WOOD PROPERTIES AND THEIR VARIATIONS WITHIN THE TREE STEM OF LESSER-USED SPECIES OF TROPICAL HARDWOOD FROM GHANA

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ABSTRACT

Due to increasing demand for traditional market species of timber, which are dwindling in quantities and quality within the Ghanaian forest, there is the need to introduce lesser-used species (LUS) to serve as substitutes. The success of LUS in the marketplace requires technical information that relates to utilization about the species. This paper examines physical and mechanical properties of wood and their variations within the tree stem of *Petersianthus macrocarpus*, a potential LUS from Ghana. There was an overall increase of wood's physical and mechanical properties from the breast height to the top of the tree. Specific gravity correlates positively with all the wood's properties, making it a good indicator for selection of the wood for use. The wood of *Petersianthus macrocarpus* is dense (specific gravity of 0.69) with moderately high shrinkage values (radial shrinkage of 4.0% and tangential shrinkage of 6.9%).

Keywords: Lesser-used species, specific gravity, shrinkage, compression parallel to the grain.

INTRODUCTION

The forest of Ghana, like most tropical forests, is being utilized commercially for a few highly priced timber species, which are a mere fraction of the timber species that are potentially useful (Chudnoff 1980). Prominent among them are *Khaya* spp., *Entandrophragma* spp., *Triplochiton scleroxylon,* and *Melicia excelsa* (FPIB 1995; François 1987). There is significant utilization of these few tree species to satisfy market demands to the neglect of about 90 species that are of merchantable sizes and commercial quantities (TEDB 1990). These constitute over 45% of the standing volume of trees in Ghana's forest (Ghartey 1990). Increasing market demand, both locally and most especially internationally, has resulted in the overexploitation of these 'traditional' market species, rendering some endangered. As prices of traditional timber increase, and quality and quantities decline, manufacturers and producers have little option other than to pay attention to the lesser-used species that were previously ignored, if they are to remain in business. There is therefore little hope for the future of the Ghanaian timber trade if diversification of market species is not encouraged to accommodate lesser-used species and to

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serve as a means for sustainable management of the tropical forest of Ghana.

Historically, most dealers in Ghanaian hardwoods have relied mainly on a traditional knowledge base of experience of use, but with very little information on their properties. Because few tree species are being utilized commercially, there is an erroneous impression that there is an insufficient raw material base.

A systematic approach is therefore needed to promote the utilization of the lesser-used Ghanaian wood species. The first step in this process is the development of information about the characteristics of their wood. This in turn would be followed by an evaluation of their utilization potential, marketability, and performance, so as to determine suitable substitutes for the fast-diminishing traditional market species.

This research was undertaken to examine the variation of the physical and mechanical properties within the stem of a tropical hardwood species, *Petersianthus macrocarpus* (also called *Combretodendron macrocarpum*) from Ghana (TEDB 1994). This species was chosen because it was one of the LUS which is branded as "Pink star promotable" by the Forestry Department of Ghana, because of its abundance, with zero % commercial utilization, and its favorable ecology in the Ghanaian forest (Hawthorne and Abu-Juam 1993). The variables included specific gravity, radial and tangential shrinkages, maximum crushing strength, and modulus of elasticity obtained from compression parallel to the grain.

METHODOLOGY

Sample collection

Three trees of merchantable sizes (i.e., dbh of 60 cm and above) of *Petersianthus macrocarpus* (Pm) were randomly selected from the open forest in the Central Region within the southwestern part of Ghana. From each tree, a bolt 76 cm long was removed from breast height, the middle portion (4.0–5.0 m from the ground), and the top (12 m from the apex of the tree) of the merchantable bole. Also, a disk 5 cm thick was removed from the breast height of one tree, for the determination of the juvenile/mature wood boundary for the species. From the cross section of each bolt, one narrow sample stick 2.0 × 2.0 × 76 cm of clear wood was marked and sawn at 10 cm from the north, south, east and west directions, respectively. Thus, four sample sticks were obtained from each bolt. The sawn sticks were kiln-dried to 8% moisture content (MC) and used for physical and mechanical strength tests. A schematic drawing showing how different samples are cut from the tree is shown in Fig. 1.

