Journal of Forestry and Environment 1(1): 01-15, 2019
ISSN 2079-214X

DOI: 10.5829/idosi.jfe.2019.01.15

Within-Stem Variations in Density and Mechanical Properties of *Acacia melnoxylon R.Br* Grown in Chencha, Southern Ethiopia

[1]Mahadi Mussa and [2]Tsegaye Bekele

[1]Ethiopian Environment and Forest Research Institute,
Wood Technology Research Center, Addis Ababa, Ethiopia
[2]Hawassa University, Wondo Genet College of Forestry
and Natural Resources, Hawassa, Ethiopia

Abstract: In Ethiopia, due to a higher rate of population growth and development of wood industries coupled in-line with increased demand for wood that has been caused a dramatic decreasing in forest resources. This study investigated the variation of density and mechanical properties within the stem of *Acacia melanoxylon*. Five trees of 30 years old *A. melanoxylon* were randomly selected and harvested. From each tree, three sample bolts of 2.5 m long were collected from the bottom, middle and top portions of stem height. The sample logs converted into lumber and a total of 1080 specimens free from visible defects were prepared for determination of density and mechanical properties along with the three stem height and along with two radial directions (heartwood and sapwood) for both green and at 12% moisture content. The overall mean values of density (0.695 and 0.609) g/cm^3, modulus of elasticity (MOE) (9249.7 and 13671.89) N/mm^2, modulus of rupture (MOR) (69.49 and 147.98) N/mm^2, impact bending (9519.60 and 9880.81) Nm/m^2, maximum crushing strength (33.96 and 62.71) N/mm^2 and hardness in tangential (3720.64 and 5373.10) N and radial (3825.8 and 5415.40) N in green and at 12% moisture conditions respectively. For both moisture conditions, the stem height had significant ($p<0.05$) effects on density and mechanical properties. However, an insignificant ($p<0.05$) effect was found between the heartwood and sapwood in both moisture conditions of density and mechanical properties. In the case of both moisture conditions, the values of density and mechanical properties were decreased from the base to the tip of the stem height. The tree showed potential as an alternative species to supply the wood industry.

Key words: *Acacia melanoxylon* · MOE · MOR · Compression Parallel to grain · Hardness · Stem Height · Radial Direction

INTRODUCTION

In Ethiopia, due to a higher rate of population growth and development of wood industries coupled in line with increased demand for wood that has been caused a dramatic decrease in forest resources. Ministry of Ethiopian Environment, Forest and Climate Change (MEFCC) [1] report showed that in 2013, Ethiopia consumed more than 124 million cubic meters of wood each year. With population growth and economic development projections, total wood product demand will increase by about 27% over the next 20 years, reaching an annual consumption of 158 million cubic meters by 2033 [1]. To satisfy the ever-increasing demands of the consumers, large quantities of lumber, panel and fiber products are being imported from different countries with hard currency [2, 3]. Besides, the high demand for wood coupled with high deforestation rates has led to an increase in the adoption of exotic trees and the introduction of plantation forestry into the country. Even though currently, natural forests and selected tree species are being cleared in excess in the country [4]. Conversely, there are numerous plantations and potential species whose industrial and other commercial benefits are not yet

---

Corresponding Author: Mahadi Mussa, Ethiopian Environment and Forest Research Institute (EEFRI),
Wood Technology Research Center (WTRC), P.O. Box: 2322, Addis Ababa, Ethiopia.
Tel: +251921179940.

fully realized [5]. The selective use of the species paired with an inefficient further processing and inappropriate utilization due to lack of information and/or technologies on different wood properties and utilization methods for the potential alternative tree species.

In Ethiopia, A number of fast-growing exotic tree species including Acacia species were introduced to Ethiopia to be used as an alternative source of raw material to meet the ever-increasing demand for different forest products and to substitutes the imports of wood products from abroad. *Acacia melanoxylon* was introduced to Ethiopia from Australia and the timber was less utilized in case of Ethiopia that has been used for firewood, charcoal, light construction, fence posts, shade, ornamental and windbreak [6]. This species has been found or planted in the country in the area of cooler and wetter upland areas, Moist and Wet Kolla Weyna Dega and Dega agroclimatic zones [6].

