Seasoning Characterstics and Density of *Acacia melanoxylon* Lumber Grown in Chencha, SNNPR, Ethiopia

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Abstract

Seasoning is one of the major factors that determine the quality, utilization and service life of wood as round and sawn lumber. Seasoning characteristics and density were investigated along with the tree height of *Acacia melanoxylon*. For this study, *A. melanoxylon* trees were selected randomly and harvested from Chencha, SNNPR Ethiopia. Sample logs were collected from bottom, middle and top portions and sample boards were prepared for determination of seasoning characteristics and density along with the tree height. The basic density and tangential, radial and volumetric shrinkages were affected by tree height ($p<0.05$) and the highest values were observed at the base and lowest at the top of tree height. The mean value of the basic density was 0.57 g/cm^3. The mean values of the tangential, radial and volumetric shrinkage from green to 12% moisture content (MC) were 3.8%, 1.97%, and 6.19%, respectively and longitudinal shrinkage was negligible. The mean initial and final MC for air and kiln seasoning stacks were 67.36% and 14% and 66.19% and 12.03%, respectively. Air seasoning time to reach 14% MC took 42 days, while kiln seasoning to reach 12.03% MC took 7 days. The species showed low shrinkage and less seasoning defects both on air and kiln seasoned boards.

Keywords: *Acacia melanoxylon*, Basic density, Kiln, Seasoning, Shrinkage, Stem height.

Introduction

In Ethiopia, wood and wood products supplies for industrial, construction including research purposes are mainly from natural forest (Teketay *et al*., 2010; MEFCC, 2017). To reduce the pressure on the remaining natural forests and endangered indigenous trees, large hectares of plantations of exotic species have been established and several exotic tree species were introduced into the country. *Acacia melanoxylon* was one of the species introduced to Ethiopia to be used as an alternative source of raw material to meet the ever-increasing demand for different forest products. *Acacia melanoxylon* R.Br belongs to the family Leguminosae and subfamily Mimosoideae (Lemmens, 2006). It is a fast-growing species with a tall and straight trunk/bole. It is commonly called Australian Blackwood (Nicholas and Brown, 2002) and locally known as Omedla in Ethiopia (Bekele, 2007). *A. melanoxylon* grows in cool, temperate rainforests, open forests of the tablelands and coastal escarpments (Nicholas and Brown, 2002). It performs well in altitude ranging from 1500 to 2300 meters above sea level with mean annual temperature 6 to 19 ^{0}C, mean annual rainfall is 750 to 2300 mm (Orwa*et al*., 2009).

Acacia melanoxylon timber is a medium density, with excellent drying and finishing properties (Chudnoff, 1980). The timber also has low shrinkage and glues well with most common adhesives (Chudnoff, 1980; Bradbury *et al*., 2010b). It is also easy to work, has even texture, usually straight and it turns and bends well (Nicholas and Brown, 2002). *Acacia melanoxylon* timber is highly used in the world for cabinet-making and furniture (Boland *et al*., 1984). It is also suitable for veneers, turnery, paneling, carving, flooring, boat building, gunstocks, musical instruments, plywood, tennis racquets and knobs (Chudnoff, 1980; Nicholas and Brown, 2002; Bradbury *et al*., 2010b). The value of *Acacia melanoxylon* wood is mainly given by its heartwood content and its golden-brown color, often containing darker veins or reddish streaks (Searle, 2000).

The use of wood is influenced by the density and seasoning characteristics of the timber. Density, moisture, seasoning and shrinkage characteristics (tangential, radial, longitudinal and volumetric), seasoning rates and defects are among the major factors that determine the quality, utilization and service life of wood as round and sawn lumber (Simpson, 1991; Denig *et al*., 2000; Desalegn, 2006; FPL, 2010). On the other hand, familiarity with density and seasoning properties are important because they can significantly influence the performance and strength of the wood used in structural applications (Winandy, 1994). Seasoning aims to dry timber uniformly with minimum deformation in the shortest possible time to a moisture level similar to the surrounding air (equilibrium moisture content). Seasoning of wood increases most strength properties of lumber and protects lumber against primary decay, fungal stain and attack by certain kinds of insects. In Ethiopia, wood seasoning research has been carried out on many home grown and exotic tree species, but no previous drying studies of Ethiopian grown *Acacia melanoxylon* wood was conducted. Seasoning studies on the species conducted in Australia and South Africa reported that *A. melanoxylon* wood seasons well and may be either air dried or kiln dried from green with no major degrade in thickness up to 50 mm thick (Boas 1947; Hartwig 1964).