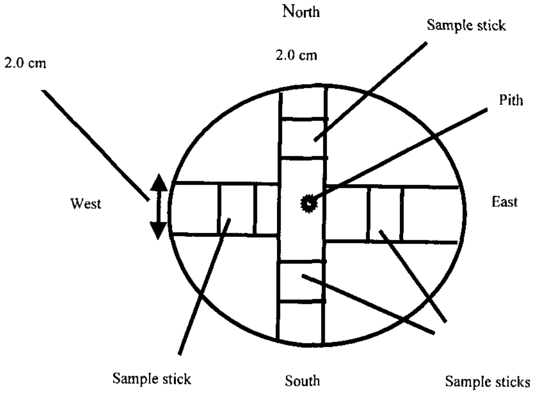

FIG. 1. A schematic showing how wood samples were cut from the cross section of tree stem.

Fiber length

A narrow strip of about 0.6 cm width was cut along the radius of the disk that was removed from the breast height of the selected tree. The width of each growth ring was measured, after which small sections were removed from each ring and macerated into fibers using Franklin's method (Franklin 1945) for fiber length measurements. The pattern of variation in fiber length is expressed by the linear regression model:

Fiber Length (mm) = a + b (Ring Number) (1)

Specific gravity

Twenty clear samples of sizes 2 × 2 × 60 cm (0.8 × 0.8 × 2.4 in.) each, were cut from the set of four sample sticks and used for specific gravity determination by weighing each wood sample when fully immersed in a beaker of water and then determining the oven-dried (OD) weight after drying at 100±3°C in an oven for 48 h until there was no change in the weight of the sample. The specific gravity (SG) of the samples was calculated based on oven-dry weight and given volume as discussed in ASTM Standard D 2395 (ASTM 1986).

Mechanical properties

Twenty clear samples, each 6-cm long, were cut from the sample sticks from each of the three axial locations within each tree stem and used for compression parallel-to-the-grain tests. Each specimen, after being measured with a pair of digital calipers to determine its actual size, was mounted on the 'Amsler' strength testing machine, and increasing loads were applied until wood failure using the NF B Standard 51-007 (AFNOR 1985). Straight-grained specimens with growth rings running parallel or almost parallel to each other were selected. Each specimen was supported on the testing machine in such a manner to permit uniform load distribution over the entire end surfaces. Deflection readings for equal increments of load were recorded until failure. The stress-strain curve for each specimen was plotted. Tangent modulus (E_{TANG}, Mpa) along the stress and strain curve was calculated as:

$$E_{TANG}(\mathrm{Mpa}) = \Delta\sigma/\Delta\epsilon \qquad (2)$$

where $\Delta\sigma$ (Mpa) is the stress increment, and $\Delta\epsilon$ (mm/mm) is the strain increment. The maximum tangent modulus was taken to be the modulus of elasticity (MOE) for the specimen. The compression strength was calculated using measured maximum load (P_{MAX}) and specimen dimensions (WIDTH*THICKNESS):

$$\text{Compression Strength (Mpa)} = P_{MAX}/\text{WIDTH*THICKNESS} \qquad (3)$$

Shrinkage

From the remainder of the sample sticks at each tree location, ten samples, each of 6-cm-length of clear timber were obtained for shrinkage tests. The samples were soaked in water for 72 h and dimensions were taken at maximum moisture content (MMC) in the radial and tangential surfaces. The samples were then oven-dried at temperatures 100±3°C for 48 h until the weights of the samples remained unchanged. The dimensions of the oven-dried samples were again taken at the same spots as when they were taken at MMC. Shrinkage was calculated for the radial and tangential surfaces based on measured dimensions at soaked and oven-dry conditions.

