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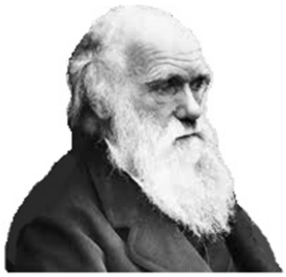

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Seasoning technologies of *Gmelina arborea* Roxb. lumber species grown at Bonga, SNNP, Ethiopia

Getachew Desalegn, Gemechu Kaba***, Anteneh Tesfaye** and **Saifu Amanuel**

Ethiopian Environment and Forest Research Institute, Forest Products Development, Innovation Research and Training Center, Addis Ababa, Ethiopia

*E-mail address: gkaba17@gmail.com

ABSTRACT

Quality and performance of wood and wood-based products have been seriously affected by the major factors, among which moisture content (MC), inappropriate drying (seasoning) and density are the preceding ones. A study was conducted on *Gmelina arborea* lumber with the main objective of determining some imperative seasoning and density characteristics of the lumber that will help determine its wood quality and decide proper utilization. *Gmelina arborea* logs were harvested from Bonga trial site of Central Ethiopian Environment and Forest Research Center (CEE-FRC). The experimental design for seasoning and density was complete randomized design. The experiments were conducted in air and kiln seasoning methods. Mean initial moisture content (IMC) of samples were determined using oven and MC for air seasoning stack was 143.80%, while for kiln seasoning was 120.19%. The final MC to reach to about 12% MC in air took 210 days, while kiln seasoning took 13.5 days. Kiln seasoning rate of *Gmelina arborea* lumber was 15 times faster than air seasoning. The species was classified as slow and fairly rapid air and kiln seasoning lumber species, respectively. When *Gmelina arborea* lumber seasoned from green to 12% MC, mean shrinkage (%) characteristic values: Tangential (3.63%), radial 1.58%), and volumetric (5.11 %). Mean density of *Gmelina arborea* lumber species at green (initial), basic and oven dried and at 12% MC was 940,400, 430 and 420 kg/m^3, respectively. The density at 12% MC, (420 kg/m^3) classified as light density lumber species. Gmelinaarboreashown good quality lumber characteristics, comparable with many indigenous and homegrown exotic lumber species in density, seasoning rate and shrinkage characteristics.

Keywords**:** Defects, density, lumber quality, seasoning defects, shrinkage and uses, *Gmelina arborea*

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1. INTRODUCTION

The demand for lumber to be used in industries, construction and energy sectors in Ethiopia has been highly exceeding the supply. Based on the annual incremental yield of forests, demand and supply for the year 2020 has been projected to 132.5 million m^3 and ~ 28.7 million m^3, respectively [6]. This indicated that demand of forest products sectors in Ethiopia is 4.6 times higher than the supply. To satisfy the ever-increasing demand of consumers, large quantities of lumber, panel and fiber products are being imported from different countries with hard currency. The country spends 55.2 million American dollar/year to import different wood products with an average increment of 13.7%/year between the years 2005-2013 [23].

Even though more than 300 indigenous and homegrown exotic tree species are available in Ethiopia their wood quality, suitability and the potential as lumber are not yet investigated and realized. Due to this many wood industries still prefer and continued to highly depend on limited lumber species and imported wood and wood-based products. The quality and performance of wood and wood-based products have been seriously affected by the physical and mechanical properties of the wood [15]. The moisture content (MC), inappropriate drying (here after, seasoning) and density have direct influence on different wood characteristics [7-10]. About 75% of the manufacturing problems in furniture industries are related to inappropriate moisture content of lumber [9, 11, and 20].

Moisture content, density, mechanical characteristics, seasoning and shrinkage characteristics, seasoning rates and defects, workability, anatomy, chemical composition and technologies of utilization are among the major factors that determine the quality, suitability and rational utilization of wood and wood products [8]. Increasing efficiency of utilization of forest products can be attained through product diversification, value addition and maximization of uses of wood and wood-based products [7].