Acacia melanoxylon R.Br is a fast-growing species that belongs to Mimosoideae subfamily and Leguminosae family with tall and straight bole form. It is commonly called Australian Blackwood [7, 8] and locally known as Omedla in Ethiopia [6]. *Acacia melanoxylon* is unusual among the acacias because it is adapted to moist rather than dry areas [7]. The species grows in cool temperate rainforests, open forests of the tablelands and coastal escarpments [7] and performs well in altitude ranging from 1500 to 2300 meters above sea level with mean annual temperature 6 to 19°C, mean annual rainfall ranging from 750 to 2300 mm [9].

Acacia melanoxylon timber is an appreciated due to the physical appearance of the wood has been attractive and an even texture and it has good strength and machining properties which make it suitable for high-quality furniture, cabinet making, fancy veneer, turnery, paneling, carving, flooring, boat building, gunstocks, plywood, tennis racquets and knobs [7, 10, 11, 12]. The wood is also used for light construction, tool handles, musical instruments, fence posts, firewood and charcoal [8]. The heartwood of *Acacia melanoxylon* tree has a rich brown color and high natural durability [13, 14]. Its percentage of heartwood content is about 61% of total tree volume [15].

The use of wood is influenced by the physical and mechanical properties of the timber such as density, moisture, MOE, MOR, impact bending, compression strength, hardness and etc. Density is one an essential physical property of wood and it is the first to be considered when assessing wood quality since it correlates with most of the mechanical properties of wood and conversion processes, including cutting, gluing, finishing, drying and papermaking [16-18]. While mechanical properties of the wood indicate the ability of wood to resist various types of external forces, static or dynamic, which may act on it [19]. Mechanical properties are very much important in the case of constructional and structural purposes of timber.

The wood properties vary from species to species, at different site qualities, within species and within individual trees [20]. Wood is anisotropic material in which the properties of wood vary in longitudinal, tangential and radial directions. The information about different wood properties is not available for *A. melanoxylon* grown in Ethiopia. Therefore, it is necessary to know the physical and mechanical properties of *A. melanoxylon* wood, obtained from the plantation, in order to properly use it and suggest its uses. The objective of this study was to examine the variation of wood density, modulus of elasticity, modulus of rupture, impact bending, compression parallel to the grain and hardness in (tangential and radial) along with tree height and radial directions (heartwood and sapwood) of *Acacia melanoxylon* stem grown in Chencha, Southern Ethiopia.

MATERIALS AND METHODS

Site, Plantation Description and Tree Sampling: A representative of five trees of *Acacia melanoxylon* was randomly selected and harvested [3, 21, 22]. The selected trees with straight trunks, normal branching and no disease or pest symptoms were harvested. The height and diameter at breast height (Dbh) of the trees were ranging from 15 to 20 m and 21 to 26 cm respectively. From each selected tree, three 2.5 m long bolts were taken from the bottom, middle and top of the tree height [22, 23] (Fig 2). The species grows on an elevation between 1,300 and 3,250 m above sea level with the geographical direction of 6°8’0”-6°26'0" N latitude and 37°22’30”-37°43’30”E longitude in Chencha, Southern Ethiopia (Fig 1). The mean annual precipitation and temperature of this area are usually about 1353 mm and 14^0C respectively [24].

Sawing And Preparation Of Wood Specimens: The sample logs were sawn tangentially using circular sawmill produced boards of 3 cm thickness in Wood Technology Research Center, Addis Ababa. The sawn boards for density and mechanical properties were cross-cut into a series of 1.25 m long stringers [25] as shown in Figure 3. These were grouped and coded into odd and even