In Ethiopia, *Acacia melanoxylon* timber is underutilized due to lack of information on the wood properties of the species. Therefore, estimating density and managing moisture content in wood for the intended purpose and environment of applications will be rational utilization of timber species in Ethiopia. The objective of this study was to investigate the density and seasoning characteristics of *A. melanoxylon* timber grown in Chencha, SNNPR Ethiopia.

Materials and Methods

Study site description

The species grows on an elevation between 1,300 and 3,250 m above sea level with geographical direction of 6^{o}8’0”-6^{o}26’0’’N and 37^{o}22’30”- 37^{o}43’30”E (Fig. 1). The mean annual precipitation and temperature of this area are usually about 1353 mm and 14^{0}C respectively (Yewubdar and Aseffa, 2017).

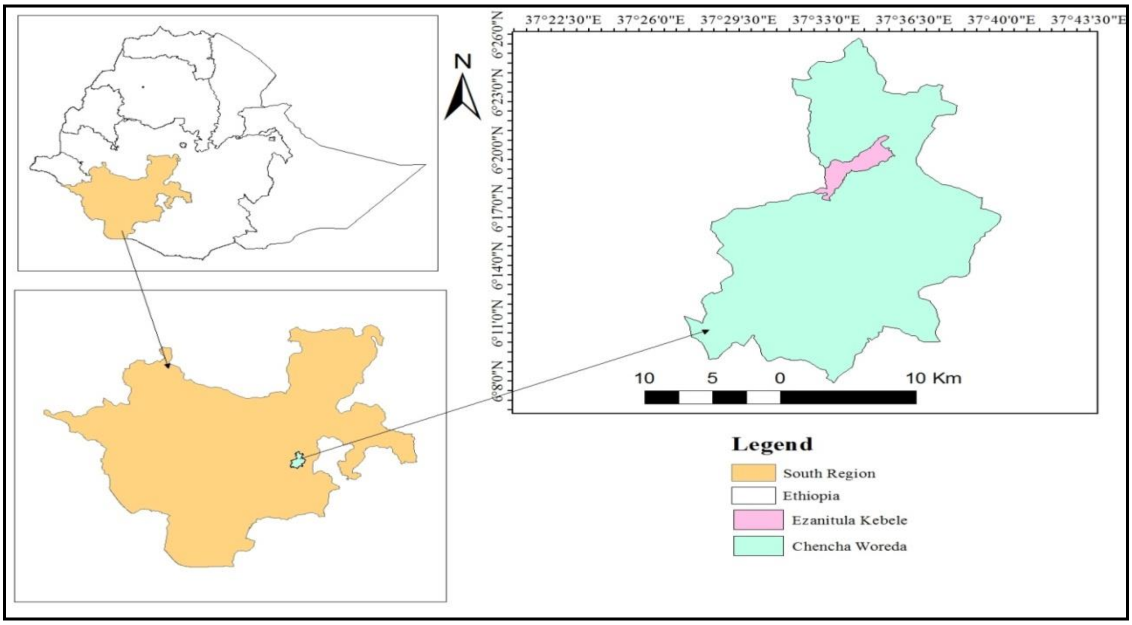

Figure 1: Map of Ethiopia showing the study area

Tree Sampling

A total of ten trees of 30 years old *Acacia melanoxylon* were randomly selected and harvested from the Chencha woreda community forest. The selected sample trees are straight trunks, normal branching and had no disease or pest symptoms (ISO 3129, 1975; Desalegn *et al*., 2012). The height and diameter at breast height (dbh) of the trees were ranging from 17 to 20 m and 21 to 26 cm, respectively. Each sample tree was cross-cut into three 2.5 m logs which represent the bottom, middle and top of the tree height (Desalegn, 2006; Moya *et al*., 2013) and, the end logs were sealed with paint to avoid moisture loss and end check/splitting. Then the sample logs were transported Addis Ababa, Forest Products Innovation Research and Training Center (FPIRTC) laboratory for further processing.

Sawing and Sampling for Seasoning Characteristics Test

The sample logs were sawn tangentially using circular sawmill produced boards of 3 cm thickness in Forest Products Innovation Research and Training Center, Addis Ababa. Defect free sawn boards which represent the bottom, middle and top of the trees are selected for the determination of seasoning characteristics for both air and kiln seasoning experiments. From each selected boards, two small sections cross-cut 20 cm inwards from sample board ends having 1.2 cm length and 3 cm thickness were prepared for determination of initial MC along with the tree height for both seasoning methods (Desalegn, 2006) as shown in figure 3. The remained middle parts of the sample boards with dimensions of 100 cm length, 3 cm thickness and width equal to bolt-diameter (Fig. 3) were used to determine seasoning characteristics along with the tree height for both air and kiln seasoning experiments.

