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ASSESSMENT OF DIMENSIONAL STABILITY OF *GMELINA ARBOREA* WOOD USING MODIFIED GREEN HOUSE DRYER

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Abstract:

The dimensional stability of Gmelina arborea wood was investigated using the modified greenhouse dryer. Daily temperature and relative humidity patterns in the Greenhouse and air-dry shed were assessed to determine their influence on the moisture variation, density, volumetric shrinkage and volumetric swelling of Gmelina arborea after drying for 40 days. Wood samples were obtained from a twenty-year old plantation at the Federal University of Technology, Akure. For laboratory work, 45 freshly cut samples of 20mm x 20mm x 60mm were dried in the oven at 105°C for 24 hours until they attained constant weight while for field experiment, 45 freshly cut samples of 25mm x 75mm x 450mm Gmelina arborea wood were loaded into the Greenhouse dryer and air-dry shed respectively. The result obtained for average daily temperature and relative humidity pattern in the greenhouse for the period was 31.17°C and 77.29% respectively while 22.47°C and 84.57% were recorded for air drying shed. The attainable moisture content for Green house dryer after 40 days of drying was found to be 19.05% while air-dry medium was 31.46% which showed that greenhouse medium dried the wood below fibre saturation point, a better performance over air drying method. Wood samples of Gmelina arborea in the Greenhouse dryer were found to be more stable in terms of swelling and shrinkage attained. The result of the overall mean density for Gmelina arborea wood was found to be 463.89kg/m^3 which classified the wood as non-refractory because of its low density.

Key words: *density; shrinkage; moisture content; moisture variation; volumetric swelling.*

INTRODUCTION

The fundamental reason for drying wood is to improve its dimensional stability and thereby reducing construction error. Wood is dried before use to ensure that dimensional changes are kept within drying process. Lumber that is not dried under controlled environment conditions is prone to warping, staining and other defects that diminishes the quality (Nyle 2006). Wood must be dried to the equilibrium moisture content of the environment to prevent absorption and desorption caused by fluctuation in the weather. The primary objective of drying wood is to produce a quality product by minimizing any degrade, thereby ensuring sustainable use of wood. Wood dried below 20% moisture content is not susceptible to decay or sap staining. Removal of most of the water in the wood reduces lumber weight by 35% or more. Drying increases the stiffness, hardness and strength of wood. Most species of wood increase their strength characteristics by at least 50 percent during the process of drying to 15% moisture content (Joseph *et al.* 2000).

Most wood users in Nigeria do not appreciate the importance of drying before utilisation; hence, large quantities of timber are used immediately after conversion from logs leading to insect attack and fungal infestation. Warping of entrance doors in cold weather has been reported by Kubler (1980) to be a result of shrinkage with a lot of deformities and damages caused. These problems therefore necessitated the research study to investigate the variation in moisture content and the dimensional stability of *Gmelina arborea* since this specie is now largely used for all forms of construction due to decline in the supply of wood from natural forest.

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Gmelina arborea is a fast-growing, deciduous tree that can grow up to 30m in height and over 80cm dbh (Diameter at breast height). The tree usually grows to about 20m with a clear bole of 6 to 9m and a high taper. The species is moderately adaptable and survive swell on a wide range of soil types: acid soils, calcareous loams, and lateritic soils. It performs best on fresh, well-drained, fertile soils where rainfall annually varies from 1200 to 4500mm, temperature range from 12 to 45^{0}C and elevations range from sea level to 1000m, (Soerianegara and Lammens 1994).

General research objective

The general objective was to study the variation in moisture content and the dimensional stability of *Gmelina arborea* using Greenhouse dryer.

The specific objectives were to:

1. Determine the moisture content and density variation along and across the *Gmelina arborea*.
2. Assess the influence of temperature and relative humidity of the Greenhouse on the drying rate of *Gmelina arborea.*
3. Compare the performance of modified Greenhouse dryer with Air drying shed.

METHODS

Study area

The experimental greenhouse dryer and air-drying shed were set up at the Central Laboratory, Federal University of Technology, Akure (FUTA), Ondo State, located on the longitude of 7^{o}29^{1}N and latitude of 5^{o}13^{1}E which lies in the tropical rainforest zone of Nigeria.

