation tests with the reference data in Table 1. Shape of vessels observed in wood transections was either round or oval but the two sometimes occurred together in a species (Figure 1a; Table 2). Tylose was observed in the vessels of *S. guinense*, *T. grandis* , *A. pachyloba* and *A. africana* but absent in the other two species. Among those species with vessel tylose, *T. grandis* had the highest number in its wood structure (i.e. 50.36%) while the lowest (i.e. 20.64 %) was observed in *S. guinense* (Table 3). Axial parenchyma in all the species studied was predominantly paratracheal but the sub types varied and can be diagnostic. In addition, apotracheal types were observed in *T. grandis* and *G. arborea* (Table 2).

The entries in Table 3 indicate that wood fibres in the six tree species were generally short (mean values ranging between 956.42 µm in *T. grandis* and 1472.78 µm in *S. guinense*) but thin (mean diameter of 16.95 to 27.65 µm) with narrow lumina (mean of 9.98 to 21.50 µm). The widest vessels (mean of 214.85 µm) was recorded in *T. grandis* while the narrowest (mean value 136.19 µm) was in *A. africana*. The vessels frequently occurred as solitary units and sometimes in radial multiples of two and three (Table 2). Percent fibre content of wood was observed to be generally low, the mean values ranging between 33.68% in *A. pachyloba* and 55.81% in *T. grandis*. However, the respective mean values of % fibre content and number of fibre cells /mm^2 area of wood tissue in each species was greater than that of vessels or rays or axial parenchyma (Table 3). The two tree species with the most fibrous wood were *T. grandis* and *G. arborea*, having F/NF (Type I) of 1.24 and 1.01 respectively, while A. pachyloba, with a value of 0.51 was the least in this respect. The wood specific gravity in the species studied ranged between 0.46 in G. arborea and 0.57 in T. grandis (Table 3).

Table 2 Some qualitative anatomical features of wood in the six hardwood species studied.

	Wood parameter in transverse section	*SYG*	*TEG*	*AFP*	*AFA*	*GMA*	*DAO*
1	Shape of vessel	Round; Oval*	Round; oval*	Oval	Oval; Round	Round; oval**	Round
2	Occurrence of vessels	Solitary; pairs*	Solitary; pairs*; threes**	Solitary; pairs; threes**	Solitary; pairs*; threes*	Solitary; pairs	Solitary; pairs*; threes*
3	Vessel tylose	present	present	present	present	absent	Absent
4	Ray type	Unis*; bis; multi*	Uni*; bis; multi	Unis	Unis*; bis; multi	Unis; bis; multi	Unis; bis; multi
5	Ray cell	Procumbent	Procumbent (often long)	Procumbent*; Square	Procumbent	Procumbent	Procumbent; square*
6	Type of axial parenchyma	Paratracheal (vasicentric; scanty*)	Paratracheal (scanty); Apotracheal (diffuse)	Paratracheal (confluent; aliform*)	Paratracheal (confluent; aliform*)	Paratracheal (scanty) Apotracheal (diffuse)	Paratracheal (aliform)

SYG, Syzygium guinense; TEG, Tectona grandis; AFP, Afzelia pachyloba; AFA, Afzelia africana; GMA, Gmelina arborea; DAO, Daniellia oliveri; Unis = uniseriate; Bis = biseriate; Multi = multiseriate; *sometimes present; ** present but rare.