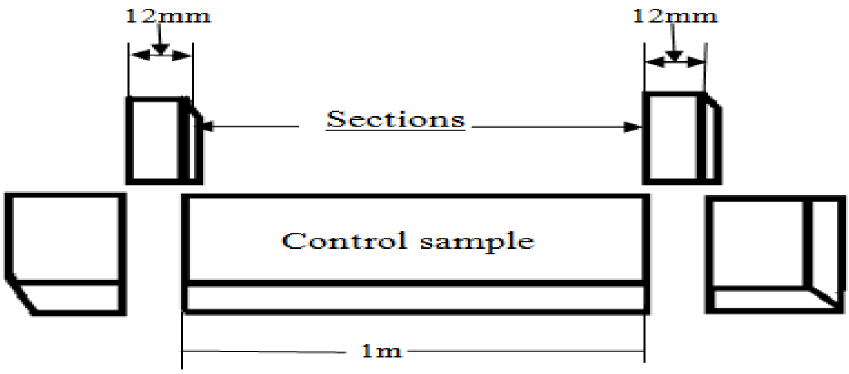

Figure 2: Sample preparation for determination of seasoning characteristics

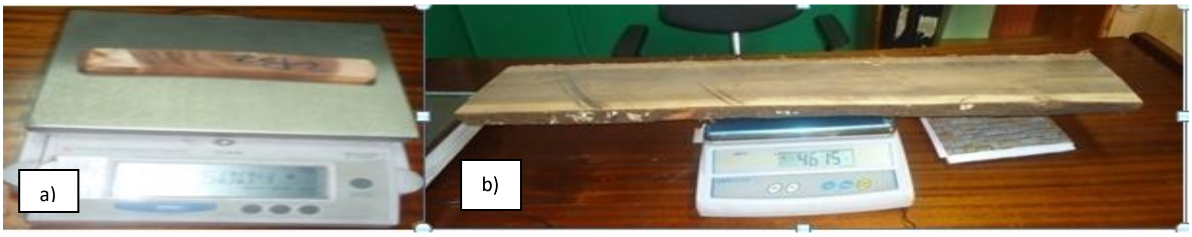

Figure 3: Pictures showing sample of initial moisture content weighing (a) and sample board weighing (b)

Sample Preparation for Basic density and Shrinkages

Specimens free from visible defects having a cross-section of 20x20 mm and length of 30 mm at green state were prepared from the bottom, middle and top boards for determination of basic density and shrinkage characteristics of *A. melanoxylon*. The method used for the determination of basic density and tangential, radial and volumetric shrinkage based on international standards and procedures (ISO/DIS 4469, 1975; ISO/DIS 4858, 1975; Simpson, 1991; Haygreen and Bowyer, 1996; Denig *et al*., 2000).

Stacking Sawn Boards for Seasoning Characteristics tests

Immediately after sawing, boards were transported to the air seasoning yard and compartment kiln-seasoning chamber areas. Boards were stacked at 3 cm spacing between successive boards to facilitate the circulation of air (Simpson, 1991). They were stacked horizontally in vertical alignments separated by well-seasoned, squared and standard stickers (Reeb and Brown, 2007).

The sample boards were distributed in each stack to represent the lumber in the stack and the seasoning process at different positions (top- bottom, left right and vice-versa). Weighing and replacing the samples into the stack was done repeatedly until the MC reached the desired amount of about 12% moisture content. The control sample boards were properly distributed and positioned in the pockets of the different layers of each stack.

Boards for air seasoning were stacked in air-seasoning yard under shed on firm foundations having 45 cm clearance above the ground and a dimension of 1.80x0.45x4 m.The boards were aligned in a north-south direction where the ends were not exposed to the direction of the wind. This was done to facilitate good air circulation and reduce the direct influence of fungi, temperature, wind and relative humidity. Board for kiln seasoning was stacked out of the kiln on the transfer carriage having a dimension of 2.7x1.6x 0.30 m and placed in the kiln-seasoning chamber.

Figure 4: Pictures showing lumber stacked for air drying (a) and kiln seasoning (b) of *A. melanoxylon* lumber

Air Seasoning

Green weights of all air seasoning sample boards were measured immediately after planing and crosscutting using the sensitive electrical balance. Weighing of samples for initial MC determination was carried out 4 hours interval until the difference between two successive weights of each specimen was between 0.1-0.2 g (Desalegn, 2005) and the final weight was taken as the oven-dry weight (ISO 3130, 1975; Reeb and Brown, 2007; FPL, 2010). The sample boards were weighed (Fig. 4b) and replaced into the stacks and re-weighed at a one-week interval. The process was continued until the average final MC of the stack reached about 15-12%, which is the equilibrium moisture content (EMC) for in and outdoor purposes.