Estimations of variation in the tested physical and mechanical strength characteristics of wood were conducted for each tree within each species at the three axial locations (B, M, T) and the overall variations between the three axial locations for all trees within each species, using SPSS (Statistical Package for the Social Sciences) computer software package. Test for significant differences of the measured characteristics between locations (breast height, middle and top of merchantable bole) for each tree and for all trees within the species were conducted using ANOVA and t-test. Correlation between each pair of the measured wood properties within each tree was tested.

RESULTS AND DISCUSSION

Fiber length

Fiber length increased rapidly outward from the pith around the region close to the pith (juvenile wood zone), and less rapidly within the portion of wood beyond this region (mature wood zone) (Fig. 2).

The regression equations relating fiber length to ring number for juvenile wood are:

$$\text{Fiber Length (mm)} = 1.015 + 0.021\ (\text{Ring Number})\quad r^2 = 0.969 \qquad (4)$$

and for mature wood:

$$\text{Fiber Length (mm)} = 1.048 + 0.007\ (\text{Ring Number})\quad r^2 = 0.664 \qquad (5)$$

The regression equation for fiber length within the juvenile wood zone shows a higher

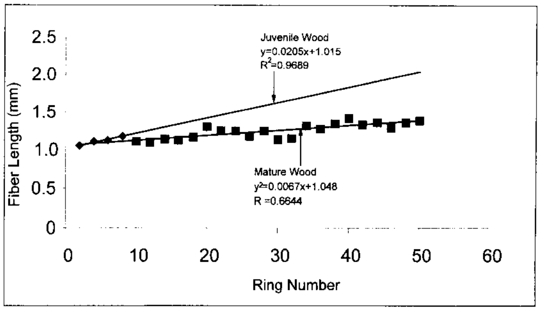

FIG. 2. Radial variation of fiber length with ring number at breast height for *Petersianthus macrocarpus.*

rate of increase (with slope 0.021) than that of the mature wood zone (with slope 0.007), with the differences in the slopes being statistically significant. This confirms Bannan (1967), who pointed out that the frequency of the anticlinal division of the fusiform initials (which is responsible for the shorter fiber lengths of the juvenile wood) was higher near the pith and decreased outward with increasing age of the tree. Thus, two distinct wood types are produced in the tree stem: juvenile wood (which has shorter fibers that increase at a faster rate) and mature wood (that has longer fibers that increase at a much slower rate). This distinction in tree stem is important for wood utilization, as juvenile wood has its unique properties that favor certain applications, especially in pulp and paper making, while mature wood is considered more acceptable in many applications that require higher strength and stability. Juvenile/mature wood boundary of *P. macrocarpus* was estimated to be around the sixth ring at a distance of approximately 4 cm from the pith outward. Thus, a distance of 10 cm from the pith outwards was chosen for all samples to ensure that they were well within the mature wood zone and were free from any juvenile wood at all levels within the tree stem. The six-ring juvenile wood zone related well with many reports that the juvenile wood usually falls within the first 20 rings from the pith (Haygreen and Bowyer 1989).

Physical properties

The variation of the physical properties within the three selected trees of *Petersianthus macrocarpus* showed no dominant pattern (Table 1). The mean value was 0.69. This relates well with the reported value (Tree Talk 1997).

Bunn (1981) emphasized the importance of

TABLE 1. *Variation of wood properties within three tree stems of* Petersianthus macrocarpus.

Tree No.	Average DBH (cm)	Tree Length (m)	Location		MC (%)	SG	MCS (MPa)	MOE (× 1000 MPa)	R. shrink (%)	T. shrink (%)
1	103	20.3	B	Mean	8.2	0.55	41	9	3.1	5.3
				SD	0.802	0.030	5.441	1.871	0.443	0.868
			M	Mean	7.4	0.74	63	11	4.2	7.6
				SD	0.200	0.004	11.948	0.710	0.381	0.268
			T	Mean	7.3	0.65	48	8	4.2	6.7
				SD	0.170	0.028	7.739	1.338	0.469	1.222
2	61	21.5	B	Mean	7.9	0.67	56	10	3.3	7.6
				SD	0.259	0.022	5.597	1.581	0.310	1.022
			M	Mean	8.0	0.73	76	14	4.3	8.8
				SD	0.170	0.013	4.364	2.036	0.177	0.670
			T	Mean	7.9	0.68	73	13	4.9	7.6
				SD	0.171	0.010	3.703	2.157	0.416	0.407
3	72	23.0	B	Mean	8.1	0.74	61	11	3.3	5.5
				SD	0.260	0.009	5.877	2.059	0.374	0.574
			M	Mean	8.2	0.71	59	11	4.2	6.4
				SD	0.154	0.009	4.661	1.792	0.384	0.671
			T	Mean	7.7	0.73	58	10	4.6	6.5
				SD	0.118	0.025	5.654	1.515	0.529	0.665