Import substitution and export promotion will be possible in Ethiopia after determining the different characteristics, quality and suitability of each lumber species [8, 9]. *Gmelina arborea* is one of the exotic tree species introduced to Ethiopia. It is one of the species for which the wood characteristics and seasoning technologies is not studied and utilized in Ethiopia. It is worth thus, to undertake research on lesser known lumber species such as *Gmelina arborea* that is not yet known by processers, construction sectors, manufacturers and end users of the country.

The general objective of this study was to investigate the different seasoning and density characteristics, generate technical information on seasoning and density characteristics, appropriate utilization technologies, and assess potential uses of *Gmelina arborea* sawn lumber.

Specific objectives were to:

(i) appraise appropriate seasoning methods for the lumber

(ii) determine appearance, moisture content, seasoning characteristics, seasoning rate, shrinkage characteristics, and density of the lumber at different MC levels

(iii) observe bio-deterioration attack during and after seasoning, and

(iv) search potential uses of the lumber. Therefore, this research report includes the results on imperative lumber seasoning and density characteristics, and potential uses of *Gmelina arborea* lumber tree species grown in Bonga, Ethiopia.

2. MATERIALS AND METHODS

2. 1. Study species and growth performance

Gmelina arborea Roxb. (Family: Verbenaceae), the study tree species has been known to be fast growing and provide high yield ranging from 20-25 m^3/ha/year) with impressive exceptions of over 30 m^3/ha/year [5, 16] and 18-32 m^3/ha/year [3, 16]. The tree species has been introduced to Bonga, Aman and Tole Kobo and showed good adaptability and good height and diameter growth performance at these sites. It is native from Pakistan south to Sri Lanka and east to Myanmar, Thailand, Vietnam and southern China. It is extensively planted as a fast-growing tree in tropical areas of Africa, Asia and America. In tropical Africa, it is planted in many countries, and large-scale plantations are found in Senegal, Gambia, Sierra Leone, Cote d'Ivoire, Mali, Burkina Faso, Ghana, Nigeria, Cameroon and Malawi. The total area of *Gmelina arborea* plantations in Africa has been estimated at 130,000 ha [5, 16].

Bonga-Keja site located 449 km from Addis Ababa and 6 km west of Bonga town on the way to Mizan. Bonga belongs to SNNP (South Nations Nationalities and People) region of Ethiopa. Bonga site has an altitude of 1700 m, latitude 07°16 and longitude 36°15. The site has mean annual rainfall of 1,700 mm and mean annual temperature of 21 °C [16]. In Ethiopia, *Gmelina arborea* available at CEE-FRC growth trial research sites of Bonga, Bebeka, Tole Kobo, Aman [16].