Kiln Seasoning

The conventional type of artificial kiln seasoning machine was used for this study. The machine has about 2.5 m^3 wood loading capacity room or chamber. It has controlled air circulation, temperature and humidity that can be adjusted using psychrometers (dry bulb and wet bulb thermometers) and has been equipped with fans to force air circulation and an air outlet at a temperature range of 40-70ºC. The kiln seasoning schedules were selected based on the species type, initial MC and density of the lumber species. Kiln schedule Ethiopia number three (Wood Utilization Research Center, 1995), was used for the *Acacia melanoxylon* lumber (Table 1). Kiln seasoning test sample boards were weighed, moisture content calculated, psychrometers regulated, steaming done, and the direction of the fan changed at 8 hours interval (three times in 24 hours) to allow uniform air circulation, control the seasoning process and quality of the seasoned wood. The process was continuous until the required final 12% MC reached (FPL, 2010; Desalegn *et al*., 2012; Moya *et al*., 2013).

Table 1: Kiln Schedule for hardwoods of Ethiopia

Initial MC (%)	Temperature (°C)		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

Basic density determination

The prepared specimen blocks were soaked in distilled water for 72 hours to ensure that their moisture content was above the fiber saturation point. Then the dimensions in all three principal directions (tangential, radial and longitudinal) were measured with a digital caliper and their weights were taken for green weight. The green volume was calculated based on these green dimensions measurement. Finally, the specimens were oven-dried at 105^0C and relative humidity 65% for 24 hours and again the dimensions and weight measurements were taken. This is continued until constant weights were obtained. Basic density was determined on a green volume, oven dry weight basis (ISO/DIS 3131, 1975). The formula used to calculate the basic density was:

Basic density= $\frac{\text{Wo (g)}}{\text{Vg (mm}^3\text{)}}$--- (1)

Where, Wo: is the oven-dried weight in (gm), Vg: is the green volume specimen in (mm^3)

Shrinkage determination

The radial, tangential and volume dimensions of the basic density specimen blocks were marked and measured using a digital caliper. The blocks were then oven dried at 105°C for 24 hours. The oven-dried blocks were then weighed and the dimensions were measured again along with the points marked earlier using the same digital caliper. The green to 12% MC shrinkage in tangential and radial and volumetric shrinkage of the same blocks was determined, expressed as a percentage of the saturated dimension to its 12% MC dimension. The different formulas were adapted from ISO/DIS 4469 (1975); ISO/DIS 4858 (1975).

Shrinkage (%) = Decrease in dimension (mm)/green dimension (mm) x100 ---------- (2)

Initial Moisture Content and Rate of Seasoning Determination

Initial and final MCs were determined for both air and kiln seasoning stacks of the lumber. In both seasoning methods, the moisture content (MC) was determined as stated in (ISO 3133, 1975; Denig *et al*., 2000; Reeb and Brown, 2007; FP, 2010). The average MC of the two sections was determined using the specimens prepared in Fig. 3. The weight of each sample at the time of cutting was used to estimate the analytically determined oven dry weight of the stack samples at 12% MC. The moisture content was calculated as follows:

Moisture content (MC %) = (IW-OD/OD) x100 = (IW/OD-1) x100 = (W/OD) x100 ---- (3)
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).

Air and Kiln seasoning rates from green to about 12% MC of each lumber species were estimated from the MC samples of each species (Moya *et al*., 2013). Seasoning rate classification for air and kiln seasoning stacks was done based on the adopted standards from Longwood (1961) and Farmer (1987) respectively.

Seasoning Defects Determination

For this study, sample boards which represent (bottom, middle and top) portions from each air and kiln seasoned experiments were randomly selected and defects were separately measured for each seasoning methods. According to Simpson (1991), warp which includes (cup, crook, bow, and twist), and as well as surface splits, end-splits, surface checks and end-checks were performed on a flat surface with the aid of a measurement wedge. The boards were secured on one end while measurements were taken on the other end. According to Longwood (1961), the severities of seasoning defects were classified based on the magnitude and frequency from green to 12% moisture content. Accordingly, 1= none/defect free, 2= very slight, 3= slight, 4= moderate, 5= severe and 6= very severe defects.

Statistical Analysis

Statistical Package for the Social Sciences (SPSS) version 20 (IBM Corp. released 2011) was used to analyze the data using Descriptive statistics and analysis of variance (ANOVA) Procedure. A least significant difference (LSD) method was used for mean comparison at $P<0.05$.

