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TIMBER SEASONING AND DENSITY CHARACTERSTICS OF *CORDIA ALLIODORA* CHAM. (BORAGINACEAE) GROWN IN ETHIOPIA AND ITS POTENTIAL USES

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ABSTRACT: The knowledge on basic wood properties including timber seasoning, density and technologies of utilization would determine rational use and large-scale development of each timber species. A study was conducted on home-grown *Cordia alliodora* timber with the main objective of determining some important seasoning and density characterstics that indicate its timber quality to decide its proper utilization. The experiments were conducted using oven/microwave, air and kiln seasoning methods. Harvested logs were sawn while green and lumber stacked using stickers with three replications and seasoned from green (initial) moisture content (MC) to about 12% MC. The mean initial MC was 54.5% and density 550 kg m^{-3}. Results revealed that there were significant differences ($P<0.01$) between the seasoning methods, among shrinkage characteristics, and density values at different MC levels. Mean and range of final air seasoning MC of the species were 12.38% ± 2.7 and 11.93-12.75%, respectively while those of kiln seasoned batches were 14.24% ± 2.1 and 10.48-17.42%, respectively. Mean final MC of the seasoned timber for both seasoning methods was 13.31%. *Cordia alliodora* showed very rapid air (35 days) and kiln (2.2 days) seasoning rates. The mean density at 12% MC was 390 kg m^{-3}. Shrinkage values of the timber at oven dry (0%) MC compared at 12% MC increased by about 1.7 times. Slight seasoning defects such as cup, bow, twist, end split and checks were observed. In general, the species revealed good timber properties and qualities. Therefore, the species has to be grown and well managed, timber properly seasoned to less than 20% MC, with a method that can help increase quality, minimize seasoning defects and shrinkage characteristics. Consequently, timber has to be properly handled and rationally utilized at specified MC and density for intended construction and furniture purposes.

Key words/phrases: Moisture content, Rate and defects, Seasoning methods, Shrinkage characteristics, Uses.

INTRODUCTION

The appearance, quality and performance of wood/timber would seriously be affected by inappropriate drying (seasoning) and density. The different properties, its suitability for different purposes and all other challenges

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(>90%) associated with wood and its utilization involves moisture amount (Hodaley, 1989; Simpson, 1991; Denig *et al*., 2000; FPL, 2010), its influence, fluctuation with time and management. Among the major factors that determine the quality and utilization of wood as round and sawn lumber are thus moisture content (MC), density, seasoning mechanical and shrinkage characteristics (tangential, radial, longitudinal volumetric), seasoning rates and seasoning defects (Hodaley, 1989; Simpson, 1991; Denig *et al*., 2000; Getachew Desalegn, 2006; FPL, 2010).

Proper timber seasoning as a science of uniform moisture removing from wet or ‘green’ wood by evaporation under more or less controlled conditions is a natural resource conservation-oriented and profitable process that will minimise MC in wood and seasoning defects, enhance its properties, achieving the highest possible quality and makes the lumber more valuable for rational utilization to a great extent (Simpson, 1991; Denig *et al*., 2000).

Seasoning defects are unavoidable and occur while seasoning each tree species lumber but the extent varies from species to species and with the method of seasoning applied. This is due to shrinkage and other wood characteristics, the main causes of quality timber degradation. Most seasoning defects that develop on wood products during seasoning can be categorized as fracture (rupture-surface and end checks) or distortion (collapse-honeycomb-internal cracks), warp (cup, bow, twist and spring) and discoloration caused by an interaction of wood properties with processing factors. Defects that arise due to shrinkage result in warping while those arising due to uneven seasoning lead to rupture of the wood tissues such as checks, splits, honey-combing and case-hardening. Understanding them will provide a means to minimise damages (Simpson, 1991; FPL, 2010).

The density values of the timber are determined, as prime indicators of wood quality, as a guide to seasoning behaviour, rate of seasoning and as an index of weight since density has strong influence on the different properties (seasoning rate and defects, shrinkage, physical and mechanical properties, etc.) and timber quality (ISO 3131, 1975; Denig *et al*., 2000; MTC, 2002).

Shrinkage of wood is the basic cause of many problems that occur in wood during seasoning to $\leq$ 25% MC and in service (Denig *et al*., 2000). The major shrinkage characteristics are warp (cup, bow, twist and crook/spring-side bend), distortion/split in- and-around knots, and other seasoning stresses (cracks and checks) (Denig *et al*., 2000; FPL, 2010). The major cause of warp is differential shrinkage caused by the differences in tangential, radial and longitudinal directions during the seasoning process (Denig *et al*., 2000; MTC, 2002; FPL, 2010). According to Denig *et al*. (2000), the factors of importance that cause shrinkage and swelling are moisture loss and gain, respectively.

In Ethiopia, inappropriate seasoning and lumber handling problems, and lack of information on major wood properties, including seasoning and density are among the overlooked but they contribute to the major causes that lead to product amount and quality losses, inappropriate utilization of lumber and other products, destruction of forests and endangering of certain valuable timber tree species such as *Juniperus procera* Hochst. ex Endl., *Hagenia abyssinica* (Bruce) J.F. Gmel., *Cordia afrcana* Lam., *Podocarpus falcatus*(Thunb.) R.B. ex Mirb. and *Pouteria adolfi-friederici* (Engl.) Baehni. Thus, proper seasoning of lumber, determination of density and manag1ing of MC in wood for the intended application and environment will be important considerations towards enhancing the properties and rational utilization of *C. alliodora* timber[1] in the country.