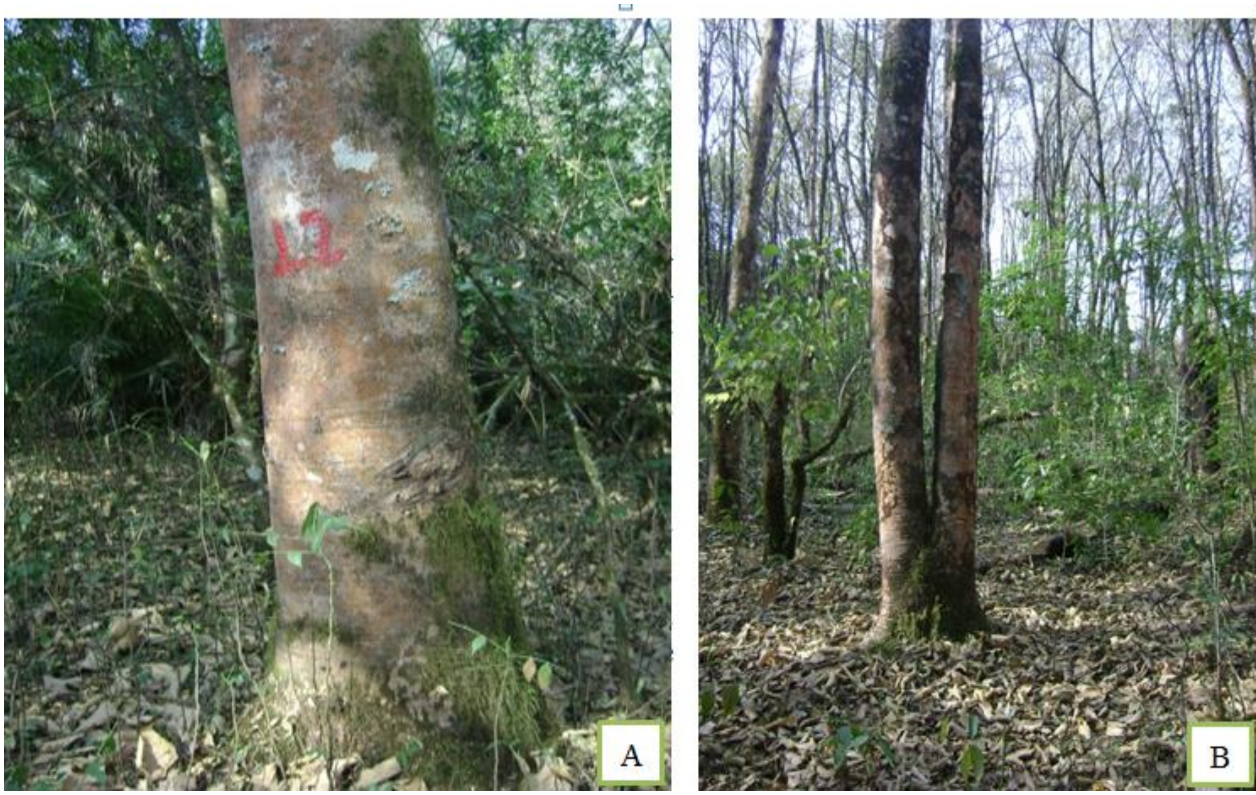

Figure 1. *Gmelina arbora* trees with clear (A) and forked (B) boles at Central Ethiopia Environment and Forest Research Center growth trial research station at Bonga-Keja.
[Photos collection by Getachew D.].

Seeds of *Gmelina arborea* were introduced to Ethiopia in early 1980. The Bonga growth trial site where sample trees harvested for this study was established 1983 summer time (**Figure 1**). It revealed about 100% survival after 17 years with a mean height of 15.4 m and DBH of 20.8 cm [16]. The base of the trees was swollen and the bark thickened. Poor stem form with sweeps and crooks. There was no regeneration and no undergrowth in *Gmelina arborea* stands, due to total canopy closure. The trees did not have clear bole and most of the stems were forked [9]. According to [3, 5, 6, 9, 16], *Gmelina arborea* is deciduous medium-sized tree up to (30-40) m tall; bole cylindrical, frequently bent, up to (80-140) CM in diameter, at base slightly swollen, without buttresses; bark smooth or scaly, corky, grey to yellowish grey or pale brown; crown with widely spreading branches. Form the tree poor to acceptable, light demanding, it has ability of coppice, frost and termite resistant [6, 16].

2. 2. Sample trees selection and harvesting (sampling techniques)

In 2015, samples of *Gmelina arborea* were harvested from Bonga. The *Gmelina arborea* trees that have mean height of 20.6 m, mean breast height diameter (dbh) of 36.2 cm were harvested at the age of 32 years. A total of sixteen matured trees that have witha total volume of 9.3 m^3 at merchantable log size were used in the study. Trees were felled, cross- cut into a series of 2.5 m long logs up to top merchantablediameter of 20 cm [9].

2. 3. Log sawing and sample preparation

Figure 2. *Gmelina arborea* logs (2a) arranged for sawing (2b).
[Photos collection by Getachew D.].

The harvested sample trees were transported to Forest products Development, Innovation Research and Training Center (FPDIRTC) while green (>30% MC) for the preparation and testing (**Figure 2a**, **2b**). Logs were sawn into 3 cm thick boards using mobile, circular sawmill by applying flat sawing method (Figure 2b).