Results and Discussion

Basic density and Shrinkage

The basic density and shrinkages percentages are among the main factors that affect the usability of wood as a raw material. The mean and standard deviation values for basic density and shrinkage percentages along the tree height are given in Table 2.

Table 2: The mean values of basic density and shrinkage at bottom, middle and top of *Acacia melanoxylon* timber

Height	n	Basic density (g/cm^3)	Tangential (%)	Radial (%)	Volumetric (%)
		Mean values of basic density and shrinkages			
Bottom	5	0.604±0.072^b	4.34±0.13^b	2.38±0.35^b	6.97±0.30^b
Middle	5	0.571±0.069^a	3.60±0.19^a	1.93±0.37^b	5.87±0.49^a
Top	5	0.536±0.079^a	3.47±0.55^a	1.60±0.18^a	5.72±0.68^a

Note: Means having the same superscript letter across the columns were not significantly different at P<0.05. Where, MC-Moisture content, n-number of specimens

Basic density

The mean basic density of the three portions along with the three tree height i.e. bottom, middle and the top is shown in Table 2.

Table 3: Summary of ANOVA on basic density and shrinkage of *Acacia melanoxylon* timber

Source of variation	DF	Mean-square and statistical significances			
Shrinkage from green to 12% MC (%)					
		Basic density	Tangential	Radial	Volumetric
Height	2	0.017*	1.755*	1.226*	3.730*

Note: ns-not significant at p<0.05,*-significant at p<0.05 **-highly significant at P<0.01. Where, DF- degree of freedom, MC- moisture content

Statistical Analysis of variance revealed that the tree height had a significant effect on basic density (P< 0.05) (Table 3). The pattern of variation in basic density, as a function of height in the stem, is shown in Table 2. The highest value of basic density was observed at the base and decreased from the base 0.604 g/cm^3 to the top of the tree 0.536 g/cm^3 (Table 2). Similar variation was reported for 10, 15 and 20 years old of *Acacia mangium* (Chowdhury*et al*., 2005) grown in Bangladesh. The same variations to this finding were also noted by different authors (Ali and Uetimane, 2010; Uetimane and Ali, 2010; Hussin *et al*., 2014) for hardwood of *Sterculia appendiculata*, *Pseudolachnostylis maprounaefolia* and *Albizia falcataria* respectively. In contrast, Santos *et al*. (2013) reported that the basic density of *A.*

melanoxylon has irregular variation which decreases from base to breast height and then increased up to the top of the tree. The variation of basic density from the bottom upwards might have been caused due to the maturity at the base and juvenility at the top of the tree. Juvenility increases from bottom towards top, and as juvenility increases basic density decreases (Getahun *et al*., 2014). Haygreen and Bowyer (1996) noted density in the juvenile wood zone is low because there are relatively few latewood/summerwood cells and a high proportion of cells have thin wall layers.

The result showed that the overall mean basic density of *Acacia melanoxylon* timber was 0.57 g/cm^3 with a standard deviation of 0.077. This finding was in line with the result reported by Nicholas and Brown (2002) that indicated basic density in the ranges of 0.465 to 0.670 g/cm^3 and similarly, Harris and Young (1988) also reported values ranging from 0.312 to 0.681 g/cm^3 for the same species. The mean basic density of *A. melanoxylon* found in this study was greater than the mean basic density (0.531 g/cm^3) reported by Santos *et al*. (2012) for the same species. However, the result of this study was less than 0.607 g/cm^3 as reported by Tavares *et al*. (2014). These variations may be attributed to genetics and local environmental factors which affect the growth of the trees such as soil characteristics, the density of stand, precipitation, solar radiation and age of the trees (Panshin and de Zeeuw, 1980).

In comparison with other Acacia species, the mean basic density of this finding was less than *Acacia saligna* (0.637 g/cm^3) reported by Mmolotsi *et al*. (2013) and *Acacia nilotica* (0.61 g/cm^3) reported by Mahmood *et al*. (2016). In relation to commercially known and endangered tree species in Ethiopia, the basic density of *A. melanoxylon* was comparable with density at 12% MC tested of *Hagenia abyssinica* (0.56 g/cm^3) and *Pouteria adolfi-friederici* (0.60 g/cm^3) and higher than the density at 12% MC of *C. lustanica* (0.430 g/cm^3), *P. patula* (0.450g/cm^3), *Juniperus procera* (0.54 g/cm^3); and lower than those of *E. globulus* (0.780 g/cm^3) and *E. camaldulensis* (0.853 g/cm^3) (Desalegn *et al*., 2012; Desalegn *et al*., 2015).