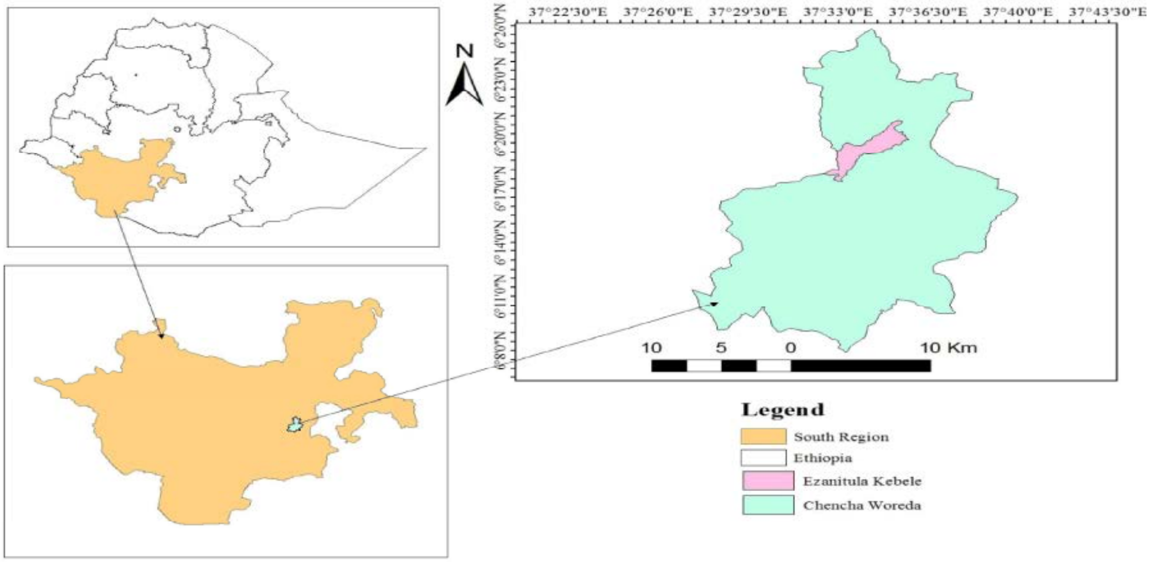

Fig. 1: Map of the study area

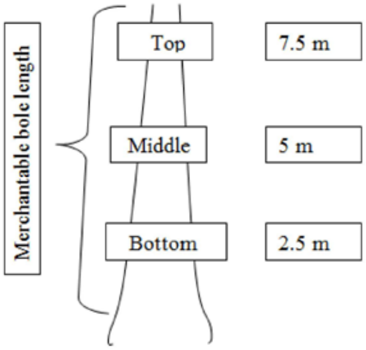

Fig. 2: Sample log section along the stem height of *Acacia melanoxylon* tree

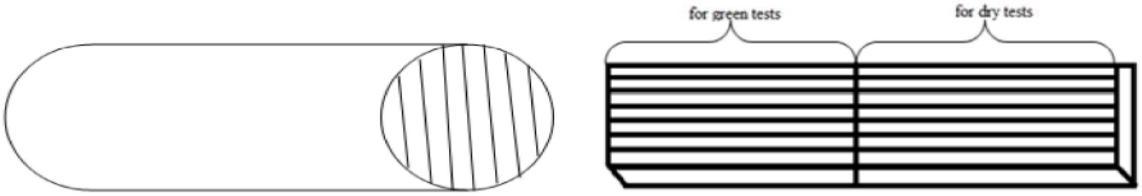

Fig. 3: Sawing pattern and sample preparations from sawn lumber for density and mechanical properties test in green and air-dry conditions

numbers for the green and air-dry tests respectively. Boards for the dry tests were subjected to air seasoning yard under shade up to 12% MC reached. While the green test sample boards were planned, ripped and cross-cut into a final cross-section of 2x2 cm and 100 cm length and finally, the heartwood and sapwood from each section separately cross-cut into standard length specimens corresponding to each wood properties test. The stringers at air-dry conditions after it reached 12% moisture content, similar to the green test specimen preparation procedure, the heartwood and sapwood from each section separately cross-cut into standard length specimens corresponding to each wood properties test.