Cordia alliodora is an introduced, fast-growing and potential species for promotion and sustainable utilization in Ethiopia. It is not yet known by the development sectors, manufactures and end-users in the country since it is still under silvicultural research undertaking of the Forestry Research Center (FRC) in the Ethiopian Institute of Agricultural Research, Addis Ababa. It has been selected for this study because the species could be among the new potential expectations of Ethiopia's future forestry and forest industries development scenarios.

Studying wood properties of the timber will help to know its quality and contribute to opt for the future, either to plant and utilize it on a large-scale or not. Therefore, the objectives of this study were to: (i) identify suitable seasoning methods for the timber, (ii) determine seasoning properties and density of the species at different MC levels, (iii) study appearance, shrinkage characteristics, seasoning defects and biodeterioration attack during and after seasoning, and (iv) evaluate better handling techniques before, during- and after-sawing and seasoning of the timber.

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[1] The technical term timber refers forest crops and stands containing timber or wood (standing tree, round wood/log) other than fuel wood, potentially useable for lumber; lumber refers sawn product/ sawn wood from a tree and board refers 2.5 to 4 cm thick lumber of all widths and lengths (Helms, 1998; Denig *et al.*, 2000; FPL, 2010).

MATERIALS AND METHODS

Test materials

Cordia alliodora is a fast growing and home- grown exotic hardwood species in Ethiopia. Selection and logging of sample trees with clear bole was carried out from Forestry Research Center (FRC) trial plots at Bebeka (Benchi-Maji Zone), Southwest Ethiopia (Fig. 1). Bebeka is located at latitude of $7^0$00'N, longitude $35^0$10'E (Desta Hamito and Feyisa Abate, 1994; Mebrate Mihretu, 2004).

A B

Fig. 1. *Cordia alliodora* tree bole and timber (A) with clear lumber appearance (B).

Sample trees used for wood property tests were harvested from 10 matured and morphologically defect-free and good quality trees having a mean height of 20 m and a breast height diameter (DBH) of 39 cm (Table 1). Trees were felled and bucked into 5 m logs. Logs while green (>30% MC) were transported to Forest Products Utilization Research Laboratory (Addis Ababa, Ethiopia). The test materials were logs selected and collected from *C. alliodora* trees and converted to boards.

Distribution, physiognomy, ecological requirements and silviculture of the species

Distribution: *Cordia alliodora* occurs widely in Latin America, from 25^0N in Central Mexico to 25^0S in the Argentinean province of Misiones (Evans, 1986; Lamprecht, 1989). It is relatively common in southern Mexico, Central America, the West Indies, Venezuela and Ecuador. It is grown in Mauritius, Nigeria and Sierra Leone (Lamprecht, 1989; Anonymous, 2007C) and south-west Ethiopia at Bebeka, Aman and Tole-Kobo research stations.

Physiognomy: It is a deciduous tree attaining a height of 30 m (40 m maximum) and a DBH of between 60 cm, and even over 100 cm (Lamprecht, 1989; Anonymous, 2007b) (Table 1). In Bebeka, it grows to 20 m and 39 cm DBH at the age of 14 years with a mean annual height increment of 1.4 m. It produces large amount of seeds at the age of six years and has high natural regeneration capacity from seeds (Mebrate Mihretu, 2004; Mebrate Mihretu and Melaku Abegaz, 2005) (Table 1). The stem is cylindrical, slender, weakly buttressed up to a maximum height of 2 m and free of branches up to half of its total height even under open-site conditions and particularly in shallow soils (Lamprecht, 1989).

Table 1. Growth of *Cordia alliodora* tree plantation in USA (Costa Rica)

Age (years)	Mean height (m)	Mean DBH (cm)	Locality
3	5.2	9	Costa Rica- Turrialba
3	12.6		Ethiopia- Bebeka
3	5.6		Ethiopia- Aman
3	4.2		Ethiopia-Tole-Kobo
8	21.7		Ethiopia- Bebeka
8	16.8		Ethiopia- Aman
10	12.5	16	Costa Rica- Turrialba
13	19.6	22.2	Costa Rica -Los diamantes
14*	20*	39*	Ethiopia- Bebeka
14	17.4		Ethiopia- Aman
15	35		Costa Rica- Turrialba
16	29.1	-	Ethiopia- Bebeka
21	25.5	30	Costa Rica- Turrialba
24	29.3	37.8	Costa Rica -Los diamantes
29.9	22	25.1	Costa Rica -La isla

Data adapted from Lamprecht (1989), Mebrate Mihretu (2004) and Anonymous (2007c).
*Mean height (20 m) and diameter (39 cm) values presented for the sample trees when logs were selected and collected for wood property tests at the age of 14 years from Forestry Research Center trial site (Bebeka).

Ecological requirements: The mean annual temperature in its native habitat is between 20 and 27^{0}C (Maximum 26-32^{0}C in warmest month and a minimum of 15-25^{0}C in coldest month), and the annual rainfall ranges between (-1000) 1400 and 3000 (-4500) mm with 0-4 dry months. It grows predominantly at elevations from sea level to 800 m, but near the equator, it can be found up to 1000 (-1500) m above sea level (Lamprecht, 1989; Anonymous, 2007c). The species grows in evergreen and deciduous moist forests (Lamprecht, 1989; Mebrate Mihretu, 2004).

In Bebeka, it grows at an altitude of 1000 m, mean annual rainfall of 2000 mm and mean annual temperature of 25^{0}C (Desta Hamito and Feyisa Abate, 1994). The Bebeka site is lower in elevation (1000 m) than others by far potential for C. *alliodora* plantation, followed by Aman (1350-1400 m) and Tole-Kobo (1350 m) (Mebrate Mihretu and Melaku Abegaz, 2005).