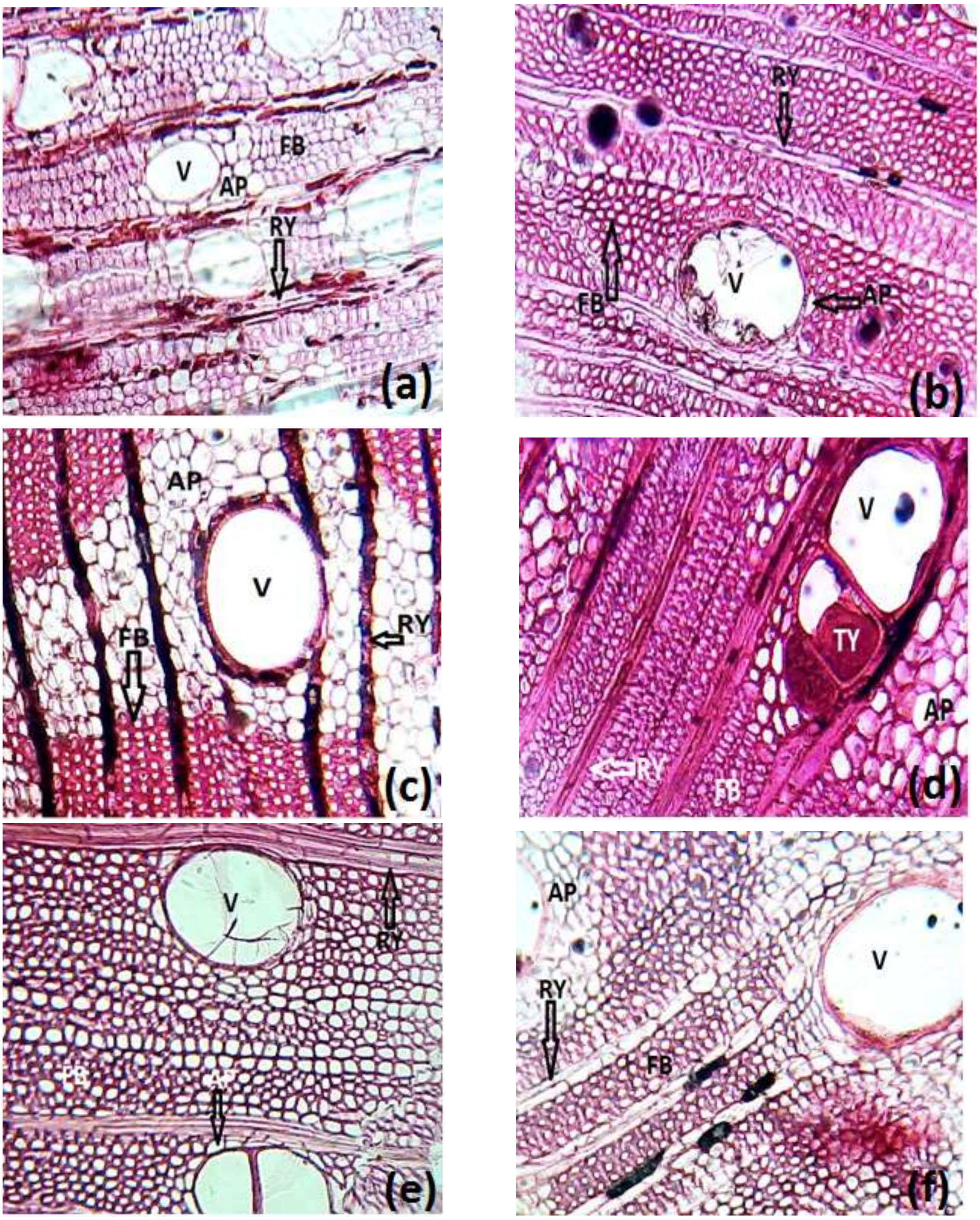

Figure 1 (a - f): Transverse Sections of Wood of Some Nigerian Hardwood Species (100X).
(a) *Syzygium guinense*, (b) *Tectona grandis*, (c) *Afzelia pachyloba*, (d) *A. africana*, (e) *Gmelina arborea* and (f) *Daniellia oliveri*. *AP*: axial parenchyma; *FB*: fibre; *RY*: ray; *TY*: tylose; *V*: vessel.

Table 3 Means and derived ratios of some wood dimensional characteristics in six Nigerian tree species and their correlation with diagnostic X-ray transmission*