Density and Mechanical Properties Test

Density Tests: A total of one hundred eighty specimens were prepared with dimension (20 x 20 x 60 cm) for determination of density along with the three stem height (bottom, middle and top) and along the two radial directions (heartwood and sapwood) in both green and

Table 1: Dimensions, standards and numbers of test specimens used for Density and mechanical properties

Property	Specimen dimensions (mm)*	Standards	Number of specimens
Density	20 x 20 x 60	ISO 3131	180
Static bending	20 x 20 x 300	ISO 3133	180
Impact bending	20 x 20 x 300	ISO 3348	180
Compression// grain	20 x 20 x 60	ISO 3387	180
Hardness	20 x 20 x 45	ISO 3348	360

(Radial x tangential x longitudinal)*

air-dried to 12% MC condition [26]. The density of wood was determined on a green-mass and air-dry-mass basis. A digital caliper was used to measure the dimensions of the specimens at the green and air-dried to 12% moisture content in order to determine their volumes. Then the specimens were weighed using an electronic balance. Densities calculated using the following formulas:

$$\rho g = \frac{Mg}{Vg} \quad (1)$$

$$\rho 12 = \frac{M12}{V12} \quad (2)$$

where, ρg is density at green (g/cm^3), $\rho 12$ is density at 12% MC, Mg is mass at the green, M12 is mass at 12% MC (g), Vg is the volume at green (cm^3) and V12 is volume at 12% MC.

Mechanical Properties Test

Static Bending: The static bending strength was determined based on ISO 3133 standard [27] using the Universal Testing Machine, type FM2750 with maximum loads of 50 Kilo Newton (KN). The dimensions of the specimens were (20 x 20 mm) cross-section and 300 mm in length. The distance between the points of suspension was 280 mm. For this study, a total of 90 specimens in green and 90 specimens at 12% MC, free from knots were tested for determination of MOE and MOR along with the three stem height (bottom, middle and top) and along with two radial directions (heartwood and sapwood). The load was applied to the center of the specimen, on the radial face at a constant speed of 0.11mm/s. The Load of the force plate and corresponding deflection were recorded from the dial gauge manually for each sample. Graph plotting was done for each specimen using Microsoft Excel to calculate MOE and MOR. MOE and MOR were calculated from each plotted graph using the following formulas.

$$MOE = \frac{P^1 L^3}{4\ d^1\ bh^3} \quad (3)$$

$$MOR = \frac{3\ PL}{2bh^2} \quad (4)$$

where: MOE=Modulus of elasticity (N/mm^2), MOR=Modulus of rupture (N/mm^2) P^1= Load at the limit of proportionality (N), P= Maximum Load (N) L= Span length (mm), d^1= Deflection at the limit of proportionality (mm), b= Width of specimen (mm) h= Thickness of the specimen (mm).

Impact Bending: Impact bending or Specific impact resistance is the work consumed in causing total failure in impact bending. The dimensions of specimens were (20x20x300) mm. It determined based on ISO 3348 standard [28]. A total of 90 specimens in green and 90 specimens at 12% MC, free from knots were tested for determination of impact resistance along the three stem height (bottom, middle and top) and along two radial direction (heartwood and sapwood) using a pendulum hammer, type of Impact bending Testing Machine model PW5-S. The specimens were placed on the machine and the load was applied to the center and perpendicular to the radial face of the test specimen. The joule value was read from the force plate of the test machine and the strength was computed from the following formula.

$$Sp.Im.Re. = \frac{P}{bh} \quad (5)$$

where: Sp.Im.Re=Specific impact resistance in (Nm/m^2), P=Joule value (Nm), b=width of the specimen (mm), h=Thickness of the specimen (mm).

Compression Parallel to the Grain: Compression parallel to grain test was done based on ISO 3387 standard [29]. The dimension of specimens was (20 x 20 x 60 mm). The load was applied through a spherical bearing block, preferably of the suspended self-aligning type, to ensure uniform distribution of stress. On some of the specimens, the load and the deformation in a 15 cm central gage length was read simultaneously until the proportional limit was passed. The test was discontinued when the maximum load is passed and the failure occurs. A total of 90 specimens in green and 90 specimens at 12% MC, free from knots were tested for determination of maximum crushing strength along the three stem height (bottom, middle and top) and along two radial direction (heart and sapwood) using Universal Testing Machine with speed of loading 0.01 mm/sec. The Maximum Crushing Strength (MCS) was determined from the following formula:

$$MCS = \frac{C}{bh} \qquad (6)$$

where: MCS=Maximum crushing strength (N/mm^2), C=Maximum load (N), b=width of the specimen (mm), h=Thickness of the specimen (mm).