Sawn boards were converted to samples with appropriate dimensions and numbers for each wood characteristic test. The laboratory tests were conducted following the ISO standards/ protocols (ISO 3129, 3131). From the sawn boards 24 defect- free samples boards were selected and prepared. The samples were used to conduct the seasoning process and determination of the seasoning characteristics using natural air and kiln seasoning technologies. The green (initial) MC of lumber species was determined using small sections (having 1.2 cm length) cross-cut from both ends of sample boards. Samples with 2 cm width × 2 cm thickness × 3 cm length at green state were used to determine shrinkage characteristics. This samples were also used to determine the density values of the species at different MC using mathematical formulae [13, 19].

Stacking sawn boards: Sawn boards were transported to the air seasoning yard and compartment kiln-seasoning chamber (**Figure 3**) areas. Boards of the species were stacked horizontally in vertical alignments separated by well-seasoned, squared, uniform sized standard stickers with 3 cm spacing between successive boards. The stickers were placed at an equal distance across each layer of lumber aligned one on top of the other from bottom of the stack to the top. This alignment helped to separate boards, facilitate uniform air circulation, minimize warp, avoid stain and decay occurrence during the seasoning process. The dimension of stickers adapted from Sweden standard.

Figure 3. Seasoning stacks of *Gmelina arborea*.
[Photos collection by Getachew D.].

To minimize warping, heavy stones weighing about 50 kg/m^2 were loaded on stack at a spacing of 0.75 m [12]. The ends of boards were made equal in both directions. The control sample boards were properly distributed and positioned in the pockets prepared in different layers of each stack. The control sample boards were prepared and placed in the stack to determine the progress of seasoning (moisture reduction rate). Boards for air seasoning were stacked under shed without direct interference of moisture, rainfall or sunshine. Boards were stacked on firm foundations/ yards having 45 cm clearance above the ground and a dimension of 1.80 × 0.45 × 4 m. The boards were aligned in a north-south direction where the ends were not exposed to the direction of the wind and to facilitate good air circulation. Boards for kiln seasoning were stacked out of the kiln on the transfer carriage having a dimension of 2.7 × l.6 × 0.30 m and placed in the kiln-seasoning chamber. The experiments were conducted using oven/ microwave, air and kiln seasoning methods. To determine initial moisture content of the stack sections were cut from control sample boards and dried using oven drying machine. Weighing of sections at 4 hours interval was carried out as soon as samples were withdrawn from the oven to minimize moisture absorption and desorption [19]. The process was continued until the difference between two successive weights of each specimen is between 0.1-0.2 g and the oven- dry weight were taken as the final weights [10, 22, 26]. The average intial and final Mc of the stack were caliculated using the ISO standard 3130.

Kiln seasoning**:** The conventional type of artificial kiln seasoning machine was used in this study. The machine is well insulated and has about 2.5 m^3 wood loading capacity. It has controlled air velocity, temperature and humidity that can be adjusted according to characteristics of each species. It has psychrometers (dry bulb and wet bulb thermometers) from both ends of the kiln. It has been equipped with fans to force air circulation, through the chamber and also air outlet. It works at a temperature range from 40-70 °C. The kiln seasoning schedules are steps/ norms involving serious of temperature and relative humidity at different corresponding MC levels [22]. The kiln seasoning schedules wereadapted from Sweden schedules. Kiln Schedule Ethiopia - has been applied (**Table 1**).

Table 1. Kiln Schedule Ethiopia

Initial mc %	Temperature [ºC]		Relative humidity
	Dry bulb	Wet bulb	
100-70	38	35	80
70-60	42	37	70
60-50	44	39	65
50-40	50	40	60
40-30	53	42	55
30-20	55	43	50
20-10	60	45	40

2. 4. Lumber characteristics determination

Moisture content determination

Moisture content (MC) was determined for both air and kiln seasoning stacks of the lumber species. The oven-dry weight method of MC determination (the standard way) [17, 24] was applied in this test since it is an indication of the amount of solid substance present. In both seasoning methods, the MC (%) was determined in accordance with ISO 3130 procedures. [9, 12, 17].