	Wood parameter	*SYG*	*TEG*	*AFP*	*AFA*	*GMA*	*DAO*	Coeff.
1	Fibre length (μm)	1472.78^b ±100.99	956.42^a ±65.34	1380.67^b ±85.20	1034.25^a ±56.07	1420.3^b ±79.61	1078.9^a ±76.59	.216
2	Fibre diameter (μm)	19.45^{ab} ±0.68	20.73^b ±0.89	16.95^a ±1.18	17.66^{ab} ±1.11	25.08^c ±1.37	27.65^c ±1.19	-.540
3	Fibre lumen width (μm)	11.26^a ±0.57	12.54^a ±0.71	9.98^a ±1.04	11.06^a ±1.10	17.92^b ±1.21	21.50^c ±1.02	-.488
4	Fibre wall thickness (μm)	4.09 ±0.32	4.09 ±0.33	3.46 ±0.33	3.46 ±0.27	3.58 ±0.26	3.07 ±0.21	-.048
5	Vessel diameter (μm)	138.49^a ±5.29	214.85^c ±2.59	151.04^{ab} ±9.09	136.19^a ±9.29	180.89^b ±15.71	169.47^b ±13.98	-.757*
6	Vessel lumen width (μm)	126.98^a ±4.20	206.28^c ±2.19	141.06^{ab} ±8.66	126.72^a ±8.83	170.01^b ±15.44	158.21^b ±13.77	-.753*
7	Vessel wall thickness (μm)	4.76 ±0.62	4.38 ±0.49	4.99 ±0.48	4.74 ±0.33	4.49 ±0.48	5.63 ±0.44	.461
8	% fibre content	42.98^{abc} ±3.89	55.81^c ±4.99	33.68^a ±5.58	34.33^a ±5.18	50.35^{bc} ±3.75	36.75^{ab} ±2.64	- .734*
9	% vessel content	10.21 ±2.91	15.52 ±7.76	14.39 ±7.1	8.75 ±4.38	15.49 ±7.59	14.54 ±7.27	-.591
10	% of vessels with tylose	20.64^a ±3.23	50.36^b ±7.07	36.12^{ab} ±5.75	42.49^{ab} ±5.79	*NA*	*NA*	-.864*
11	% ray content	31.86^b ±4.75	12.84^a ±2.43	24.62^{ab} ±5.63	36.26^b ±1.92	30.85^b ±4.58	29.98^b ±5.85	.287
12	% parenchyma content	14.99^{ab} ±2.24	16.49^{ab} ±3.69	27.25^b ±2.31	20.65^b ±4.61	3.29^a ±0.67	18.72^b ±9.18	.754*
13	No of fibres/mm^2	514 ±123	444 ±46	543 ±50	543 ±73	452 ±47	637 ±46	.569
14	No of vessels/mm^2	20^d ±2	9^c ±1	4^a ±1	4^a ±1	6^{ab} ±1	7^{bc} ±1	.324
15	No of parenchyma cells /mm^2	68^a ±7	42^a ±6	212^b ±34	196^b ±19	22^a ±3	216^b ±31	.607
16	Specific gravity	0.5473^c ±0.011	0.5739^c ±0.012	0.4677^a ±0.014	0.5277^{bc} ±0.034	0.4584^a ±0.009	0.4802^{ab} ±0.012	.123
17	F/V ratio	4.2096	3.5960	2.3405	3.9234	3.2505	2.5275	.003
18	F/(V+R+P) ratio	0.7532	1.2444	0.5083	0.5228	1.0145	0.5811	-.742*
19	(F+V)/ (R+P) ratio	1.1353	2.4319	0.9267	0.7569	1.9285	1.0532	-.787*

SYG, Syzygium guinense; TEG, Tectona grandis; AFP, Afzelia pachyloba; AFA, Afzelia africana; GMA, Gmelina arborea; DAO, Daniellia oliveri; Coeff. = coefficient of correlation with X-ray transmission; *F*= mean % fibre; *V* = mean % vessel; *R* = mean % ray; *P* = mean % axial parenchyma. *Correlation is significant at P<0.05.

4. Discussion

Table 1 indicates that on the average, there was no significant transmission of diagnostic X-rays across the wood of different tree species studied. Moreover, the Table has not only shown that there was significant differences in the X-ray

transmission across the different wood thicknesses; it has
confirmed that the transmission reduced with increasing wood thickness. These results are a confirmation of the long standing belief that shielding increases with thickness of material (Rossi *et al.*, 1991). This observation from the statistical analyses of our reference data (Oni *et al.*, 2001) is an indication that the magnitude of X-ray attenuation by a piece of wood may be independent of tree species, but strictly on the quantity of wood tissue material serving as a barrier to the movement of the rays. Arrangement or orientation of the wood elements relative to the long axis of the tree trunk (i.e wood grain) could also be an important factor for consideration because loose structural make up of a radiation shielding material will make room for air spaces that are undesirable where effective shielding is required (Herrmann, 2014).

Species difference could sometimes be a contributing factor to determining the extent of X-ray attenuation by a piece of wood. The reason is that wood is highly heterogeneous in structure and composition depending of its origin (in terms of species or climate), tree age and position of the piece in the trunk (Walton, 1981). The structural and chemical components of wood have also been implicated in its physical properties (including density and strength), which in turn form the basis for its utilization (Ogunkunle, 1998). On the average, radiation shielding has been acknowledged to increase with increasing density (i.e specific gravity) of a material, with the result that denser objects transmit lesser than lighter ones (HMSO, 1971; Simpkin, 1995). Going by the results of this study (Table 3), it is doubtful that wood specific gravity has a contribution to the X- ray shielding effectiveness of the samples studied. Instead, the results suggest a closer look into other wood characteristics as possible contributors.