Key: B—breast height, M—middle and T—top of the merchantable bole, MC—moisture content, MCS—maximum crushing strength, MOE—modulus of elasticity, R. shrink—radial shrinkage, T. shrink—tangential shrinkage and SD—standard deviation.

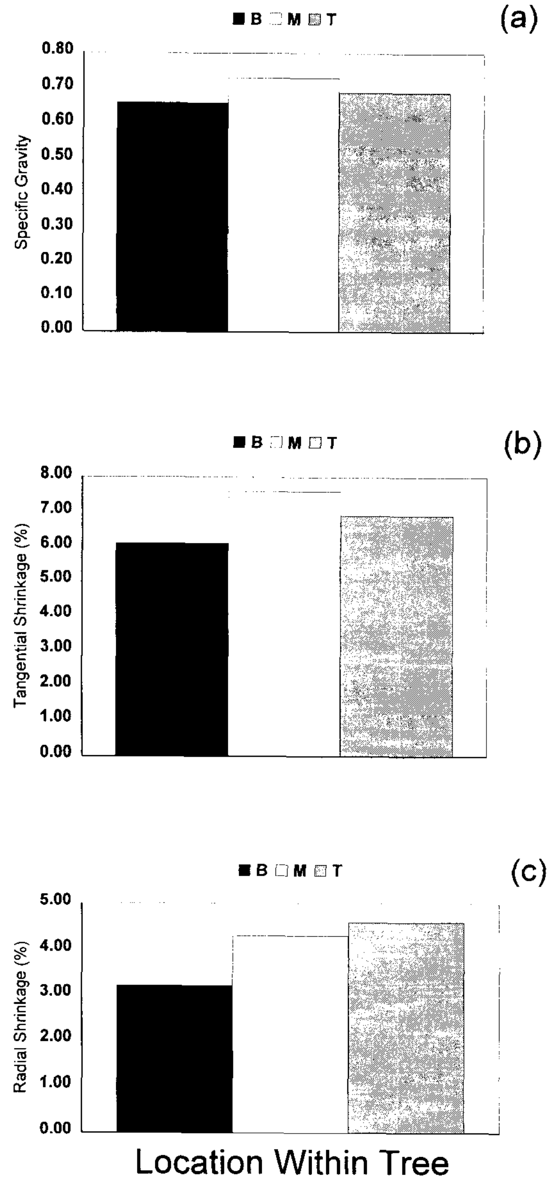

FIG. 3. Variation of physical properties between tree locations for *Petersianthus macrocarpus* (n = 3 trees). a) Specific gravity, b) Tangential shrinkage, and c) Radial shrinkage.
Key: B=breast height, M=middle, and T=top of the merchantable bole.

specific gravity, stating that it is the single most important physical property of wood. It could be used to estimate the suitability of wood for many end-product uses and wood strength (Panshin and de Zeeuw 1980). When the physical properties within all three trees in the study were combined, specific gravity indicated a slight but significantly different increase from the breast height to the middle and followed a slight decrease to the top (Fig. 3). This pattern conforms to many authors' claim of inconsistent pattern of variation of specific gravity with tree height, especially among hardwoods (Land and Lee 1981; Saucier and Taras 1966; Inokouma et al. 1956). This variation could be due to the complex interactions among many factors including site, climate, geographic location, age, position in stem, growth rate and auxin gradient formation (Parham and Gray 1984; Kollman and Côté 1968; Maeglin and Wahlgren 1972; Chudnoff 1976).