Rate of seasoning determination

Air and kiln seasoning rates of the species was estimated from the MC samples of the species. Seasoning rate (% / hour) = IMC-FMC (%)/Drying time (Hour) [14] where, IMC-initial moisture content and FMC- final moisture content. Air and kiln seasoning rates classification lumberfor the lumber was done based on the adapted standard [9, 10].

Shrinkage characteristics determination

The shrinkage characteristics caused by the differences in tangential, radial and longitudinal directions are the major causes of warpages (cup, bow, twist, crook/ spring), distortion in and around knots, cracks and checks [1]. To determine shirnkage samples prepared with a dimension of 2×2×3 cm was seasoned in the oven seasoning chamber to a constant dimension at a temperature of 103±2 ºC [9]. The measurements on shrinkage samples like MC tests were continued until the difference between the two successive weights of each specimen was constant i.e. between 0-0.2 g. Then, the final weights and dimensions were taken as oven dry weight and dimensions, respectively. Shrinkage rates of each specimen at tangential, radial, longitudinal direction and volumetric was determined from green to 12% MC and from green to 0% Mc using the different formulas adapted [8-10].

Density determination

The density (specific gravity) values of lumber species were determined, as prime indicator of wood quality, since it has strong influence on wood pysical characteristics seasoning rate, defects and possible remedies, shrinkage) and mechanical characteristics [15]. Specific gravity is unit less and is the density of wood per density of water, numerically equal to density since an equal volume of water at 4 °C has a density of 1g/ cm^3 or 1,000 kg/m^3 [18]. The samples (2×2×3 cm), procedures and measurements applied during shrinkage tests were used to determine the density values of each species using mathematical formulas at different MC and sample volume conditions. Basic density was determined based on green volume and oven dry weight, since the two are relatively constant conditions [15]. The dry density values were converted to standard 12% equilibrium MC (Table 1) by applying the formula adapted from [15] and classified based on the adapted standard classification [9, 10].

3. RESULT AND DISCUSSION

Appearance

The appearance of heart wood and the sap wood is indistinctly demarcated from each other. The heartwood of *Gmelina arborea* has pale brown to yellowish brown and sometimes with a pinkish tinge appearance. Whereas the sapwood has a whitish, a greenish or yellowish tinge appearance (**Figure 4**) with a 5-7 cm wide. The grain is straight to interlocked, while texture is coarse. Growth rings are distinct in regions with a marked dry season, but not distinct in other regions. The wood is somewhat oily to the touch as [5] indicated.

Figure 4. Lumber pictures of study tree species at Forest products Development and Innovation Research and Training Center sawmill before stacking.
[Photos collection by Getachew D.].