MATERIAL AND EQUIPMENTS

Material for this study was freshly cut wood samples of *Gmelina arborea* obtained from twenty-year old plantation at the Federal University of Technology, Akure (FUTA), Ondo State, Nigeria. Equipments for this study were weighing balance, thermometer, hygro-thermometer, air drying shed and greenhouse dryer (Fig. 1 and 2) at the Central Laboratory, FUTA.

Fig. 1.
Wood drying under a drying shed.

Fig. 2.
Greenhouse dryer built in FUTA.

Preparation of timber samples

Three stands of *Gmelina arborea* were freshly felled at Department of Forestry and Wood Technology *Gmelina* Plantation of the Federal University of Technology, Akure. Five sample sizes of 25mm x 75mm x 450mm from the three trees were selected each from three different sampling heights of 25%, 50% and 75% (top, middle and base) of each log making a total of 90 samples. Another five samples each of 20mm x 20mm x 60mm were selected each from the top, middle and base longitudinally while outer and inner part were taken transversely from the trees. The study was divided into two phases: laboratory and field work.

Laboratory work: Sample sizes of 20mm x 20mm x 60mm selected from top, middle, base (along the stem), outer and inner (across the stem) were used in this phase to determine initial moisture content, density and moisture content variation along and across the bole.

Determination of moisture content of *Gmelina arborea*

The wood samples were first weighed on the weighing balance to know the initial green weight and then dried in the oven at 105°C for 24 hours until it attained constant weight. The wood was reweighed again to obtain the dry weight of the samples. The initial moisture content was determined using:

$$Moisture\ content = \left(\frac{Green\ weight - Oven\ dry\ weight}{Oven\ dry\ weight}\right) \times 100)\ [\%] \quad (1)$$

Determination of moisture content variation

The initial weight and oven dry weight of the test samples 20mm x 20mm x 60mm selected from the outer and inner portion from the top, middle and the basal parts of the trees were taken to determine the portion that contains more moisture across and along *Gmelina arborea* tree.

Density determination of *Gmelina arborea*

The density of the wood specie was determined using the following formula:

$$Wood\ density = \frac{Oven\ dry\ weight\ of\ the\ wood}{oven\ dry\ volume\ of\ the\ wood}\ [kg/m^3] \quad (2)$$

Determination of volumetric shrinkage

The volume of the wood samples was taken at the green stage and also at the end of the drying period to determine the volumetric shrinkage along and across the tree using:

$$Volumetric\ Shrinkage = 100\left(\frac{Wet\ volume - Oven\ dry\ volume\ of\ the\ wood}{Wet\ volume}\right)\ [\%] \quad (3)$$

Determination of percentage volumetric swelling

The volumetric swelling depicting the change in the volume when immersed in water was determined using:

$$Volumentric\ swelling = \left(\frac{Final\ volume - Initial\ volume}{Initial\ volume}\right) \times 100\ [\%] \quad (4)$$

Assessment of variation in temperature and humidity

The daily temperature and relative humidity pattern of the greenhouse and air drying shed were assessed by taking daily temperature readings at 2 hours interval from 6am to 6pm using thermometer and hygrometer respectively, the values obtained during the period for maximum and minimum temperature in the morning, afternoon and evening were recorded. This was used to determine daily periodic mean temperature and relative humidity.

Determination of periodic moisture loss/attainable moisture content

This is determined by using estimated oven dry weight and current moisture content according to Siau, 1998:

$$Estimated\ oven\ dry\ weight = \left(\frac{Wet\ weight}{100 + (\%Moisture\ content)} \times 100\right)\ [g] \quad (5)$$

$$Current\ moisture\ content = \left(\frac{Current\ weight}{Estimated\ oven\ dry\ weight} - 1 \times 100\right)\ [\%] \quad (6)$$

Experimental design

The experimental design that was used for this research was 2 x 3 factorial experiments in a Completely Randomized Design (CRD) replicated five times. Data collected was subjected to descriptive and graphical data presentation while statistical analysis was carried out using Statistical Packages for Social Sciences (SPSS) to determine moisture variation, density, swelling and shrinkage of the wood samples. Follow up test was carried out using Duncan Multiple Range test (DMRT) to test for the significant differences among the levels.

