GREEN MOISTURE CONTENT, BASIC DENSITY, AND SHRINKAGE CHARACTERISTICS OF THE WOOD OF ALSTONIA BOONEI, ANTROCARYON MICRASTER, BOMBAX BUONOPOZENSE, DIALIUM AUBREVILLEI AND STERCULIA RHINOPETALA

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ABSTRACT

A study was undertaken on the green moisture content, basic density and shrinkage properties for the wood of five Ghanaian species: ***Alstonia boonei*** *(Sinduro),* ***Antrocaryon micraster*** *(Aprokuma),* ***Bombax buonopozense*** *(Akata),* ***Dialium aubrevillei*** *(Duabankye) and* ***Sterculia rhinopetala*** *(Wawabima). The overall green moisture content of the wood species ranged from a low of 51-52% (for* ***D. aubrevillei*** *and* ***A. micraster****) to a high of 177% (for* ***B. buonopozense****), while the overall mean basic density of the wood species ranged from a low of 366 kg/m^3 (for* ***B. buonopozense****) to a high of 738 kg/m^3 (for* ***A. micraster****). Green moisture content appeared to be inversely proportional to the basic density with a correlation coefficient of -0.962. Mean total tangential shrinkage was medium (4.6-4.7%) in* ***A. boonei*** *and* ***B. buonopozense****, and very large (9.0-10.3%) in* ***S. rhinopetala****,* ***D. aubrevillei*** *and* ***A. micraster****. Mean partial tangential shrinkage were small (2.7%) in* ***A. boonei*** *and* ***B. buonopozense****, medium (5.0%) in* ***S. rhinopetala*** *and* ***D. aubrevillei****, and large (6.1%) in* ***A. micraster****. Mean total radial shrinkage was medium (3.6-3.9%) in* ***B. buonopozense*** *and* ***A. boonei****, large (4.4%) in* ***S. rhinopetala****, and very large (5.3-6.3%) in* ***D. aubrevillei*** *and* ***A. micraster****; and mean partial radial shrinkage was medium (2.0-2.5%) in* ***A. boonei****,* ***B. buonopozense****,* ***D. aubrevillei*** *and* ***S. rhinopetala****, and large in* ***A. micraster*** *(3.5%). Except for* ***A. micraster*** *(~ 0.65%) total longitudinal shrinkage was typically less than 0.4%.*

Keywords: Moisture content, basic density, shrinkage characteristics

INTRODUCTION

Ghana is blessed with some 680 naturally growing tree species (Hall and Swaine, 1981). Approximately 420 tree species attain timber size and therefore, are of potential economic value. About 126 of these species occur in sufficient volumes to be considered exploitable as a raw material for the timber industry (Ghartey, 1989). However, only 10 species account for some 90% of timber export sales. The timber production figures in 1999 indicated that 66 species dominated the harvest that year. Four species accounted for 60% of the total production. These were Wawa *(Triplochiton scleroxylon)* 31%; *Ceiba (Ceiba pentandra)* 19%, while Ofram *(Terminalia superba)* and Chenchen *(Antiaris toxicara)* contributed 5% each to the total production. The remaining 62 timber species accounted for 40% of the year's production value (Upton and Attah, 2003). This unbalanced utilisation needs to be addressed to ensure the long term sustainability of these popular species. The increasing world demand for tropical timbers suggests that some of the less well known but commonly found species (known as 'Lesser Used Species', LUS) could be for commercial use.

To allow for increased efficiency and a more judicious use of the forest resource, the Ghana Forest Sector Development Plan (Upton and Atta, 2003) which spans the period 1997-2010 sought to provide assistance and guidance through incentive schemes for the development of the kiln-drying sector, promotion of LUS and modernisation of existing plant and equipment.

TEDB (1994) reported that forest availability of wood species in Ghana indicated that *Alstonia boonei (*Sinduro*), Bombax buonopozense (*Akata*),* and *Sterculia rhinopetala (*Wawabima*)* were 'Plentiful' (i.e. mean volumes of 250-1000 m^3/km^2), while *Antrocaryon micraster (*Aprokuma*)* and *Dialium aubrevillei (*Duabankye*)* were 'Average' (i.e. mean volumes of 50-250 m^3/km^2). Historical commercial log production volumes in 1991 reported by TEDB (1994) were: 'High' (5000 - 20000 m^3/annum) for *B. buonopozense*, 'Medium' (500 - 5000 m^3/annum) for *A. micraster*, 'Low' (100 - 500 m^3/annum) for *S. rhinopetala*, and 'Insignificant' (0-100 m^3/annum) for *A. boonei* and *D. aubrevillei*. In 1997, the reported Annual Allowable Cut for some of the species were: *B. buonopozense* - 45,000 m^3, *A. boonei* - 5,000 m^3, *D. aubrevillei* - 17,000 m^3, and *S. rhinopetala* - 11,500 m^3 (Upton and Attah, 2003).