Silviculture: It is a light-demander and some-what shade-tolerant when young (Lamprecht, 1989). It bears fruit for the first time at the age of 5-10 years and thereafter every year. As lumber production source, rotation ages of 25-30 years are practiced. It is a light demanding species and, thus, to achieve well-developed crown and stem, intensive thinning is essential (Lamprecht, 1989). In Cota Rica, planted *C. alliodora* at the age of 15 years has shown a density of 180 stems per ha, a basal area of 17.6 m^2/ha, an average height of 35 m, and a standing volume of 308 m^3/ha. After age 20, growth declined (Table 1) (Catie, 1979 cited in Lamprecht, 1989). At Bebeka, it regenerates well from seeds falling on the ground, and adequate management on stocking is needed as it is somewhat aggressive.

Log sawing and sample preparation

Log sawing, sample preparation, lumber stacking, testing and determination of the different wood characterstics of *C. alliodora* were based on the methods adapted from Tack (1969), ISO 3130 (1975), ISO/DIS 4469 (1975), Desch (1986), WUARC (1989), Simpson (1991), Reeb (1997), Denig *et al.*(2000), MTC (2002) and FPL (2010).

Before commencing sawing, the logs were bucked into 2.5 m bolts while green. Logs were sawn to 3 cm thick tangential boards at the mobile circular sawmill by applying through-and-through type of sawing method. Samples were prepared and selected proportionally from each tree and log along height and marked with identification codes using waterproof permanent ink.

For the following-up of the seasoning processes and determination of MC, rate of seasoning and defects, 30 defect-free sample boards with dimensions of 100 cm in length, 3 cm thick and wide equal to log-diameter were prepared and used from the sample trees. Green (hereafter, initial) MC of the timber species was determined from the samples, two small sections (1.2 cm length and 3 cm thick and wide equal to log-diameter) cross-cut into 20 cm inwards from each sample board ends to eliminate the effects of end seasoning. Other 30 defect-free sample specimens at initial state, with three replica and standard dimensions (length, width and height) of 2 cm x 2 cm x 3 cm were used for the determination of shrinkage characteristics and density.

Lumber stacking

Sawn boards were immediately transported to the air seasoning yard and compartment kiln seasoning chamber areas and were stacked with three replications at 3 cm spacing between successive boards. Boards were stacked horizontally in vertical alignments separated by well-seasoned, stickers and top loading was applied to counteract against warping (cup, bow, twist and crook/spring). In air seasoning stacks, 50 kg m^{-2}, 40 cm thick and two meter long solid wood blocks were applied while in kiln seasoning heavy stones weighing 50 kg m^{-2} were loaded, and in all cases, the loads on the stacks were used at a spacing of 0.5 m interval.

Long stickers with a dimension of 2.5 cm x 2.5 cm x 180 cm (width, thickness and length, respectively), and short ones (2.5 cm x 2.5 cm x 20 cm) were prepared and placed at equal distance, 0.5 m interval across each layer of lumber, aligned on top of one another from the bottom of the stack to the top. This was done to facilitate uniform air circulation, to distribute the weight of the lumber vertically from top to bottom and conduct uniform seasoning, minimize warp and to avoid stain and decay occurrence during the seasoning process. Long stickers were used to separate boards while the short strips placed up on the long stickers were used to easily access the sample boards of each stack, withdraw from the stack, measure and replace into the stack.

The seasoning samples were distributed in each stack to represent the lumber in the stack and the seasoning process at different positions (top-bottom, left-right). Where the heartwood and sapwood boards were clearly separated, the sapwood boards were placed at the sides, top and bottom of the stacks since they have more MC than the heartwood. The heartwood boards were placed in the middle. The ends of boards were made equal on both directions and the control sample boards were properly distributed and positioned in the pockets of the different layers of each stack.

Air seasoning replica boards were stacked separately under air seasoning yard on firm foundations having 45 cm clearance above the ground and stickers with a dimension of 4 x 1.80 x 0.45 m to facilitate good air circulation and reduce the direct influence of fungi, temperature, wind and relative humidity. Boards were stacked under shed without direct interference of moisture, rainfall, sunshine and aligned north-south direction where the ends were not facing the wind direction. After stacking boards out of the kiln on the transfer carriage having a dimension of 1.6 x 0.30 x 2.7 m was placed inside the kiln seasoning chamber/room.

Seasoned boards of the species were transported from the seasoning laboratories and piled in a well conditioned room on supports of 45 cm from the ground, board on board and without stickers, and no top loading was used. This was done to follow the conditions while storing and handling of post-seasoned lumber.

Lumber seasoning tests

Air seasoning

Seasoning is required for wood to be used in most products. Control of the seasoning process is, thus, the key to successful and efficient seasoning. This involves timely application of optimum or at least adequate temperature, relative humidity and air circulation as critical activity. Natural (air) and artificial (kiln) seasoning methods were used for testing and determination of seasoning properties. Immediately after planing and crosscutting, initial weights and dimensions (length, width and thickness) of all air seasoning sample boards were measured using sensitive electrical balance and calliper, respectively. Small sections (3 cm thick and 1.2 cm length) cross-cut from seasoning sample boards (3 cm thick and 1 m length) for the determination of initial MC were weighed at four hours interval as soon as samples were withdrawn from the oven drier to minimize moisture absorption and desorption. Seasoning lumber is usually accomplished by seasoning “from the outside in” and evaporating the moisture from the surface of the wood where the amount of moisture leaving the wood will be determined by the relative humidity of the atmosphere surrounding the wood.