Moisture content

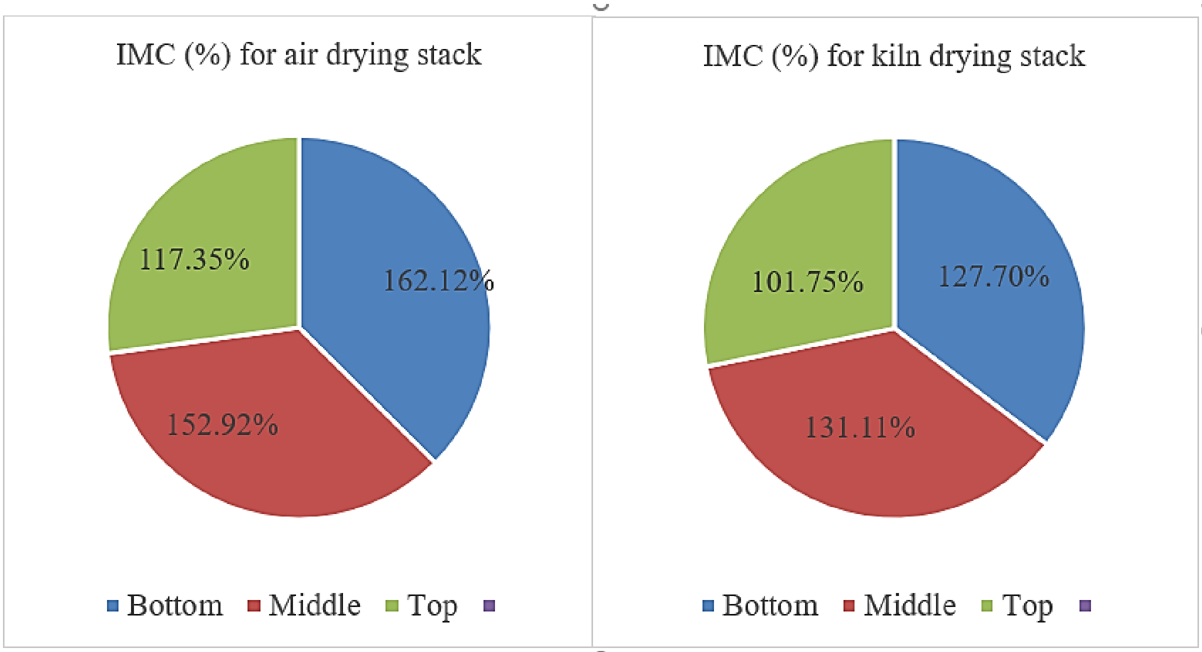

Figure 5. a) IMC (%) for air drying stack, **b)** IMC (%) for kiln drying stack.

Mean initial MC along height of lumber during air seasoning varies slightly. *Gmelina arborea* bottom part had ~162% MC; middle part had 153% MC, while top part had relatively the least MC (117%). Kiln seasoning lumber stack had 128% mean initial MC for bottom part, middle part had 131% and top part 102% MC. Mean initial MC decreased along height (**Figure 5a**, **b**).

Rate of seasoning

When comparing the air seasoning and the kiln seasoning rate of *Gmelina arborea* lumber, the kiln drying was 15 times faster. At controlled environmental conditions the seasoning defects was less likely in the air seasoning process. Air seasoning rate of *Gmelina arborea* was 7.37% / day, whereas kiln seasoning rate was 0.61% / day. Based on the adapted rate of seasoning categories for air seasoning [25] and for kiln seasoning [21], this study revealed that the rate of air seasoning of *Gmelina arborea* sawn boards of 3 cm thickness took 210 days in air, while kiln seasoning took 13.5 days (about two weeks) to reach to about 12% MC. The species was classified as slow in air (189-399 days) and fairly rapid in kiln (10-5-17.5 days). Kiln seasoning technology was better than natural air seasoning in terms of seasoning rate and quality mainly in terms of low shrinkage and seasoning defects of seasoned lumber. According [3], seasoning of *Gmelina arborea* is reported as either good and fairly rapid or slow with some risk of warping and collapsing that may result from either genetic variation or growing conditions.

Shrinkage and swelling (Dimensional changes)

When lumber of *Gmelina arborea* seasoned from green (~138%) to 12% MC, the mean shrinkage percentage values was tangential (3.63%), radial (1.58%), and volumetric (5.11%), respectively. The mean shrinkage percentage values when lumbers seasoned from green (138%) to 0% MC was tangential (6.05%), radial (2.63%) and volumetric (8.52%), respectively (**Table 2**).

Table 2. Mean shrinkage characteristics of *Gmelina arborea* lumber species at 12% and 0% MC

Position	Shrinkage (%) at 12% MC				Shrinkage (%) at 0% MC			
	Tan.	Radial	Long.	Vol.	Tan.	Radial	Long.	Vol.
Bottom	3.89	1.29	0	5.09	6.49	2.15	0	8.49
Middle	3.61	1.89	0	5.39	6.02	3.15	0	8.98
Top	3.38	1.56	0	4.85	5.64	2.60	0	8.09
Mean	**3.63**	**1.58**	**0**	**5.11**	**6.05**	**2.63**	**0**	**8.52**

The shrinkage characteristics of *Gmelina arborea* along height (bottom, middle and top parts) did not vary significantly when boards seasoned from green condition (~ 134% - 141% MC) to 12% MC. Tangential shrinkage of *Gmelina arborea* was 2.3 times greater than radial shrinkage. Tangential and radial shrinkage values of the study species *Gmelina arborea* at 12% MC was compared with similar study of [20] indicated that the value of tangential shrinkage is between 2.4-3.5% and the radial shrinkage value is in a range of 1.2-1.5% was found to be slightly high. The lower the shrinkage value, the higher the quality of lumber for application. The respective mean tangential, radial, and volumetric swelling characteristics of *Gmelina arborea* lumber at 12% MC were 7%, 4%, and 11%, respectively. The rates of shrinkage according to [3, 20] were low, from green to 12% moisture content tangential 2.4-3.5% and radial 1.2-1.5% while from green to oven dry tangential was 4.3-7.4% and radial 2.4–5.3% [3].