RESULTS AND DISCUSSIONS

Temperature pattern in the greenhouse and air-dry shed at different hours of the day

The intensity of temperature in the greenhouse dryer (GHD) and air dry shed at different hours of the day for the period of drying is shown in Fig. 3. The temperature in the GHD increased from 23.0°C to 30.0°C between an hour of 6am to 12pm and at 4pm the temperature increased to 34.0°C and drops back to 25.1°C at 6pm. The high intensity of the sun during the day was responsible for the highest temperature increased between 2 – 4pm. The temperature in the air-dry shed increased from 22.88°C to 24.94°C between an hour of 6am and 12pm. The temperature reaches a peak of 24.86°C and drops back to 22.0°C by 6pm. It was therefore observed that the temperature gained was higher in the GHD than the air dry shed. Variation in temperature obtained in both media is similar to those obtained by Ogunsanwo and Amao (2011). It was recorded that the GHD temperature was higher than that of the air drying shed. It can be concluded that the temperature rate of a medium is in relation with the ambient weather of the day because heat energy from the sun was trapped and conserved for in the GHD.

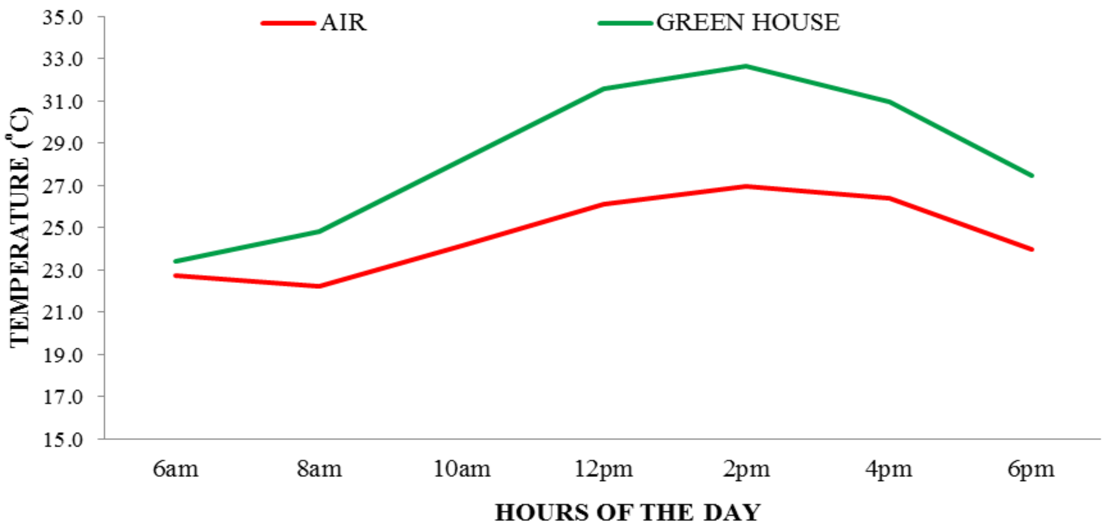

Fig. 3.
Temperature pattern in the Greenhouse and Air-dry shed at different hours of the day.

Hourly Relative Humidity Pattern in the Greenhouse and Air-Dry Shed

The rate of Relative humidity in the greenhouse and air dry shed is shown in Fig. 4. Relative humidity in the greenhouse was 90% at 6am and dropped to 55% by 2pm but later increased to 85% at 6pm during the period. In the air-dry shed, relative humidity decreased from 90% at 6am to 80% at 2pm but increased to 86.19% at 6pm. Relative humidity was high in both Greenhouse and air-dry shed during this period as a result of frequent rainfall but relative humidity in the air dry shed was higher than in the greenhouse between 8am and 4pm due to exposure to ambient weather conditions. The pattern of variation recorded in both media was similar to early observation by Uetimane (2010), which stated that relative humidity of a medium decreased with increase in temperature. The high relative humidity recorded for the media may be as a result of frequent rains during the drying period (July 25th to September 1st, 2014). It can also be concluded that the rate of relative humidity of the medium is indirectly proportional to the temperature of the day and the drying period of the season; the higher the temperature, the lower the humidity recorded.