The unequal shrinkage that occurs along the radial (R) and tangential (T) surfaces of wood after drying below fiber saturation point led to an overall increase from breast height to the top of selected sample trees for radial shrinkage. The tangential shrinkage, however, produced an increase from the breast height to the middle, followed by a decrease to the top (Fig. 3). The overall average tangential shrinkage (6.9%) to that of the radial shrinkage (4.0%) produced a ratio of 1.7, which affirms the report of Bodig and Jayne (1973) that the tangential shrinkage in wood is greater than radial shrinkage by a factor between 1.5 and 3.0. These shrinkage variations could be accounted for by combinations of many factors including presence of ray tissue, which provides a restraining influence in the radial direction, frequent pitting on the radial walls, domination of latewood in the tangential direction, and differences in the amount of cell-wall material radially and tangentially. Other factors include:

1. The size and shape of the piece, which affects the grain orientation in the piece and the uniformity of the moisture through the thickness (Haygreen and Bowyer 1989).
2. The density of the sample whose shrinkage increases with increasing density.

Mechanical properties

Mechanical properties of wood are important in wood use. Panshin and de Zeeuw (1980) reported that wood specific gravity is a good predictor of wood strength. Thus, variability in wood strength for *Petersianthus macrocarpus* also followed a similar pattern as that of specific gravity. This variability may also be influenced by a combination of several other factors, including the inherent variability within trees (Saucer and Hamilton 1967; Harzman and Koch 1982), growth and environmental conditions (Tsoumis 1991), and presence of high extractive contents (Besley 1964; Choong et al. 1989). Other factors are the heterogeneous composition and structure of the tropical rain forest from which the trees grow (Hall and Swaine 1981).

The study showed that the maximum crushing strength and the modulus of elasticity were lower at breast height than at the top (Fig. 4). The overall average maximum crushing strength for the researched species was found to be 60 Mpa (8690 psi). This value agreed with Bolza and Keating (1972), while the modulus of elasticity that averaged 11,058 Mpa (1604 × 1000 psi) was lower than reported values for species with similar specific gravity (Anonymous 1997). The possible reason for the lower value is due to the fact that most reported MOEs are obtained through a bending strength test, which is usually easier to conduct than compression parallel to the grain test (Haygreen and Bowyer 1989). However, in comparing differences in each of the tested mechanical properties between tree locations and also for all the trees combined, significant differences were found in most cases (Table 2).

Specific gravity correlated positively and significantly with maximum crushing strength, modulus of elasticity, and shrinkage (radial and tangential) (Table 3). This confirms reports from many authors that specific gravity is a useful index in estimating wood strength and use (Dinwoodie 1981; Bunn 1981; Panshin and de Zeeuw 1980).

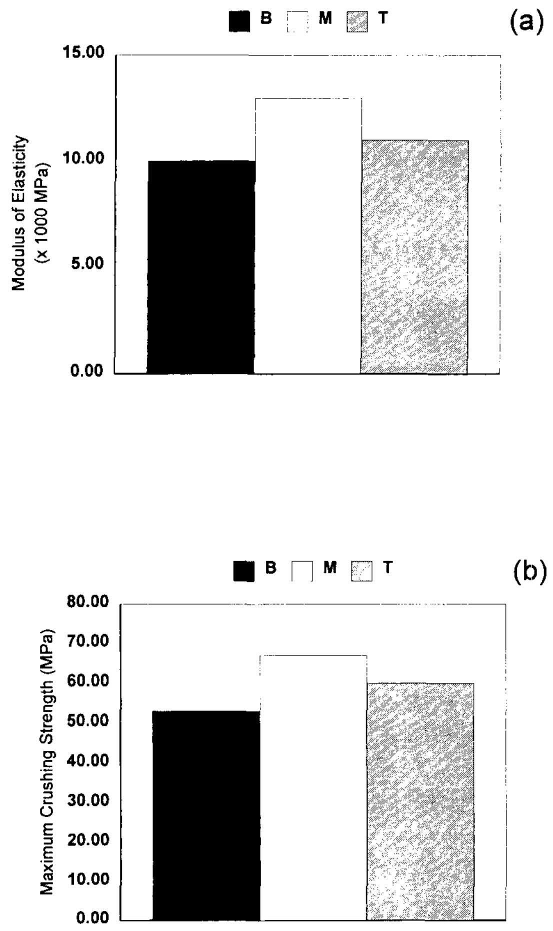

FIG. 4. Variation of mechanical strength properties between tree locations for *Petersianthus macrocarpus* (n = 3 trees). a) Modulus of elasticity and b) Maximum crushing strength.