Shrinkage characteristics

The mean tangential, radial and volumetric shrinkage percentages for the three sections along with the three tree height are shown in Table 2. The Analysis of variance revealed that the tree height had significant effects on tangential, radial and volumetric shrinkage of *A. melanoxylon* ($P<0.05$) as shown in Table 3. The pattern of variation in wood shrinkages, as a function of height in the stem, is shown in Table 2. Within the tree, the tangential, radial and volumetric shrinkages percentages were decreased along the stem height, from the base upwards. Similar variations were reported for *Sterculia appendiculata*; (Ali and Uetimane, 2010), for Athel wood (Kiaeiand Sadegh, 2011), for *Populus euramericana* (Kord*et al*., 2010) and for Oriental beech and Caucasian fir species (Topaloglu and Erisir, 2018). On the other hand, tangential, radial and volumetric shrinkage increased as wood density increased (Bowyer, *et al*., 2003; Kord*et al*., 2010; FPL, 2010). This finding of shrinkages also linked with the density of the species. The results indicated that the tangential, radial and volume shrinkage and the basic density shows a decreasing trend with increasing tree height of *Acacia melanoxylon* tree.

Despite the tree height, high average shrinkage percentages were observed at the tangential direction (3.80 %) than the radial (1.97%). This variation was comparable with other study conducted elsewhere for the same species (Nicholas and Brown, 2002) who reported that tangential and radial shrinkage from green to 12% MC was 3.6% and 1.8% respectively. The results depicted that tangential shrinkage was two times greater than the radial direction. Similar patterns have been reported by different authors for *A. melanoxylon* (Haslett, 1983; Nicholas and Brown, 2002). This indicated that the species is moderate and dimensionally stable.

The results found the mean tangential (3.80%), radial (1.97%) and volumetric (6.19%) were fewer shrinkage percentage than with other *Acacia* species reported by Jusoh *et al*. (2014) for *Acacia mangium* and *Acacia auriculiformis* for tangential (5.12 and 4.72%), radial (3.06 and 2.26%) and volumetric (15.89 and 18.18%), respectively. The variation between tangential and radial shrinkage could be accounted for by combinations of many factors including presence of ray tissue, which provides a restraining influence in the radial direction, frequent pitting on the radial walls, domination of latewood in the tangential direction, and differences in the amount of cell-wall material radially and tangentially (Haygreen and Bowyer, 1996). Other factors include the size and shape of the piece, which affects the grain orientation in the piece and the uniformity of the moisture through the thickness (Haygreen and Bowyer 1996; FPL, 2010) and the density of the sample whose shrinkage (%) increases with increasing density.

Based on the classification system adapted from (Chudnoff, 1980), the tangential (3.80%) and radial (1.97%) shrinkage values of *Acacia melanoxylon* lumber from green to 12% MC seasoning were classified as class 1, i.e., very low shrinkage value, indicating that its good stable quality lumber.

Moisture content and Rate of seasoning

Initial moisture content (MC) along with the tree height didn't show significant difference at P<0.05 level (Table 5) with the highest moisture content value was found in the upper part of the stem. This might be attributed to the high proportion of sapwood in the wood close to upper stem of this species. Similar variations have been reported for *Acacia saligna* (Mmolotsi, 2013) and *Acacia mangium* (Chowdhury*et al*., 2005) grown in Bangladesh. In contrast to this finding reported for *Acacia mangium* was significantly decreased with the increase of tree height (Moya and Muñoz, 2010) grown in Costa Rica.

The results showed that the mean initial moisture content (MC) before air and kiln seasoning of sample boards of each stack was 67.36% and 66.19 (Table 4) respectively. The mean final MC after air and kiln seasoned boards for this species was 14% and 12.03% respectively (Table 4). The ANOVA table (Table 5) didn't show significant difference on the final MC of sample lumber along the tree height at P<0.05 level.

Table 4: Mean values of seasoning characteristics of *Acacia melanoxylon* timber

Seasoning method	Initial MC	Final MC	Rate of seasoning (days)	classification
Air seasoning	67.36	14	42	very rapid
Kiln seasoning	66.19	12.03	7	very rapid

Table 5: Summary of ANOVA table on seasoning characteristics of *Acacia melanoxylon* timber

Source of variation	Mean-square and statistical significances		
	DF	Initial MC (%)	Final MC (%)
Height	2	91.157ns	3.310ns
Seasoning method	1	2.030ns	13.261ns

Note: ns-not significant at p<0.05,*-significant at p<0.05, **-highly significant at P<0.01