Based on wood property requirements, the five species under study were characterised as follows (TEDB 1994). (1) *A. boonei* is a lower strength utility species for non structural interior joinery and trim, rotary veneer, plywood, matches, boxes and crates. (2) *A. micraster* is a strong general purpose interior timber that could be used for joinery, mouldings, light structural, light flooring, furniture, veneers for plywood, boxes and packaging. (3) *B. buonopozense* is light, soft non-durable species that may be used for veneer for plywood, interior trim, mouldings, light joinery matches, food containers, carving, and boxes. (4) *D. aubrevillei* is a strong durable species for exterior uses such as sleepers, marine defence, exterior structures, mining timbers, piling, flooring, and handles. (5) *S. rhinopetala* is a dark red close-grained species of good strength that may be used for joinery, fittings, flooring, selected exterior structures, rotary veneer, and plywood.

The wood of these species are now being utilized in Ghana but the basic physical, technological and mechanical strength properties of the Ghanaian species have not been determined. Values in the literature for these properties (TEDB 1994) seem to be values belonging to the species in other countries.

Regardless of the source of a wood product, the user may be primarily interested in the variability that may be encountered in the green moisture content and the basic density of the wood. These are directly related to the weight of logs and green lumber. Information on green moisture content may be of concern to those who design harvesting and transport equipment, purchase wood on a weight basis (such as in pulpwood), or must ship or transport green wood (Haygreen and Bowyer, 1996). Data on basic density is needed in estimating the variability in the strength of a wood product (Haygreen and Bowyer, 1996).

The moisture content of green wood and the basic density of wood vary among species. Within any species, the variations depend on the location, age, and the volume of the tree. Within a single tree, there is a radial variation between moisture content of green sapwood and heartwood, especially in softwoods (Kollman and Côté, 1968, Panshin and de Zeeuw, 1980, Haygreen and Bowyer, 1996; Ofori, 1999). Since denser wood shrinks more than less dense wood, it is expected that variations in basic density might lead to some variation in shrinkage.

Measurements of these physical and mechanical properties would lead to a greater utilisation of the forest resource through a wider exploitation, promotion and exportation of many of the lesser-known species. This work is a contribution to the characterisation of some of the physical and technological properties of the wood of five Ghanaian lesser-used-species – *A. boonei*, *A. micraster*, *B. buonopozense*, *D. aubrevillei* and *S. rhinopetala*.

MATERIALS AND METHODS

Materials

The trees were obtained from three forest reserves: Bobiri Forest Reserve (Moist Semi-Deciduous – North-East sub type, 6°39’ - 6°44’N; 1°17’ - 1°51’W), Pra-Anum Forest Reserve (Moist Semi-Deciduous – South-East sub type, 6°12’ - 6°19’N; 1°9’ - 1°17’ W), and Bonsa River Forest Reserve (5°12’ – 5°29’N; 1°49’ – 1°58’ W) in the Moist Evergreen forest zone.

For each of the five wood species, five trees were extracted from one or two of the three forest reserves. *A. boonei*), *B. buonopozense* and *S. rhinopetala* were obtained from the Bobiri and the Pra-Anum Forest Reserves. The *A. micraster* was from the Bobiri Forest Reserve; while *D. aubrevillei*) was obtained from the Bonsa River Forest Reserve.

Conversion and Sampling

Twenty two (22) to 44 logs each of length 2.5 m were cut from the five trees of each of the five wood species. The diameters of the logs at 1.3 m above ground ranged from 38 – 64 cm. Bigger logs were split into quadrants. The logs and quadrants were numbered and transported from the forest to the laboratory at the Forestry Research Institute of Ghana (FORIG).

The next day, a 20 cm piece was cut off from the thicker (butt) end of each log or quadrant and discarded. Two 10 cm thick discs were then cut from the freshly cut end. One disc was used for moisture content distribution studies while the second one was used for the basic density studies. Another 25 cm thick disc was cut and used for the shrinkage studies. A further 25 cm thick disc was cut from the remaining log or quadrant for the study on seasoning characteristics and kiln schedule determination (Ofori and Brentuo, 2010b). The test samples were wrapped in polythene bags and kept in a deep freezer. The logs or quadrants left, measuring about 1.60 m were sawn into lumber of thickness 25 mm and 50 mm for another study on drying rates.