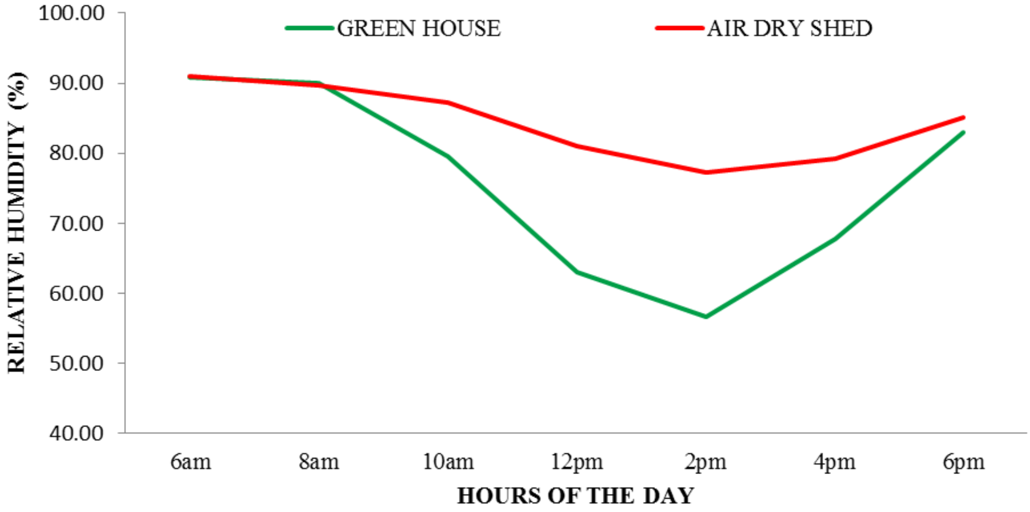

Fig. 4.
Relative Humidity pattern of greenhouse and Air-dry shed at different hour of the day.

Assessment of mean daily temperature and relative humidity patterns of the greenhouse dryer and air-drying shed

This study commenced on July 25th, 2014 at the middle of rainy season and was terminated on 1st of September, 2014 for proper assessment of mean daily temperature and relative humidity of the media. The experiment was carried out for 40 days during which the wood specie attained constant moisture content. The mean daily temperature and relative humidity was taken both in the greenhouse dryer and in the air-dry shed and the pattern of variation recorded is shown in Fig. 5 and 6. It was observed that on the eighteenth day (18), the temperature inside the greenhouse was 31.17°C with a relative humidity of 77.29% and the low temperature of 22.76°C with the relative humidity of 90% on the 29th day. The highest temperature observed in the air drying shed was 33.24°C with a relative humidity of 78.57% in day thirty-one (31) and the lowest mean temperature of 22.47°C with the relative humidity of 84.57% was also observed on the 26th day. It is therefore applicable that the daily mean temperature was higher in the greenhouse dryer than the air-dry shed because the higher the temperature in the greenhouse, the lower the relative humidity and vice versa and in air-dry shed, the lower the temperature, the higher the relative humidity. This observation is similar to the work of Wergert (2006). It was recorded that there is always relationship between temperature and relative humidity of a medium. Higher temperature performance of the media will definitely improve during the dry season due to high sun precipitation.