Key: B=breast height, M=middle, and T=top of the merchantable bole.

CONCLUSIONS

Results indicate that no dominant patterns of variation of specific gravity, radial and tangential shrinkages, maximum crushing strength, and modulus of elasticity exist in the trees of *Petersianthus macrocarpus.* This is further buttressed by the significant differences in wood properties that exist between tree locations. Specific gravity is a good indicator for wood selection for utilization since it correlates significantly and positively with strength and physical properties. *Petersianthus macrocarpus*

TABLE 2. *Comparison of significant differneces of wood properties between tree stem location of* Petersianthus macrocarpus *(n = 3 trees).*

Wood Properties/F-Value	Location	Degrees of Freedon	P-Value/ Significance Levels
Specific gravity	B/M	104	0.000**
(F = 21.43**)	B/T	119	0.007**
	M/T	104	0.001**
MCS (F = 24.07**)	B/M	104	0.000**
	B/T	119	0.001**
	M/T	104	0.001**
MOE (F = 16.23**)	B/M	104	0.000**
	B/T	119	0.137 ns
	M/T	104	0.000**
R. shrinkage	B/M	54	0.000**
(F = 81.83**)	B/T	59	0.000**
	M/T	54	0.034*
T. shrinkage	B/M	54	0.000**
(F = 11.09**)	B/T	59	0.025*
	M/T	54	0.086 ns

Key: B—breast height, M—middle and T—top of the merchantable bole, MCS—maximum crushing strength, MOE—modulus of elasticity, R. shrinkage—radial shrinkage, T. shrinkage—tangential shrinkage, *—significant at the 95% confidence level, **—significant at the 99% confidence level, and ns—not significant.

TABLE 3. *Correlation of wood properties for* Petersianthus macrocarpus *(n = 3 tress).*

Wood Properties		Wood Properties			
		Sp. Grav	MCS	MOE	R. Shrink
MCS	r	0.650**			
MOE	r	0.436**	0.692**		
R. Shrink	r	0.318**	0.374**	0.251*	
R. Shrink	r	0.295**	0.540**	0.387**	0.469**

**—correlation is significant at the 0.01 level (2-tailed), *—correlation is significant at the 0.05 level (2-tailed), r—correlation coefficient.

is a dense wood (average specific gravity of 0.69) with high shrinkage values (radial shrinkage of 4.0% and tangential shrinkage of 6.9%) with relatively high strength values (maximum crushing strength—60 Mpa and MOE—11,100 Mpa). These values compare very closely with *Chlorophora excelsa* (with average values: specific gravity—0.78, radial shrinkage—4.0% and tangential shrinkage—6.0%, maximum crushing strength—57 Mpa and MOE—12,300 Mpa) (Tree Talk 1997). *Chlorophora excelsa* also has similar aesthetic features to *Petersianthus macrocarpus.* It is a very important, but threatened wood species in the Ghanaian timber trade (Ghartey 1990). The wood formed in the merchantable-sized tree stem of *Petersianthus macrocarpus* from the breast height to the 12 m mark from the apex could have similar uses since this portion shows closely related values of physical and mechanical properties. Specific gravity correlates positively with the tested physical and mechanical properties of wood in *Petersianthus macrocarpus,* making it a good indicator for wood selection for use. However, further research is needed on more tree samples of *Petersianthus macrocarpus,* with specimens taken at shorter intervals along the tree stem in order to investigate more wood properties and to ascertain wood performance in service.

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