Moisture Content Distribution

For each moisture content disc, two 2.5 cm strips containing the pith and spatially at right angles to

each other were extracted. The strips were planed to 2 cm thickness. Each strip was marked starting 1cm from the centre of the pith outwards to the bark and then sawn to produce 2 cm x 2 cm square sections. The 2 cm x 2 cm square strips were then crosscut to 2 cm cubes. The green mass (W) of each cube was determined and the sample oven-dried at 101^{o}C to 105^{o}C until constant mass (D) was attained. The moisture content (MC) was then calculated according to the formula:
Moisture Content, MC = ((W - D) / D) x 100 %.

Basic Density

The other 10 cm thick discs earmarked for the basic density studies were similarly converted into 2 cm square sections as the moisture content samples. The sections were extracted from both the sapwood and heartwood regions of the 10 cm discs. Two (2) test samples of 2 cm cubes were cut from the 10 cm long strips. Each cube was soaked in water until it sunk under water or swollen by means of vacuum impregnation with water. The basic density, based on the swollen volume and oven-dry mass of the wood sample, was determined by the hydrostatic or immersion method. The weight of a container and the water it contained were determined. The wood specimen was submerged in the water, and the mass of container plus water plus specimen was again determined. The increase in mass of the container and its contents was equal to the mass of water displaced by the specimen in grams and that was numerically equal to the volume of water in cm^3 displaced by the wood sample. The wood blocks were then oven-dried at 101^{o}C to 105^{o}C to constant mass and the oven dry mass determined. The basic density was then calculated from the formula:
Basic density, kg/m^3 = [Oven-dry mass] / [Volume of water displaced by swollen wood specimen].

Shrinkage

The 25 cm thick discs and quadrants earmarked for the shrinkage studies were sawn to include two 2.5 cm wide strips containing the pith and spatially at right angles to each other. The strips were extracted from both the sapwood and heartwood regions of the discs and quadrants. The strips were planed to 2-cm square sections to give the radial and tangential faces. 2-cm square strips of length 10 cm were cut from the 25 cm long discs from the pith to the bark. The 2 cm x 2 cm x 10 cm specimens were cut from the 25 cm long discs and quadrants, from the pith to the bark. The specimens were air dried at room temperature in the laboratory for a few days, conditioned to 12% moisture content, and later on oven dried. During the air-drying, conditioning, and oven-drying, the specimens were weighed periodically and the dimensions of each specimen were measured using a micrometer screw gauge in the radial and tangential directions, and Vernier callipers in the longitudinal direction.

Shrinkage in drying to the various moisture contents and from the green to 12% moisture content and oven-dried state were calculated for the tangential, radial and longitudinal directions, and was expressed as a percentage using the formula:
Shrinkage = ((change in dimension) /
(green dimension)) x 100%.

RESULTS AND DISCUSSIONS

Green Moisture Content Distribution

No consistent axial variation in moisture content emerged. A summary of the basic statistics for green moisture content of the 5 trees of each of the five wood species are presented in Table 1. The overall green moisture content of the wood species ranged from a low of 51% to 52% (for *D. aubrevillei* and *A. micraster*) to a high of 177% (for *B. buonopozense*). Analysis of variance (ANOVA) indicated that differences between the mean green moisture contents of the five trees within each of the five wood species were highly significant ($p < 0.001$).

Table 1: Summary of mean green moisture content of the five Ghanaian hardwood species

Wood Species	Within tree mean moisture content, %					Statistics for all specimens			
	Tree A	Tree B	Tree C	Tree D	Tree E	Mean All 5 trees	Std. Dev.	Range	Count
A. micraster	49	57	55	50	51	52	7.9	44-78	400
D. aubrevillei	46	52	63	46	55	51	8.1	41-80	370
S. rhinopetala	74	58	60	69	75	68	12.6	47-110	600
A. boonei	123	140	141	133	130	134	15.8	115-173	308
B. buonopozense	149	191	174	235	175	177	33.3	138-294	312

Table 2: Summary of mean basic density of the five Ghanaian hardwood species

Wood Species	Within tree mean basic density, kg/m^3					Statistics for all specimens			
	Tree A	Tree B	Tree C	Tree D	Tree E	Mean All 5 trees	Std. Dev	Range	Count
A. micraster	720	735	742	745	748	738	64.5	573-954	400
D. aubrevillei	667	650	607	702	640	654	46.6	558-789	370
S. rhinopetala	548	611	616	582	602	592	97.3	433-823	600
A .boonei	449	420	413	427	470	437	33.4	365-516	308
B. buonopozense	403	341	368	303	371	366	46.1	255-459	312