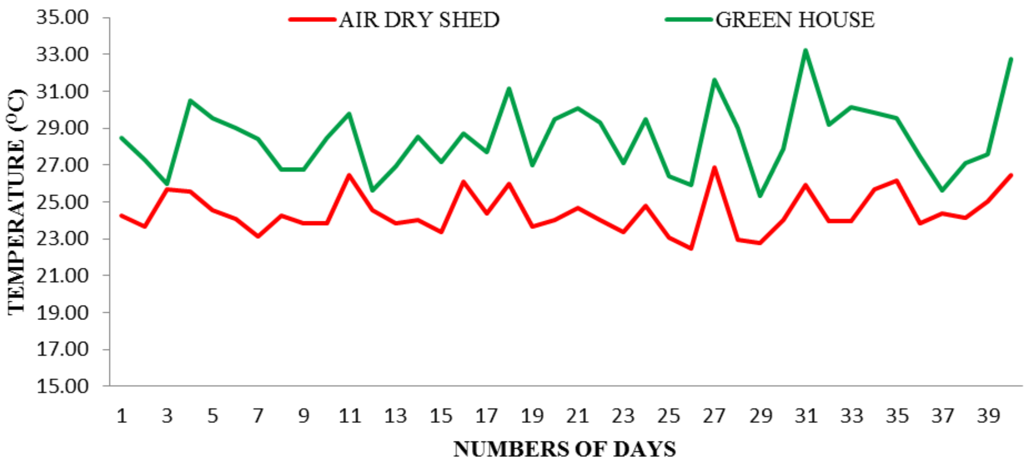

Fig. 5.
Temperature pattern of greenhouse and Air-dry shed at different days.

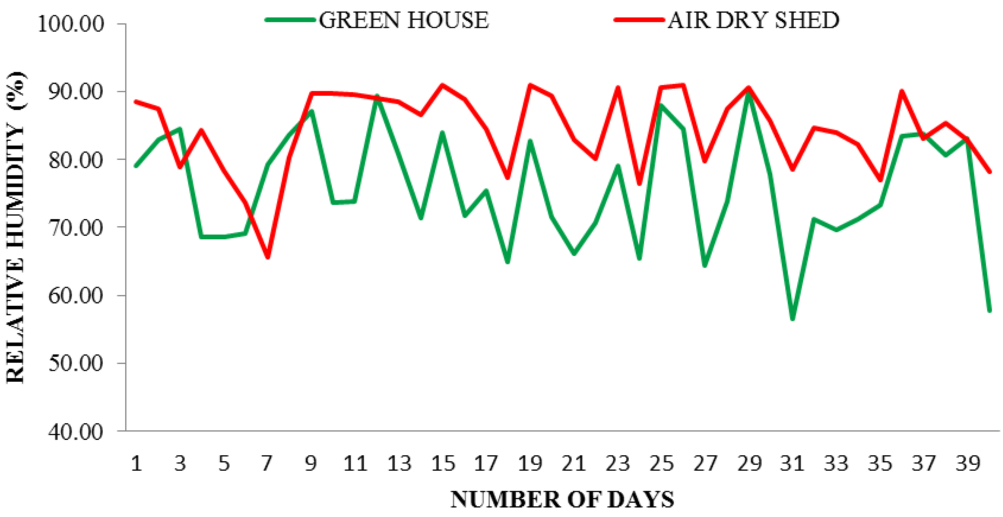

Fig. 6.
Relative Humidity pattern of Greenhouse and Air-dry shed at different days.

Effect of bole location on the moisture content variation of *Gmelina arborea*

The mean initial moisture content of *Gmelina arborea* at green stage was 145.37% for the top, 171.82% middle, 167.05% bottom (longitudinally), 159.35% outer layer and 163.48% for the inner layer (across the bole). The effect of tree location on the moisture variation of *Gmelina arborea* is shown in Table 1. The moisture variation recorded along top, middle and bottom after drying was 15.57%, 17.61% and 17.45% respectively. Variation in moisture content along the *Gmelina arborea* bole may be due to the nature of moisture passageways or wood structure as explained by Langrish and Walker (1993). These pathways consist of cavities of the vessels, fibres, ray cells, pit chambers, pit membrane openings, intercellular spaces and transitory cell wall passageways. The different size of vessels along the tree stem may be a good reason for the moisture variation. The different size of vessel which resemble pipe of varying sizes will enable difference in water holding capacity of the *Gmelina arborea* along the tree stem and it determine the porosity of the wood cell, according to Siau (1984). This variation in moisture variation may help in reducing drying defect like splits and cracks. This is a condition where there is tendency for the outer layer of the wood to dry faster than the interior one. The excess moisture at the middle of the *Gmelina arborea* bole will redistribute itself throughout the wood until the chemical potential is uniform throughout, resulting in zero potential gradient at equilibrium (Skaar 1988). The flux of moisture attempting to achieve the equilibrium state may be assumed to be proportionate to the difference in moisture content, and inversely proportionate to the path size over which the potential difference acts, thereby preventing splits and cracks (Keey *et al*. 2000). To establish the importance of fact presented above, Fig. 7 showed that moisture content after drying across outer (16.73%) is smaller compared with the inner moisture (17.02%). This will allow effective distribution of moisture within the wood cell during drying. The analysis of variance for the parts is not significant while the portion and interaction between parts and portion is significantly different as presented in Table 2.