The mean value of the rate of air and kiln seasoned lumber of tangentially sawn boards of 3 cm thickness to reach to about 14% and 12.03 MC was 42 and 7 days, respectively (Table 4). The result indicated that air seasoning was faster seasoning rate than with study conducted elsewhere for the same species (Haslett, 1983) who reported that the rate of drying was 69.3 days to reach about 15% MC. This variation might be caused by lumber thickness, location, and the time of year the lumber is stacked (FPL, 2010). This finding was carried out during dry season in the months of December and January. This result revealed that *A. melanoxylon* lumber took 42 days to reach 14% MC. This noted during the dry period, it is possible to season lumber to less than 20% MC by air seasoning. Since lumber with < 20% MC has no risk of developing stain, decay or mould (Denig*et al*., 2000; Wengert, 2006) which could be used for outdoor and above ground construction purposes. Air seasoning alone is not sufficient for lumber intended for most interior use 8-12% is required (FPL, 2010).

Table 6: Kiln Schedule developed for *Acacia melanoxlon* Lumber

Initial MC (%)	Temperature (°C)		Relative humidity (%)
	Dry-bulb	Wet-bulb	
70-60	38	36	83
60-50	44	40	78
50-40	46	41	74
40-30	50	43	66
30-20	54	45	60
20-10	60	47	50

The average value of kiln-seasoning time obtained in this study was relatively comparable with another study for the same species (Haslett, 1983) who reported that the kiln seasoning time ranges 4-5 and 8-10 days for 25 and 50-mm-thick material respectively. The mean final MC of kiln-seasoned wood based on its purpose may vary from 0 to 25% (Denig *et al*., 2000). Kiln seasoned lumber can have an average specified moisture content of typically 6-8% or a MC suitable for certain use (Denig*et al*., 2000). Based on the rate of seasoning categories (Longwood, 1961; Farmer, 1987), the lumber of *A. melanoxylon* can be classified as very rapid seasoning rate for both air and kiln seasoning methods (Table 4).

The air seasoning rate was comparable with accuracy of ± 5%, and determined with the same method and laboratory, were *Eucalyptus grandis* (37.8 days), *Croton macrostachyus* (44.8 days) and *Pinus Ekebergiacapensis* (44.8 days) (Desalegn *et al*., 2012; Desalegn *et al*., 2015). The kiln seasoning rate of *A. melanoxylon* lumber was comparable with *E. deglupta* (7 days)

(Desalegn*et al*., 2015). Compared with air seasoning, kiln seasoning gave better possibility of controlling the relative humidity and temperature, moisture content, rate of seasoning, seasoning defects, appearance and the quality of seasoned timber besides reducing moisture content (MC) to the desired amount (about 12% MC) in a relatively very short period of time (Table 4). The kiln seasoning schedule applied for this timber species was suitable and achieved faster seasoning compared with air seasoning, and not many seasoning defects occurred.

Seasoning Defects

The types and extents of defects are shown in Table 7 and Table 8. The seasoning defects found on this species were the cup, crook, bow, end-split, surface-split, end check and surface-checks. The seasoning defects didn't show significant difference along the tree height for both air and kiln season ($P<0.05$) as shown in Table 9. However, analysis of variance (Table 9) showed that there was a significant difference between air and kiln seasoned defects except for cup ($P<0.05$).

Table 7: The mean values of air seasoning defect at the bottom, middle and top of *A. melanoxylon* tree

Height	n	Mean value of air seasoning defects along with tree height in (mm)						
		Cup	crook	bow	e-split	s-split	e-check	s-check
Bottom	5	$1.76{\pm}0.67^{a}$	$1.72{\pm}0.41^{a}$	$3.66{\pm}0.59^{a}$	$31.75{\pm}3.50^{a}$	$81.25{\pm}20.16^{a}$	$0.75{\pm}0.5^{a}$	$0.25{\pm}0.5^{a}$
Middle	5	$1.35{\pm}0.46^{a}$	$2.06{\pm}0.83^{a}$	$2.99{\pm}1.86^{a}$	$30.75{\pm}2.99^{a}$	$46.59{\pm}45.99^{a}$	$0.50{\pm}0.58^{a}$	$00{\pm}00^{a}$
Top	5	$1.37{\pm}0.39^{a}$	$1.46{\pm}0.68^{a}$	$3.50{\pm}0.68^{a}$	$6.25{\pm}12.5^{b}$	$42.50{\pm}50.57^{a}$	$0.50{\pm}0.58^{a}$	$0.25{\pm}0.5^{a}$

Note: Means having the same superscript letter across the columns are not significantly different at $P < 0.05$. Where, n- number of specimens