Of the 19 wood parameters studied, only six can be considered relevant to evaluate the diagnostic X-ray shielding potentials of the wood samples. These parameters include vessel diameter, vessel lumen width, % fibre content, % of vessels with tylose and F/NF ratios of types I and II, all of which showed significant negative correlation with X-ray transmission. The seventh is % axial parenchyma content, which showed a significant but positive correlation (Table 3). Hard (or dense) objects are known to attenuate X-rays better, the hardness being referred to , not only in terms of physical density, but also with respect to chemical composition, particularly the atomic number of the constituent chemical elements (Sprawls, 2014). With respect to plant histology, highly lignified tissues such as fibres and vessels are said to be harder than those that are not (Oladele, 1991). It is therefore expected that wood with higher quantity of fibres, such as *T. grandis* (55.81%) and *G. arborea* (50.35%) will transmit lesser amount of hazardous radiation as noted in this study. There is little wonder, therefore, that a significantly positive correlation with X- radiation transmission was obtained for % axial parenchyma content of the wood samples (Table 3). For the same reason, it is considered appropriate for tree species such as *T. grandis* and *G. arborea* with high amount of wood F/NF ratios of 1.24 and 1.01 to have transmitted lesser quantities of the hazardous rays. Thus, the rule that dense materials shield radiation better, which was not corroborated by the results of wood specific gravity values obtained in this study (Table 3) has indeed been observed to hold perfectly at the wood microscopic level.

The highest value of coefficient of correlation (r = 0.864) obtained in this study was between % vessels with tylose and the relative transmission of X-rays through the wood of the six tree species. Going by the R^2 adjusted value (i.e. 0.620) of the regressed model, and the marginal standard error (0.023) of this estimate, it can be said of a given tylose- containing wood that 62.0% of diagnostic X-ray transmission through a piece of average thickness (approximately 5cm; Table 1) can be explained by its relative proportion of its vessels with tyloses. In plants, tyloses and phenolic deposits in vessels are known to impede water transport (Kitin et al, 2010), but it is not clear how vessel tyloses can effectively enhance X-ray shielding capability of wood. By definition, tyloses are ballon-like outgrowths of adjacent parenchyma (ray) cells that enter the vessel lumina through pit apertures (Murnanis, 1975; Figure 1d). They are distinct structures in some angiosperms, which may partly or completely permeate the vessels (Obst *et al.*, 1988).

For tylose that is essentially of parenchyma (non-lignified cell) origin to have been implicated in X-ray attenuation capability of wood, a possible explanation is that it must have undergone some form of lignification in the course of wood tissue maturation. This position had earlier been established through studies such as those of Sachs *et al.* (1970) and Kitin *et al.* (2010) with the information that walls of tyloses are reservoirs of many phenolic compounds, including lignin. With a relatively high amount of lignin content (28.6%), the large number of tyloses in the wood of white oak has been said to make this material particularly suitable for tight cooperage, such as whiskey barrels, because the vessels are plugged and leakage is small (Obst *et al.*, 1988). Thus, the presence of tyloses in large number can be beneficial where physical barriers are required in wood to prevent leakage. Tyloses do however interfere with the processing of wood by hampering the drying of timber, limiting the penetration of chemical preservatives and reducing the rate of chemical pulping (Obst *et al.*, 1988). On the strength of the foregoing argument, it is understandable that a piece of wood with notable proportion of tylose- occluded vessels, can effectively function to attenuate X- rays, and to that extent which is additionally permissible by the magnitude of other parameters such as mean vessel diameter, mean width of vessel lumen, % fibre content, % axial parenchyma content, and its F/NF ratio.

5. Conclusions

Studies on wood anatomy and specific gravity in six Nigerian hardwood species (Syzygium guinense, *Tectona grandis, Afzelia pachyloba, A. africana, Gmelina arborea and Daniellia oliveri*) revealed that they are short-fibred (mean length of 956.42 ± 65.34 to 1472.78 ± 100.99), with generally low % fibre contents (33.68 ± 5.58 to 55.81 ± 4.94) and number of fibre cells/mm^2 of wood tissue in transverse section (444 ± 46 to 637 ± 46). The mean values of % fibre content and number of fibres/mm^2 were each, greater than that of the sum of vessels, axial parenchyma and rays in *T. grandis* and *G.*

arborea with their fibre-to-non-fibrous tissue ratios (F/NF) being 1.24 and 1.01 respectively, and hence, were adjudged the two most fibrous of all the species studied. The wood of these two species also transmitted the least amount of 60 kVp X-rays at a mean thickness of 5cm. Tyloses were observed in the wood of all but *G. arborea* and *D. oliveri*, and the % of vessels with tylose varied in the species concerned. At 0.05 level of probability, the adopted reference data on relative X-ray transmission showed significant positive correlation with % axial parenchyma content (r = 0.754), but significant negative correlations with mean vessel diameter (-0.757), mean vessel lumen width (-0.753), % fibre content (-0.734), % of vessels with tylose (-0.864) and F/NF (-0.742). The diagnostic X-ray attenuation capability of a piece of wood from the hardwood species examined can therefore be anatomically explained by these parameters. The results of their evaluation in prospective wood samples for shielding hazardous radiations can be a useful clue.

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