The seasoning sample boards were re-weighed and re-placed into the stacks at one-week interval. This was continued until the difference between two successive weights of each specimen became 0.1 - 0.2 g and the final weight was taken as the oven dry weight. The process was continued until the average final MC of the stack reached about 12%, which is the equilibrium MC for in- and out- door purposes and standard for comparison within and between timber species.

Kiln seasoning

The kiln seasoning machine (conventional type) used in this study was well insulated and had about 2.5 m^3 wood loading capacity room/chamber per kiln operation. In this kiln, the timber remained stationary and the temperature and humidity of the circulated air were altered in a set sequence The machine has controlled air circulation, temperature and humidity mechanisms where temperature and humidity can be adjusted using psychrometers (dry bulb and wet bulb thermometers) to get quality lumber after seasoning. It was equipped with fans to force air circulation and air outlet, and operated at temperature ranges of 40 -70^{0}C.

The kiln seasoning schedule, a serious of temperature and relative humidity steps at different corresponding MC levels, was selected based on the initial MC of *C. alliodora* timber. Kiln seasoning schedule Ethiopia No. 3 (hardwood schedule type) was applied.

In a similar way like air seasoning described before, samples were weighed and dimensions measured. To allow uniform air circulation and seasoning, control the seasoning process and maintain the quality of the seasoned wood, measurements were taken and the direction of the fan was changed at eight hours interval, three times in 24 hours.

Moisture content and seasoning rate determination

Moisture content was determined for both air and kiln seasoning stacks of the timber. The oven dry weight method of MC determination (Haygreen and Bowyer, 1996; Reeb, 1997; Denig *et al*., 2000; MTC, 2002; FPL, 2010) was applied. The general formula applied for MC (%) determination was:

MC (%) = (IW-OD/OD)*100 = (IW/OD-1)*100 = (W/OD)*100

Where, IW= initial weight of wood with water (g), OD = oven dry weight of wood without water (g), W = weight of water alone (IW-OD) (g).

The air and kiln seasoning rates of the timber species were estimated from the MC samples of each stack. Seasoning rate classification was done based on the adapted standard (Farmer, 1987).

Shrinkage characteristics determination

For shrinkage values determination, samples were seasoned in the oven seasoning chamber to a constant dimension at a temperature of 105^{0}C. Initial and current dimensions and weight of all samples were measured like MC tests, but in this case, measurements were done once per day since MC reduction less than a day is very low. Then, the final weights and dimensions were taken as oven dry weight and dimensions, respectively.

Shrinkage characteristics (tangential, radial and longitudinal directions, and volumetric) and shrinkage rate of each specimen from green (54.5%) to 12% MC, and to oven dry (0%) MC, were determined using the different formulas adapted (ISO/DIS 4469, 1975; ISO/DIS 4858, 1975; Simpson, 1991; Reeb, 1997; Denig *et al*., 2000; MTC, 2002) (Table 2). The general and specific formulas used for the shrinkage characteristics (%) were:

Shrinkage characteristics (%) = (Decrease in dimension (mm)/green (Initial) dimension (mm))*100

Tangential shrinkage (%) = [(T1-T2)/T1]*100= (1-T2/T1)*100

Radial shrinkage (%) = [(R1-R2)/R1]*100 = (1-R2/R1)*100

Longitudinal shrinkage (%) = [(L1-L2)/L1]*100 = (1-L2/L1)*100

Volumetric shrinkage (%) = [(V1-V2)/V1]*100= (1-V2/V1)*100

Where, T1, R1, L1, V1- green (initial) tangential, radial, longitudinal, and volumetric dimensions in mm before oven seasoning progression, respectively, and T2, R2, L2, V2- final (seasoned) tangential, radial, longitudinal, and volumetric dimensions in mm after oven seasoning progression, respectively.

Seasoning defects

Seasoning defects were qualitatively determined from boards stacked and seasoning both in air and kiln seasoning methods, before and after seasoning. Every species may not have necessarily all seasoning defects, since the defects vary from species to species and on the seasoning methods applied.

Density test

The density (g cm^{-3} or kg m^{-3}) and/or specific gravity values of the species were determined from the shrinkage samples, procedures and measurements as stated earlier using mathematical formulae. Specific gravity is unit less and the density of wood per density of water numerically equals to density since an equal volume of water at 4^{0}C has a density of 1 g cm^{-3} or 1000 kg m^{-3} (Haygreen and Bowyer, 1996; Denig *et al*., 2000; MTC, 2002).

Basic density = (Sample oven dry weight/sample green volume)

Density was determined at different MC and sample volume conditions (ISO 3131, 1975). The dry density values were converted to standard 12% equilibrium MC (Table 2) by applying the formula below and classified based on the adapted standard classification (Framer, 1987).

Density at 12% MC ($\rho 12$) = $Pw^* [1-0.01^*(1-K_0)^*(W-12)]$

Where, K_0= coefficient of volumetric shrinkage for a range in 1% MC. For approximate calculations, the value of K_0= $0.85^*10^{-3}{}^*Pw$ when density is expressed in kg m^{-3} and K_0= 0.85*Pw when density is expressed in gcm^{-3}; Pw = density at test

Experimental design and data analysis

The experimental design of the study was completely randomized design (CRD). One-way ANOVA with SAS (2000) was used for the analysis of the data (SAS, 2000).