Basic Density

The basic density (kg/m^3) was obtained by dividing the oven dry weight (kg) by the weight of water displaced by the swollen specimen (or volume of cube, m^3). Analysis of variance indicated that the differences between the mean basic densities of the sapwood and heartwood of the 5 species were not significant. As an example in the

case of *S. rhinopetala*, heartwood density was 597 kg/m^3 and that of sapwood was 586 kg/m^3, (df = 1, 599; F = 1.657; F_{crit}. = 3.857; P value = 0.1985).
A summary of the statistics of the basic densities of the five wood species studied are shown in Table 2. The overall mean basic density of the wood species ranged from a low of 366 kg/m^3 (for *B. buonopozense*) to a high of 738 kg/m^3 (for *A. micraster*). The analysis of variance indicates that the differences between the mean basic densities of the five trees within each wood species were highly significant (P < 0.001). The 'green' moisture content was inversely proportional to the basic density, with a correlation coefficient of -0.962. The overall mean basic densities compare with the densities at 12% moisture content of 350 kg/m^3 (for *A. boonei*), 440 kg/m^3 (for *B. buonopozense*), 660 kg/m^3 (for *A. micraster*) and 840 kg/m^3 (for *S. rhinopetala*) (ATIBT, 1986).

Shrinkage

Partial shrinkage from green to 12% moisture content and total shrinkage from green to the oven-dry state were expressed as a percentage using the formula:
Shrinkage = ([change in dimension] / [green dimension]) x 100%.

Directional shrinkage in the sapwood was slightly more in the heartwood, but was not significantly different. The combined shrinkage of both the sapwood and heartwood in drying from green to 12% moisture content and to the oven dried state have been summarized in Table 3.

According to the classification of Bolza and Keating (1972), TEDB (1994) and Upton and Attah (2003), the mean total tangential shrinkage values obtained indicate that shrinkage was small [3.5~5.0%] in *A. boonei* (4.6%) and *B. buonopozense* (4.7%), and very large [over 8.0%] in *S. rhinopetala* (9.0%), *D. aubrevillei* (9.5%) and *A. micraster* (10.3%). The corresponding total radial shrinkage values obtained indicate that shrinkage was medium [3.0~4.0%] in *B. buonopozense* (3.6%) and *A. boonei* (3.9%), large [4.0~5.0%] in *S. rhinopetala* (4.4%), and very large [over 5.0%] in *D. aubrevillei* (5.3%) and *A. micraster* (6.3%).

For partial shrinkage, the mean tangential shrinkage values obtained were small [2.5~4.0%] in *A. boonei* (2.7%) and *B. buonopozense* (2.7%), medium [4.0~5.5%] in *D. aubrevillei* (5.0%) and *S. rhinopetala* (5.0%), and large [5.5~7.0%] in *A. micraster* (6.1%). However, the corresponding partial radial shrinkage values obtained indicate that shrinkage was medium [2.0~3.0%] in *A. boonei* (2.2%), *B. buonopozense* (2.0%), *D. aubrevillei* (2.5%) and *S. rhinopetala* (2.3%), and large [3.0~4.0%] in *A. micraster* (3.5%).

The mean total longitudinal shrinkage was between 0.31% for *D. aubrevillei* and 0.65% for *A. micraster*. Typically, total longitudinal shrinkage is only 0.1~0.2% for most species and rarely exceeds 0.4% (Haygreen and Bowyer, 1996). *A. micraster* seemed to exhibit excessive longitudinal shrinkage (up to 0.96%); attention should therefore be paid to structural design detailing in uses where longitudinal stability is important.

The ratio of total tangential shrinkage to total radial shrinkage (T/R) or partial tangential shrinkage to partial radial shrinkage (T_{12}/R_{12}) is used as an index of dimensional stability. The T/R or T_{12}/R_{12} ratios were lower than 1.4 in *A. boonei* (1.18 or 1.23) and *B. buonopozense* (1.31 or 1.35), but typically higher than 1.5 in *A. micraster* (1.64 or 1.74), *D. aubrevillei* (1.79 or 2.00) and *S.*

rhinopetala (2.05 or 2.17). Ratios higher than 1.5 are considered pronounced. This pronounced differential shrinkage is likely to cause wide splits, checks and distortions if the necessary precautions are not taken during the kiln drying of *A. micraster*, *D. aubrevillei* and *S. rhinopetala*.