Hardness Test: Hardness represents the resistance of wood to indentation and marring. It was comparatively measured by force required to embed 11.3 mm ball one-half its diameter into the wood [19]. Hardness values were obtained by the Janka method [30] using Universal Testing Machine with the rate of loading was 0.11 mm/s for both radial and tangential faces; A total of 180 specimens were tested in green for (tangential and radial) direction and 180 specimens at 12% moisture content in (tangential and radial) along the three stem height (bottom, middle and top) and along two radial directions (heartwood and sapwood) parts of the specimen free from knots were tested.

Statistical Analysis: Descriptive statistics and analysis of variance (ANOVA) were used to analyze the data using Statistical Package for the Social Sciences (SPSS) version 20. For mean comparisons, a least significant difference (LSD) method was used at P<0.05, SPSS [31].

RESULTS AND DISCUSSION

Density: The green density along the three stem height i.e. bottom, middle and top of *Acacia melanoxylon* was 727.57 g/cm^3, 682.28 g/cm^3 and 675.00 g/cm^3 respectively (Table 2). On the other hand, the density at 12% MC condition for the bottom, middle and the top was 648.64 g/cm^3, 591.00 g/cm^3 and 590.00 g/cm^3 respectively (Table 3). In the case of both moisture conditions, the stem height had a significant effect on the density (Table 4 and Table 5) p<0.05. However, the heartwood and sapwood had insignificant effects on density in green and at 12% moisture conditions of *A. melanoxylon* timber (Table 4 and Table 5) p<0.05. From the study, it had been found that *A. melanoxylon* at the base had higher density and decreased from the base to top of the tree in both moisture conditions. A similar variation to this study, a significant decrease with height was found for *Acacia melanoxylon* trees [32] grown in Argentinian. The present study also confirms that, density at 12% MC decreased from the base to upwards of Oriental beech (*Fagus orientalis*) [33]; *Populus euramericana* [34] and Athel wood [35]. On the other hand, a significant decrease in specific gravity with increasing stem height was observed in the hardwood of *A. mangium*, *Bombacopsis quinata*, *Sweitenia macrophylla*, *Termenalia amazonia* and *Termenalia oblonga* [36] in Costa Rica. However, insignificant decrease of density at 12% MC upward from the base to top was found in *Casuarina equisetifolia* [37].

In contrast to this finding, *Acacia melanoxylon* density at 12% MC condition was decreased from base to 5% and then increased upward from 35% to 65% of tree height [38] grown in Portugal. This noted that within the stem, most hardwood species properties have inconsistent variation. Even if all softwood species

Table 2: The means and standard deviation values of density and mechanical properties in green basis along with stem height of *A. melanoxylon*

Tested properties	n	Bottom	Middle	Top
Density (g/cm^3)	90	727.57±46.05^{a}	682.28±25.78^{b}	675.00±45.12^{b}
MOE (N/mm^2)	90	9655.40±1203.86^{b}	9129.90±1074.59^{ab}	8963.91±1090.29^{a}
MOR (N/mm^2)	90	72.73±8.79^{b}	69.25±8.03^{ab}	66.49±9.57^{a}
Sp.Im.Re. (Nm/m^2)	90	10055.2±1703.51^{b}	9450.00±1855.96^{b}	9054.20±1261.88^{a}
MCS (N/mm^2)	90	35.69±7.13^{b}	34.44±5.83^{b}	31.7483±6.56^{a}
H. tangential (N)	90	3932.33±605.28^{b}	3659.3±466.39^{a}	3570.0±387.51^{a}
Hardness radial (N)	90	3998.0±611.59^{b}	3861.7±483.92^{b}	3617.7±384.59^{a}

Note: Means having the same Superscript letters across the rows were not significantly different at P<0.05. Where, MOE: Modulus of elasticity, MOR: Modulus of rupture, MCS: Maximum compression strength, Sp.Im.Re: Specific impact resistance, T. hardness: Tangential hardness, R. hardness: Radial hardness, n is number of observations and DF: degree of freedom.