RESULTS AND DISCUSSSION

Moisture content

There were significant differences (P<0.01) in the mean values of air and kiln seasoning green (initial) and final MC of sawn boards. The mean initial MC before air and kiln seasoning commenced was 54.5% ± 5.1 In air seasoning, the mean initial MC of *C. alliodora* using control sample boards of each stack was 45.8% ± 2.7while for kiln seasoning it was 69.28% ± 2.1(Table 2) where the mean for the two seasoning methods was 57.54% ± 2.4 MC. The kiln seasoning samples, especially that of replication 3 revealed high MC than air seasoning since the samples were covered with sawdust until the kiln seasoning process started.

The mean initial MC 54.5% ± 5.1 of *C. alliodora* means that the timber before seasoning was holding water/moisture about 0.55 times its own weight. Seasoned boards in the two seasoning methods were in average holding about 13.31% final MC, which is about 0.13 times their own weight of moisture (Table 2 and Fig. 2), where the wood substance occupied about 87% or 0.87 times its own weight.

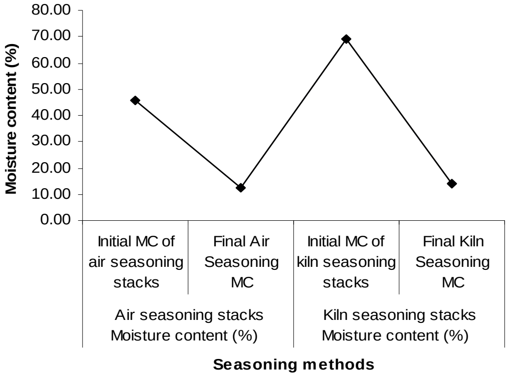

Fig. 2. Mean moisture content values of *C. alliodora* lumber at air and kiln seasoning methods.

The results indicated that mean final MC of air seasoning and the range of MC for this species were 12.38% and 11.93-12.75%, respectively. The final kiln seasoned mean and range of MC of the stacks was 14.24% (10.48-17.42%) (Table 2 and Fig. 2). The mean initial (green lumber) MC in air and kiln seasoned stacks was different while the final (seasoned) MC was similar within the species/replications and seasoning methods (Table 2). The mean final MC of kiln seasoned wood based on its purpose may vary from 0 to 25% (Denig *et al.*, 2000).

Table 2. Some important seasoning and density properties of *C. alliodora* timber.

		Air seasoning stacks MC (%) and rate of seasoning*			**Kiln seasoning stacks MC (%) and rate of seasoning****			**Density^ (gcm^{-3})*****		
Replication	Green (Initial) MC of sections before seasoning commenced	Initial MC of air seasoning stacks	Final air seasoning MC	No. of days in air seasoning (days) and rate of seasoning	Initial MC of kiln seasoning stacks	Final kiln seasoning MC	No. of days in kiln seasoning (days) and rate of seasoning	Green /Initial	Basic density	At 12% MC
1	54.61	46.3	12.75	35	42.39	17.42	1.3	0.55	0.35	0.40
2	54.17	42	11.93	35	43.82	10.48	3	0.55	0.36	0.39
3	54.59	49.1	12.47	35	121.63	14.82	2.3	0.54	0.35	0.38
Mean	54.46	45.80	12.38	35	69.28	14.24	2.20	0.55	0.35	0.39

***-Air seasoning rates (days)** have been adapted from Longwood (1961) and classified as very rapid < 77 days; rapid, 77-119; moderate, 126-182; slow, 183- 189; very slow > 189 days.

****- Kiln seasoning rates (days)** have been adapted from Framer (1987) and classified as very rapid <10.5 days; rapid, up to 10.5; fairly rapid (moderate), 10.5-17.5; fairly slow, 17.5-30; slow, 30; very slow, over 30 days.

***-The formulas applied for the determination of density (kgm^{-3}) of the timber (ISO 3131, 1975): (i) Green/initial density = Initial weight (kg)/green volume (m^3), (ii) Oven dry density = Oven dry weight /Oven dry volume, (iii) Basic density = Oven dry weight /green (initial)volume, and (iv) Density at 12% MC (ρ12) = P_w (1-0.01 (1-Ko) (W-12), Ko = 0.85*Pw, where, ρ_{12}= density at 12% MC (Kgm^{-3}), Ko = the coefficient of volumetric shrinkage for a range in 1% MC, for approximate calculations the value of Ko=0.85*10^{-3}*Pw when density is expressed in kgm^{-3} and Ko=0.85*Pw when density is expressed in gcm^{-3}, W= MC at test (%), and density at test (Pw)= 0.85*10^{-3}*Pw (Kgm^{-3}).

Note: Density values (kgm^{-3}) classifications adapted from Farmer (1987) and categorized as exceptionally light <300, light, 300-450, medium, 450-650, heavy, 650-800, very heavy, 800-1000 and exceptionally heavy > 1000.

Rate of seasoning

The number of days required to reach about 12% MC air seasoning for *C. alliodora* timber sawn boards of 3 cm thickness to about 12% MC was 35 days. Air seasoning of 2.9-3.2 cm thick *C. alliodora* lumber from green to 18% MC took 154 days, medium seasoning rate (Longwod, 1961). The number of days to reach the kiln seasoning to about 12% MC was 2.2 (1.3-3) days (Table 2). Based on the adapted rate of seasoning categories (Farmer, 1987), the timber species has been classified as very rapid in both air and kiln seasoning methods (Table 2).