Table 1
The overall result of the tests carried out on the samples selected along the length of Gmelina arborea tree

Parts	*MC (%)*	*Moisture Variation (%)*	*Density (kg/m^3)*	*Vol.Shrinkage (%)*	*Vol. Swelling (%)*
Top	*145.37^b*	*15.57^b*	*482.25^a*	*9.26^a*	*9.57^a*
Middle	*171.82^a*	*17.61^a*	*452.38^b*	*9.30^a*	*8.83^a*
Bottom	*167.05^a*	*17.45^a*	*457.05^b*	*8.65^a*	*7.74^a*
SE±	*3.73*	*0.31*	*5.61*	*1.02*	*1.02*

Means with the same letter are not significantly different at 5% probability level.

Table 2

Result of Analysis of Variance for Effect of Parts and Portion on all the variable

Source	*df*	*Moisture variation (%)*	*Moisture content (%)*	*Density (kg/m³)*	*Vol. shrinkage (%)*	*Vol. swelling (%)*
Pts	*2*	*38.674**	*155.96 ns*	*7747.07**	*25.44 ns*	*25.44 ns*
Pt	*1*	*1.989 ns*	*13.25**	*950.31 ns*	*3.461 ns*	*3.461 ns*
*pts * Pt*	*2*	*7.091 ns*	*68.78**	*5390.08**	*60.74 ns*	*60.74 ns*
Error	*72*	*2.962*	*10.29*	*42.8781*	*31.14*	*31.14 ns*

**= Significantly difference at 0.05 probability level, ns=Not significantly difference.*

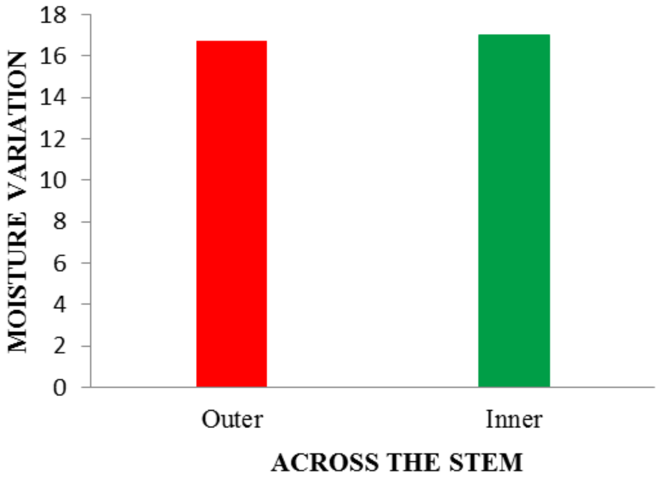

Fig. 7.
Moisture content distribution across Gmelina arborea.

Density variation across and along *Gmelina arborea* stem

The density recorded across the girth was 467.14kg/m^3 and 460.65kg/m^3 for the outer and inner portion of the tree respectively (Fig. 8). The result of the overall mean density was found to be 463.89kg/m^3, due to this, *Gmelina* wood was classified to be in the low density group using the classification method of Owoyemi *et al*. (2013). Low density wood absorbs moisture faster due to large pores (Plumtre and Jayanetti 1996). The inner portion (cell lumen) of *Gmelina arborea* will dry faster than the outer portion (cell wall) of the wood. High density part is more complex and its permeability to moisture is much less than the low density part, making it more difficult to dry. This kind of variation in the *Gmelina arborea* density between the inner and outer part will enable drying the wood to equilibrium moisture content without any degrade. When the wood is subject to drying, the free water held by capillary forces only will be the first to go off. Physical properties, such as shrinkage and strength are generally not affected by the removal of free water in the cell lumen. This will allow the wood to reach fiber saturation point because the cell wall will still be saturated with water after the cell lumen has been empty. It is normal drying condition for the inner part of the wood to dry faster than the outer portion because it helps to prevent drying defects (Walker *et al*. 1993). There was no significant difference between density of the middle and bottom but the density of the top is significantly different as shown in Table 1. The analysis of variance for the portion is not significant while the parts and interaction between parts and portion is significantly different as presented in Table 2.