Table 8: The mean values of kiln seasoning defect at the bottom, middle and top of *Acacia melanoxylon* tree

Mean value of kiln seasoning defects along with tree height in (mm)								
Height	n	Cup	crook	bow	e-split	s-split	e-check	s-check
Bottom	5	1.03±0.86[a]	1.12±0.44[a]	1.72±0.39[a]	11.25±8.54[a]	19.24±29.86[a]	0.25±0.50[a]	0.50±0.78[a]
Middle	5	1.29±0.19[a]	0.85±0.84[a]	1.93±1.29[a]	2.50±5.00[b]	2.64±10.00[b]	00±00[a]	0.750±0.50[a]
Top	5	0.61±0.52[a]	0.81±0.50[a]	1.69±0.75[a]	15.0±12.91[a]	12.068±17.07[c]	0.250±0.5[b]	0.75±0.5[a]

Note: Means having the same superscript letter across the columns were not significantly different at $P < 0.05$. Where, n-number of specimens

As depicted in Table 7 and 8 comparatively, air-seasoned boards had more excessive defects than to the kiln seasoned boards. This noted that air seasoning depends on the atmospheric conditions, so it is difficult to control temperature, relative humidity and air velocity of the surrounding (FPL, 2010). In kiln seasoning, it is possible to control temperature, relative humidity and air velocity (Keey *et al*., 2000).

Table 9: Summary of ANOVA on seasoning defects of *Acacia melanoxylon* lumber

Source of		Mean-square and statistical significances						
Variation	DF	Seasoning defects in (mm)						
		Cup	crook	bow	e-split	s-split	e-check	s-check
Height	2	0.802ns	0.250ns	0.215ns	237.38ns	2526.59ns	00ns	0.042ns
Drying method	1	0.956ns	4.076*	17.819*	1066.67*	7397.33*	1.042ns	1.50*

Note: ns-not significant at $p<0.05$,*-significant at $p<0.05$, **-highly significant at $P<0.01$ Where, e-split: end-split, s-split: surface split, e-check: end-check, s-check: surface check and DF: degree of freedom.

The overall mean values of air-seasoned defects for cup (1.49 mm), crook (1.75 mm), bow (3.38 mm), end-split (22.92 mm), surface split (56.78 mm), end-check (0.58 mm) and surface check (0.17 mm). On the other hand, the overall mean values of kiln-seasoned defects were cup (0.98 mm), crook (0.67 mm), bow (1.78 mm), end-split (9.58 mm), surface split (11.32 mm), end-check (0.17 mm) and surface split (0.67 mm).

According to Longwood (1961), *A. melanoxylon* lumber defects are categorized under fewer defects in case of both air and kiln seasoning experiments. The results showed that there was somewhat problem of splits on the lumber. Splits occurred at the pith line and end splitting was a common defect in the air and kiln seasoned boards. This was due to a combination of growth stress, end drying, and lack of fillet restraint in the overhanging ends (Haslett, 1983).The results revealed that warps such as a cup, crook, and bow were a little problem on this species particularly, on the kiln seasoned boards. These types of defects might be caused by poor stacking and natural factors (tension wood and juvenile wood) (Wengert, 2006). Warps occurred during seasoning of *Acacia melanoxylon* lumber could be reduced by proper stacking using stickers and top loadings.

Conclusions and Recommendations

From this study, the following conclusions are made.

- Within stem height of *Acacia melanoxylon*, the basic density and shrinkages (tangential, radial and volumetric) decreased from the base towards top of the tree height. The highest values observed at the base and lowest at the top of the tree height while the green moisture content (MC) of the species was insignificantly increased from the base towards the top.
- *Acacia melanoxylon* lumber is categorized under fast drying rate species in case of both air and kiln seasoning methods. The species had also low shrinkage and low seasoning defects in the case of both seasoning methods.
- The species was comparable with many indigenous and home-grown exotic timbers in terms of density, seasoning rate, and shrinkage characteristics. Therefore, *Acacia melanoxylon* could substitute the over-harvesting tree species in the country.
- Generally, trees and logs have to be properly harvested, sawn, boards stacked properly and seasoned to less than fiber saturation point (< 20% MC). Lumber shall be seasoned using kiln seasoning method to minimize seasoning time, maintain wood quality and suitability for different applications.
- Air seasoning technology needs shed with a good foundation and air circulation without direct access to moisture and rainfall. The air seasoning technology is not expensive and recommended to small scale forest products processing industries, construction sectors, and marketing enterprises while the kiln seasoning technology is

expensive that could be affordable and recommended to medium and large scale forest products processing industries, construction sectors and marketing enterprises.

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