Compared to open-air seasoning, kiln seasoning gave better possibility of controlling the relative humidity and temperature, MC, rate of seasoning, seasoning defects, shrinkage characteristics, appearance and the quality of seasoned timber besides reducing MC to the desired amount (about 12%) in a relatively very short period of time, i.e. about 2 days (Table 2). The kiln seasoning schedule applied was suitable for the species, and the seasoning was achieved faster compared to air seasoning, and no pronounced seasoning defects occurred.

Shrinkage characteristics

There were significant differences (P<0.01) among the shrinkage characteristics of the sawn timber. The mean tangential, radial, longitudinal and volumetric shrinkage percentage values from green (54.5%) to seasoned condition (12% MC) were 3.8% ± 0.31, 2.45% ± 0.29, 0.36% ± 0.09 and 6.36% ± 0.43, respectively. Shrinkage values at oven dry MC were 6.33%, 4.08%, 0.60% and 10.61%, respectively. Compared to shrinkage values at 12% MC, seasoning to 0% MC increased shrinkage values in average by more than 1.7 times (Table 3 and Fig. 3). These findings agree with those reported from Costa Rica where lumber seasoned from green to 12% MC indicated shrinkage values of 3.26%, 1.42%, 0.04% and 6.15 %, respectively (Longwood, 1961; Anonymous, 2007b).

Table 3. Shrinkage characteristics/values (%) of *C. alliodora* timber at 12% and oven dry (0%) MC.

		Shrinkage characteristics			
Replication	MC	Tangential	Radial	Longitudinal	Volumetric
1	At 12%	4.57	3.39	0.49	7.99
2	"	3.59	2.08	0.22	5.74
3	"	3.24	1.88	0.38	5.36
Mean	"	3.80	2.45	0.36	6.36
1	At 0%	7.61	5.64	0.82	13.32
2	"	5.98	3.47	0.36	9.57
3	"	5.40	3.13	0.63	8.93
Mean	"	6.33	4.08	0.60	10.61

The ratio of mean tangential shrinkage to radial shrinkage of *C. alliodora* from green to both 12% and oven dry MC was about 1.55%. This indicates that mean tangential shrinkage of the species was 1.55 times higher than that of radial shrinkage (Table 3 and Fig. 3). Wood shrinks about 1.5 to 2 times (Simpson, 1991) and more than half times (Denig *et al.*, 2000) as much parallel to the growth rings (tangential) as it does at right angle to the growth rings (radial). The shrinkage along the grain (longitudinal) was small (≤ 0.2%) and, thus, can be considered negligible (Simpson, 1991). As the MC decreases, shrinkage value increases, and the more difficult will be the lumber as a result of high shrinkage. Thus, care is needed for its seasoning and rational utilization.

The multiplying shrinkage coefficients for each 1% MC reduction below 30% have been estimated for tangential, radial, longitudinal directions and volumetric as 0.21, 0.14 and 0.02 and 0.35, respectively. The lower the shrinkage value and the shrinkage class, the better will be the species for the purpose intended.

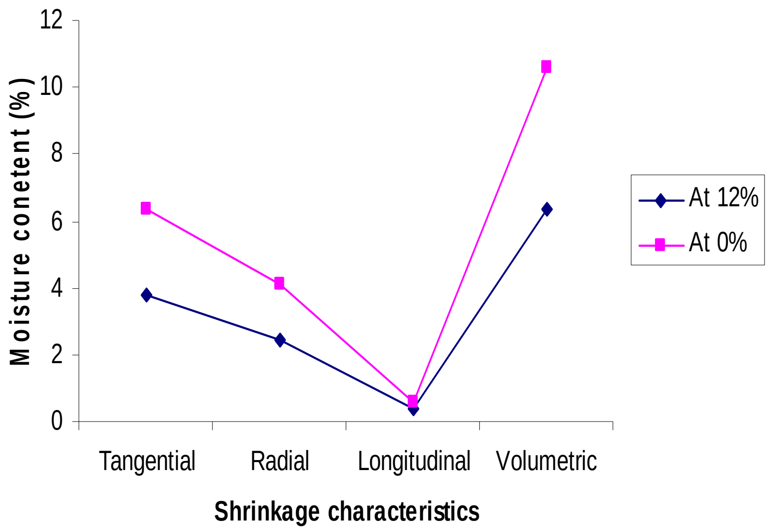

Fig. 3. Shrinkage characteristics (%) of *C. alliodora* based on mean values at 12% and 0% MC.

Tangential and radial shrinkage values from green to oven dry were classified based on Chudnoff (1980), i.e. tangential shrinkage: class 1 < 5%; class 2: 5-6.5%; class 3: 6.5-8%; class 4: 8-9.5% and class 5 > 9.5%; and radial shrinkage: class 1 < 3%; class 2: 3-4%; class 3: 4-4.5%; class 4: 5-6%

and class 5 > 6% (Chudnoff, 1980). Thus, the tangential (3.8%) and radial (2.45%) shrinkage values of *C. alliodora* can be classified as class 1, very low shrinkage class indicating its quality.

All the shrinkage values of the species were within the range of shrinkage classes given for timbers, i.e. tangential shrinkage (3.5-15%), radial shrinkage (2.4-11%) and longitudinal (0.1-0.90%) (Kollmann and Côté, 1968). In both air and kiln seasoning methods, *C. alliodora* revealed lower shrinkage values, which is good for proper utilization.