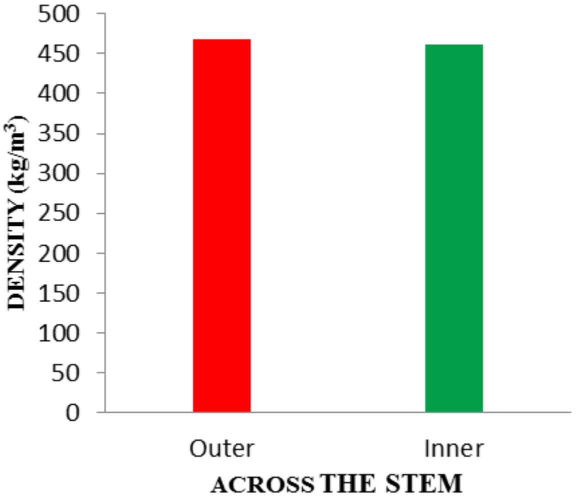

Fig. 8.
The density across Gmelina arborea tree.

Effect of location and portion on volumetric shrinkage and swelling of *Gmelina arborea*

The volumetric swellings recorded were 9.57%, 8.83% and 7.74% while the percentage shrinkages recorded were 9.30% and 8.65% for the top, middle and bottom respectively (Table 1). Shrinkage and swelling from the pith outwards, or radially, is usually considerably less than the tangential shrinkage, while longitudinal (along the grain) shrinkage and swelling is so slight and usually negligible. The longitudinal shrinkage is usually between 0.1% to 0.3%, 2% to 6% on radial direction and 5% to 10% on the tangential direction according to Walker *et al*. (1993). All the wood samples for shrinkage and swelling were along and across *Gmelina arborea* growth ring, hence, the reason for swelling and shrinkage in both directions. The differences in the shrinkage and swelling may be as a result of the following reason; the alternation of late wood and early wood increments within the annual ring; the features of the cell wall structure such as microfibril angle modifications and pits; the influence of wood rays on the radial direction and the chemical composition of the middle lamella of *Gmelina arborea* (Kollmann and Cote 1968). The swelling and shrinkage can be reduced by treating the wood with chemicals to replace the hydroxyl groups with other hydrophobic functional groups of modifying agents (Stamm 1964). Analysis of variance in Table 2 revealed that there was no significant difference in the percentage swelling and shrinkage along the length. The percentage volumetric swelling obtained across the girth was 8.91% and 8.51% while 9.55% and 9.36% was recorded as volumetric shrinkage for the outer and inner portion of the bole respectively as shown in Fig. 9 and 10.

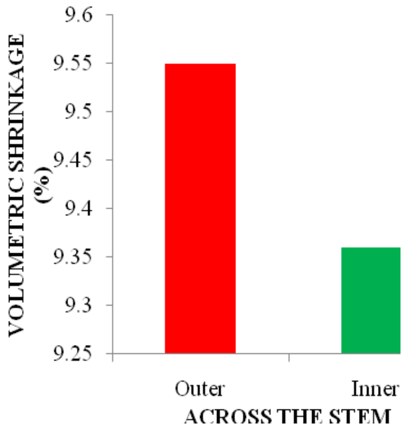

Fig. 9.
Volumetric shrinkage across Gmelina arborea tree.

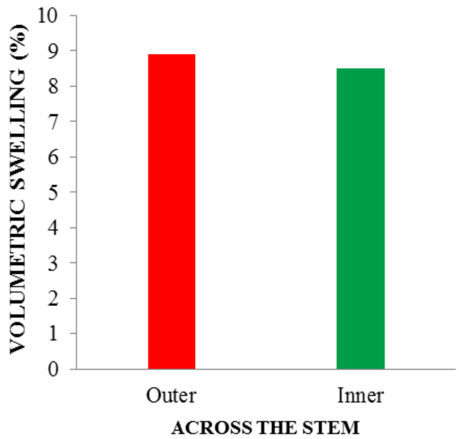

Fig. 10.
Volumetric swelling across Gmelina arborea tree.