Comparable lumber species with the tangential shrinkage G. arborea was 3.63% at 12% MC, and this was comparable with species like Celtis africana (3.95%), Grevillea robusta (3.42%), Mimsopus kummel (3.87), Morus mesozygia (3.45), Olea welwechii (3.97%), Melica excelsa (3.64%), Eucalyptus globulus (3.48%), E. saligna (3.63%), Fagaropisis angolensis (3.91%). Comparable lumber species in radial shrinkage characteristics (1.58%) at 12% MC include Cordia africana (1.59%), Warburgia ugandensis (1.52%), Pinus patula (1.63%). Comparable lumber species with Gmelina arborea in volumetric shrinkage characteristics (5.11%) at 12% MC were Croton macrostychus (5.20%), Celtis africana (5.89%), Diospyros abyssinica (5.99%), Morus mesozygia (5.24), Pinus patula (5.27%), Pinus radiata (5.2%). Comparable species can be used as substitute when ever need arises for the purpose.

Density characteristics

Mean density of *Gmelina arborea* lumber species at green (initial), basic and at oven dry conditions and when dried to 12% MC, *Gmelina arborea* (**Table 3**) was 940, 400, 430 and 420 kg/m^3, respectively (Table 3). The oven dried density of *Gmelina arborea*, 420 kg/m^3 at 12% MC has been = was classified as light density (300-450 kg/m^3) lumber species. According to [20], the density of *Gmelina arborea* was 400–510 kg/m^3 at 12% moisture content.

Table 3. Density characteristics of *Gmelina arborea* at different MC (%)

Position along height	Initial MC (%)	Density (km/m^3) at			
		Density at Test	Basic Density	Density at Oven dry	Density at 12% MC
Bottom	140.84	920	380 L	420 L	410 L
Middle	134.12	1010	430 L	480 M	470 M
Top	139.12	880	370 L	400 L	390 L
Mean	**138.03**	**940**	**400 L**	**430 L**	**420 L**

Gmelina arborea is a light weight hardwood tree species. The density of *Gmelina arborea* at 12% MC (420 kg/m^3) were comparable with *Celtis africana* (410 kg/m^3), *Cordia alliodora* (390 kg/m^3), *Cupressus lusitanica* (430 kg/m^3), *Eucalyptus deglupta* (410 kg/m^3), *Pinus patula* (450 kg/m^3), *Pinus radiata* (450 kg/m^3) and *Polyscias fulva* (440 kg/m^3) [9].

4. CONCLUSIONS AND RECOMMENDATIONS

The study revealed the lumber from *Gmelina arborea* produce lumber that have good characteristics and qualities. The species was comparable with many indigenous and exotic lumber species in density, seasoning rate and shrinkage. It has multipurpose lumber and wood-based products, non-timber forest products and live trees have ecological uses/cultural aspects. The lumber tree species *Gmelina arborea* have to be well grown and managed, logs have to be properly harvested and sawn, boards stacked properly and seasoned to less than 20% MC.

Gmelina arborea boards have to be seasoned preferably with kiln seasoning method that can help to minimize seasoning time, seasoning defects and shrinkage haracteristics thereby increase quality. However, in the absence of kiln seasoning technology, air seasoning under shed, with proper stacking and top lading has been recommended. Seasoned lumber of the study species have to be properly handled and rationally utilized at specified MC and density for intended construction and furniture purposes. *Gmelina arborea* lumber, to a certain extent can substitute comparable and endangered lumber species in Ethiopia.

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