Appearance of *C. alliodora* tree sawn timber

Cordia alliodora is an attractive, durable and much-used wood throughout the American tropics. The wood is moderately strong and hard, resembling Mexican mahogany (*Swietenia macrophylla* King) in this respect. The freshly cut heartwood is light greenish brown to olive brown in color, frequently with darker streaks. Seasoned wood becomes a pale golden-brown to brown, and narrow dark lines of pores delineate the darker streaks. Small dark rays give the wood a lightly mottled appearance on quarter-sawed surfaces (Anonymous, 2007abc). The sapwood is lighter in color than the heartwood and not clearly delineated from it (Fig.1).

The grain is generally straight, texture is fine to medium and luster is medium to high. The appearance and working properties of well-seasoned *C. alliodora* have been comparable with *Cordia africana* and *Eucalyptus deglupta* Blume (Getachew Desalegn, 2005; Getachew Desalegn, 2006; Melaku Abegaz *et al*., 2006).

Seasoning defects, post-harvest handling and biodeterioration attack

On some boards, wormholes were observed. Knots and initial seasoning defect of cup were observed on *C. alliodora*. During- and after- seasoning loosening of knots, cup (2), bow (2), twist, and slight end split, and end checks were observed. Lumber from Costa Rica also revealed seasoning defects cup (2), bow (2), twist (3) and crook (4), where 1- none, 2- very slight, 3- slight, 4- moderate, 5- severe and 6- very severe seasoning defects (Longwood, 1961).

The control measures recommended to minimize seasoning defects, shrinkage and stain on *C. alliodora* lumber were: (i) proper stacking using stickers and top loading, where this can reduce cup, bow and twist; stacking in a way that reduce rapid seasoning (end not facing the wind direction) will also minimize surface tension and the accompanying checking and distortion (Longwood, 1961; Simpson, 1991; Haygreen and Bowyer, 1996;

Denig *et al*., 2000; MTC, 2002); (ii) applying stickers at < 3 cm narrow spacing; and (iii) coating ends with a moisture-resisting paint or wax emulsion and slow seasoning schedule (Denig *et al*., 2000). Biodeterioration attack was not observed before, during- and after- seasoning, except some stain marks.

Storing and handling of post-seasoned lumber

The observations made for more than two years on both air and kiln seasoned lumber revealed that there was no stain and/or fungal attack for boards of the timber stacked. After seasoning and during storage of the boards, no pronounced seasoning defects were observed.

Density

The density values of the timber were determined, as prime indicators of wood quality, as a guide to seasoning behaviour, rate of seasoning and an index of weight since it has strong influence on the different wood properties (seasoning rate and defects, shrinkage, physical and mechanical properties, etc.) and timber quality (ISO 3131, 1975; Denig *et al*., 2000; MTC, 2002).

There was significant difference (P<0.01) in the density of sawn timber at different MC. Mean green (initial) density at 54.5% MC was 550 kg m^{-3} ± 24.63. Samples of *C. alliodora* have a mean basic density (dry weight and green volume) of 350 (350-360) kg m^{-3} ± 12.79 and at 12% MC a density of 390 (380-400) Kg m^{-3} ±12.66. The density and mechanical properties of *C. alliodora* at 12% MC with an accuracy of ± 5% was comparable with timber species namely *Cordia africana*, *Cupressus lusitanica*, *Eucalyptus deglupta*, *Hagenia abyssinica*, *Pinus patula*, *Pinus radiata* and *Podocarpus falcatus* (Tiruneh Kide, 1988; Lamprecht, 1989; WUARC, 1995; Getachew Desalegn, 1997; Getachew Desalegn, 2005; Getachew Desalegn *et al*., 2005; Getachew Desalegn, 2006; Anonymous, 2007b; Anonymous, 2008).

There was no significant difference between the densities at oven dry and 12% MC. The classification of density based on Farmer (1987) and mean value at 12% MC for *C. alliodora* (390 kg m^{-3}) that was classified as light. Seasoning and density properties of the species varied at different MC levels (Table 2). In Costa Rica, plantation grown *C. alliodora* has a density of 360 kgm^{-3} and lumber from natural forest has a density of 560-800 kg m^{-3} at 15% MC (Longwood, 1961; Lamprecht, 1989). The results agree with the plantation grown *C. alliodora* elsewhere as stated above. Studies on seasoning and density properties showed that *C. alliodora* lumbercould be utilized for certain uses as sawn timber and as substitute of the endangered indigenous timber species (*Juniperus procera*, *Hagenia abyssinica*, *Cordia afrcana*, *Podocarpus falcatus* and *Pouteria adolfi-friederici*) as well as *C. lusitanica*, *E. deglupta*, *P. patula* and *P. radiata* satisfactorily, provided that care is taken during felling, sawing, stacking, seasoning, and appropriate preservative treatments made against fungal, beetle, borer and termite attacks. For some applications, *C. alliodora* can be used as a substitute for teak (*Tectona grandis*), walnut (*Lova tirchilioides*) or mahogany (*Swietenia macrophylla*) (Anonymous, 2007b).

In general, physical and mechanical properties of the wood are quite good and similar to mahogany. Freshly felled materials season rapidly with only slight warping and checking. Wood is easy to work, finishes smoothly, and glues readily. The wood preservation study in Ethiopia at Meisso and Zway stations revealed that it was non-durable against termite and fungal attack (Getachew Desalegn, 2012).