Effect of Drying Media on the attainable Moisture Content

The overall percentage final moisture content attained after 40 days by *Gmelina arborea* were 19.05% and 31.46% for Green house and air dry media respectively (Fig. 11). There was significant difference in the overall percentage final moisture content attained by the wood specie and through the drying media. The variation in the moisture content attained by the wood specie could be as a result of different drying media. Wood samples dried in the Greenhouse were able to attain lower moisture content because the solar energy was trapped and conserved for use compared to the samples in the air-drying which was affected by exposure to high humidity caused by the rainfall. The higher moisture loss by wood samples in the Greenhouse may be as result of high temperature attained, low relative humidity and accelerated air flow by the circulating fan. Siau (1984) and Walker *et al.* (1993) agreed to the fact that temperature influences the drying rate by increasing the moisture holding capacity of air as well as accelerating the rate of diffusion of moisture within the wood cells, lower relative humidity enhances higher drying rate and air flow improves the movement of water vapour from the surface of the wood.

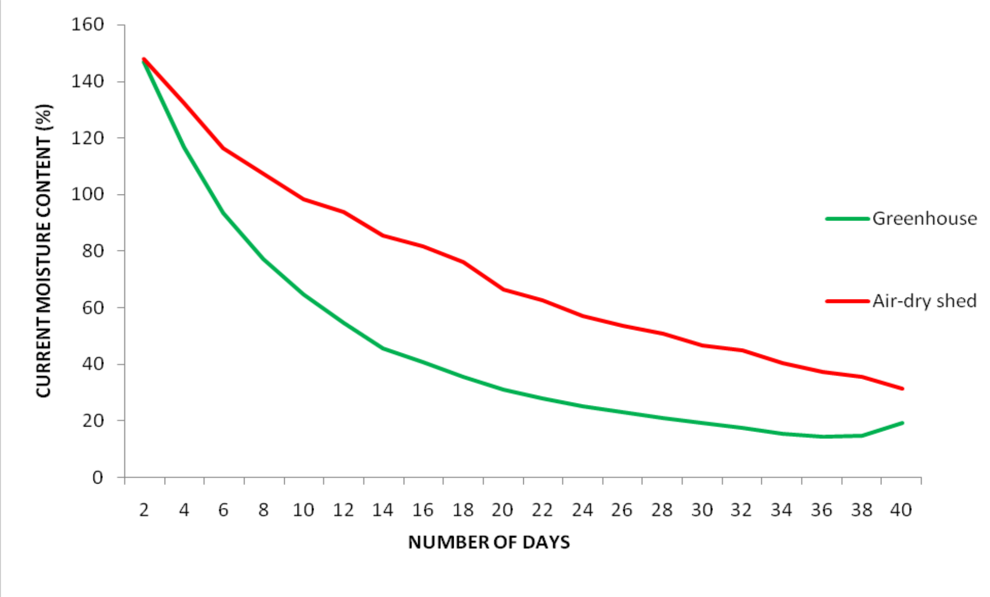

Fig. 11.
Rate of percentage current moisture content in the Greenhouse and Air-dry shed at two days interval.

CONCLUSION

Density variation recorded across *Gmelina arborea* wood for this study could be of great help towards attainment of stable condition during drying. The outer part of the wood contains fewer pores while the inner layer of the wood species are more porous and this could have contributed to drying the wood to 19% M.C without any degrade because of variation of moisture in the porous cells and well distribution of moisture from the inner to the outer layer during drying. This stable condition was obtained using modify Greenhouse dryer and it may be a good reason for preference over air drying shed. Although, the wood showed large increase in volumetric swelling along and across the bole, this could be stemmed by appropriate methods to modify the hydroxyl group of the wood in order to reduce the affinity of the wood to atmospheric moisture and a better way of making *Gmelina arborea* wood stable by reducing the hygroscopicity of the wood. The attainable temperature in the modify Greenhouse dryer discouraged the growth of mould that may result from presence of moisture in the wood because the wood dried below the fibre saturation point (25 – 30%). *Gmelina arborea* must be properly dried before use to improve the wood quality and enhance its stability/durability in service. To attain lower moisture content in wood within a very short period of time, modified Greenhouse dryer can be adopted as a viable alternative to air drying.

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