Table 3: Directional shrinkage data on the five Ghanaian hardwood species

Wood species (Count)*	Green moisture Content %	Total shrinkage (from Green to oven dry)** %				Partial shrinkage (from Green to 12% MC) %			
		Tang	Rad	Long	T/R	$Tang._{12}$	$Rad._{12}$	$Long._{12}$	T_{12}/R_{12}
A. micraster (242)	43 [37-49]	10.3 [7.1-12.1]	6.3 [5.0-9.4]	0.65 [0.34-0.96]	1.64	6.1 [4.3-5.2]	3.5 [2.3-4.7]	0.23 [0.11-0.65]	1.74
D. aubrevillei (228)	51 [36-83]	9.5 [4.7-12.6]	5.3 [1.9-9.1]	0.31 [0.06-0.92]	1.79	5.0 [1.3-7.6]	2.5 [0.2-5.9]	0.15 [0.00-0.66]	2.00
S. rhinopetala (253)	64 [36-124]	9.0 [3.9-15.0]	4.4 [3.0-12.0]	0.36 [0.06-2.20]	2.05	5.0 [2.2-11.0]	2.3 [1.1-8.0]	0.26 [0.01-2.16]	2.17
A. boonei (180)	115 [85-168]	4.6 [3.8-7.0]	3. 9 [2.8-5.9]	0.36 [0.14-0.90]	1.18	2.7 [1.9-3.8]	2.2 [1.5-3.8]	0.22 [0.05-0.78]	1.23
B. buonopozense (175)	151 [115-206]	4.7 [3.3-6.5]	3.6 [2.6-5.6]	0.37 [0.16-0.94]	1.31	2.7 [1.8-3.2]	2.0 [1.3-3.6]	0.26 [0.08-0.84]	1.35

* (Count): No. of specimens used. ** Range in square [ ] brackets.
(T = Tang. = Tangential; R = Rad. = Radial; Long. = Longitudinal; MC = Moisture Content)

Table 4: Correlation between Basic Density and Dimensional Shrinkage values

Correlation	Basic density	Tang.	Rad.	Long.	$Tang._{12}$	$Rad._{12}$	$Long._{12}$
Basic Density	1.000	-	-	-	-	-	-
Tang.	0.968	1.000	-	-	-	-	-
Rad.	0.951	0.876	1.000	-	-	-	-
Long.	0.546	0.436	0.704	1.000	-	-	-
$Tang._{12}$	0.976	*0.988*	0.910	0.566	1.000	-	-
$Rad._{12}$	0.847	0.738	0.946	0.891	0.819	1.000	-
$Long._{12}$	-0.406	-0.336	-0.413	0.236	-0.243	-0.170	1.000

Correlation between Basic Density and Dimensional Shrinkage Values

Correlations between the densities and dimensional shrinkage values have been shown in Table 4. There was a good correlation (84.7 ~ 97.6%) between the Basic Density and the Tangential and Radial shrinkage values of the 5 wood species. Total tangential shrinkage was highly correlated (98.8%) with the partial tangential shrinkage. Similarly, the total radial shrinkage was highly correlated (94.6%) with the partial radial shrinkage.

CONCLUSIONS

The overall green moisture content of the wood species ranged from a low of 51% (for *D. aubrevillei)* to a high of 177% (for *B. buonopozense*). Differences between the mean basic densities of the sapwood and heartwood of the 5 species were not significant.

The overall mean basic density ranged from 366 kg/m^3 (for *B. buonopozense*) to a high of 738 kg/m^3 (for *A. micraster*). Green moisture content was inversely proportional to the basic density, with a correlation coefficient of -0.962.

Mean total tangential shrinkage (from green to oven dry) was small (4.6-4.7%) in *A. boonei* and *B. buonopozense*, and very large (9.0-10.3%) in *S. rhinopetala*, *D. aubrevillei* and *A. micraster*. Mean total radial shrinkage were medium (3.6-3.9%) in *B. buonopozense* and *A. boonei*, large (4.4%) in *S. rhinopetala*, and very large (5.3-6.3%) in *D. aubrevillei* and *A. micraster*.

The mean partial tangential shrinkage (from green to 12% moisture content) were small (2.7%) in *A. boonei* and *B. buonopozense*, medium (5.0%) in *D. aubrevillei* and *S. rhinopetala*, and large (6.1%) in *A. micraster*. The corresponding partial radial shrinkage was medium (2.0-2.5%) in *A. boonei*, *B. buonopozense*, *D. aubrevillei* and *S. rhinopetala*, and large in *A. micraster* (3.5%). Except for *A. micraster* (~ 0.65%), total longitudinal shrinkage was typically less than 0.4%.

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