Potential uses of *Cordia alliodora*

The appearance and working characteristics of well-seasoned *C. alliodora* have been comparable with those of *Cordia africana* and *E. deglupta*. The density and mechanical characteristics of *C. alliodora* at 12% MC with an accuracy of ± 5% was comparable with timber species namely *Cordia africana*, *Cupressus lusitanica*, *Eucalyptus deglupta*, *Hagenia abyssinica*, *Pinus patula*, *Pinus radiata* and *Podocarpus falcatus* (Tiruneh Kide, 1988; Lamprecht, 1989; WUARC, 1995; Getachew Desalegn, 1997; Getachew Desalegn *et al*., 2005; Getachew Desalegn, 2006; Melaku Abegaz *et al*., 200; Anonymous, 2007b)

Physical properties: *C. alliodora* has green (initial) and dry (at 12% MC) density of 550 kg/m^3 and 390 kg/m^3, respectively. It has an initial and seasoned moisture content of 55% and 16.2%, respectively.

Mechanical properties (at 12% MC): Bending strength - 84 N/mm^2; modulus of elasticity - 10411 N/mm^2; work to maximum load - 0.0690 mmN/mm^3; compression parallel to the grain - 44 N/mm^2; and side hardness - 4445 N (Anonymous, 2008).

Comparable/substitute species: Wood is moderately strong and hard, comparable with Mexican mahogany (*Swietenia macrophylla*). For some applications, *C. alliodora* is used as substitute for teak (*T. grandis*), walnut (*Lovoa tirchiliodies*) or mahogany. *C. alliodora* is comparable with *Cordia africana*, which is native to Ethiopia and also belongs to the same family

Boraginaceae (Getachew Desalegn, 2010). It has decorative/attractive appearance like the indigenous species *Cordia africana* and Mexican mahogany (*Swietenia marophylla*), durable and much used wood throughout tropical America (Longwood, 1961; Lamprecht, 1989, Anonymous, 2008).

Product/lumber uses: *C. alliodora* exhibits excellent growth characteristics and its wood is satisfactory for processing and utilization. The wood has high durability that should qualify it for many of the same uses as cedero hembra (*Cedrela odorata*) and mahogany, but it is probably most valuable for decorative purposes (Longwood, 1961; Anonymous, 2007c). The timber can be used for different construction and furniture purposes with appropriate seasoning methods, handling of seasoned wood, at a specified MC, shrinkage allowances and density.

Because of its ease in working, low shrinkage, and attractiveness, it is an economically interesting pioneer tree species, an excellent general-purpose softwood timber and used extensively for the production of fine and decorative office and household furniture as well as cabinetwork. It is useful for general indoor and outdoor construction purposes and millwork, carving, turnery, inlay work, interior trim, balusters, excelsior, floor lamps, moldings, parquet flooring, wainscoting, poles, posts and decorative and figured veneers, plywood, cooperage, bridge timbers, ship decking, boat planking, other boat parts, turnings and instruments, production of industrial wood and pulpwood for the paper industry. It is very popular for knife handles and pens because of the extreme figure available. It can be used as long fiber pulp and plywood (Longwood, 1961; Tack, 1969; TRADA, 1979; Lamprecht, 1989; Azene Bekele, 2007; Anonymous, 2007a). It is good for earthworks and hydraulic engineering applications. Improved uses will be possible when knot-free timber with more consistent physical and mechanical properties is available (Lamprecht, 1989; WUARC, 1995). In Bebeka area, it is also used as firewood, poles, posts and timber.

Special uses: Role in land use includes shade and shelter, windbreak and hedging, ornamental, and live fence (Webb *et al*., 1984; Bowen, 1985; Lamprecht, 1989; Azene Bekele, 2007). Throughout its range, *C. alliodora* is also used as a shade tree for coffee and cacao plantations as well as in pastures. Humans eat fruits in some places. Both seeds and leaves are used for home medicinal purposes. *C. alliodora* is suitable for ornamental use in urban residential areas and has been tried for use in honey production because of its copious flowering. In Brazil, it yielded 266 litres of ethanol per ton of dry material. This compares well with a yield of 325 litres of ethanol per ton produced from *Protium* spp., the best of 25 species in Barazil tested as source of ethanol (Anonymous, 2007c).

CONCLUSIONS AND RECOMMENDATIONS

Natural air and artificial kiln seasoning methods have shown good timber properties of *C. alliodora,* including density, appearance shrinkage and seasoning characteristics. The seasoning rate and density values were comparable with some indigenous and home-grown exotic timber species grown in the country so as to introduce alternative raw material to lumber market and industries and reduce pressure on the endangered indigenous timber specie of Ethiopia. It is an important fast growing and decorative timber tree species that has to be further studied for its timber quality and other properties and promoted for large-scale plantations in the country. Proper seasoning, handling and storing of *C. alliodora* lumber has improved the properties, which will ensure quality of the products and enhance rational utilization of this timber species as one competent and potential source of construction and furniture material in Ethiopia.

The following recommendations are forwarded regarding properties and rational utilization of *C. alliodora* timber: (i) *C. alliodora,* which is prone to various forms of distortion have to be seasoned very carefully and slowly; (ii) proper stacking methods including stickers and top loading have to be applied by avoiding overhanging ends; (iii) kiln seasoning using appropriate schedule have to be used, if lower MC at faster seasoning rate below 30% and minimizing of shrinkage and seasoning defects are required; (iv) control measures have to be taken into account against MC levels (≥ 12% for out door construction, and 8-12% for indoor construction and furniture purposes); (v) proper MC, shrinkage allowances and density values have to be considered before installing and/or manufacturing lumber and other wood-based products from timber; (vi) applying lumber for ground and moisture contact construction purposes strongly entails adequate preservative measures; and (vii) undertake tree planting activities of the species with best provenance and good silvicultural management practices at a large-scale to improve yield, recovery rate and obtain quality lumber.

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