Table 3: The means and standard deviation values of density and mechanical properties at 12% MC along the stem height of *Acacia melanoxylon*

Tested properties	n	Bottom	Middle	Top
Density (g/cm^3)	90	648.64±37.10^{a}	591.00±32.94^{b}	590.00±41.71^{b}
MOE (N/mm^2)	90	14155.30±1524.14^{b}	13643.20±1395.79^{ab}	13215.50±1507.49^{a}
MOR (N/mm^2)	90	152.10±13.10^{b}	147.91±8.35^{ab}	143.94±13.05^{a}
Sp.Im.Re (Nm/m^2)	90	10398.21±1299.11^{b}	9655.80±1726.71^{a}	9589.20±1764.32^{a}
MCS (N/mm^2)	90	65.41±6.61^{b}	62.01±7.05^{a}	60.71±6.50^{a}
H. tangential (N)	90	5664.70±722.30^{b}	5333.00±611.15^{b}	5121.70±866.55^{a}
H. radial (N)	90	5665.00±536.37^{b}	5321.00±530.49^{a}	5260.30±661.23^{a}

Note: Means having the same Superscript letters across the rows were not significantly different at P<0.05. Where, MOE: Modulus of elasticity, MOR: Modulus of rupture, MCS: Maximum compression strength, Sp.Im.Re: Specific impact resistance, T. hardness: Tangential hardness, R. hardness: Radial hardness, n is number of observations and DF: degree of freedom.

Table 4: Summary of ANOVA at green density and mechanical properties of *A. melanoxylon*

		Mean-square and statistical significances						
Source of variation	DF	Density (g/cm^3)	MOE (N/mm^2)	MOR (N/mm^2)	Sp. Im. Re (Nm/m^2)	MCS (N/mm^2)	T. hardness (N)	R. hardness (N)
Height	2	24343.79*	3909024.63*	292.96*	6039583.33*	121.80*	1068974.44*	1113881.11*
Section	1	3187.06ns	2046989.37ns	118.38ns	3258506.94ns	132.06ns	938401.11ns	693444.44ns

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

where, MOE: Modulus of elasticity, MOR: Modulus of rupture, MCS: Maximum compression strength, Sp.Im.Re: Specific impact resistance, T. hardness: Tangential hardness, R. hardness: Radial hardness and DF: degree of freedom.

Table 5: Summary of ANOVA at 12% moisture content of density and mechanical properties of *A. melanoxylon* timber

		Mean square and statistical significances						
Source of variation	DF	Density (g/cm^3)	MOE (N/mm^2)	MOR (N/mm^2)	Sp. Im. Re (Nm/m^2)	MCS (N/mm^2)	T. hardness (N)	R. hardness (N)
Height	2	34090.42*	6652744.23*	498.53*	7614925.21*	176.414*	2247567.78*	1428857.78*
Section	1	2117.70ns	3324087.49ns	161.36ns	7504179.39ns	39.64ns	932284.44ns	646854.44ns

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

Where, MOE: Modulus of elasticity, MOR: Modulus of rupture, MCS: Maximum compression strength, Sp.Im.Re: Specific impact resistance, T. hardness: Tangential hardness, R. hardness: Radial hardness and DF: degree of freedom.

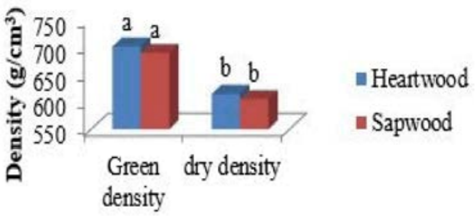

Fig. 4: Density variation between heart-sapwood and between green-dry conditions of *Acacia melanoxylon* timber

Note: Means having the same letters were not significant at P<0.05.

have no consistent variations along with stem height; For instance, increase in density with stem height found for Norway spruce [39].

The variation along the stem height of *A. melanoxylon* might be due to maturity at the base and juvenility at the tip of the tree. Maturity decreases from bottom to top and as maturity decreases; density also decreases [40]. On the other hand, density in the juvenile wood zone is low because there are relatively few late woods/summerwood cells and a high proportion of cells have thin wall layers [20]. This implies that the high-density wood from bottom logs should be used for structural purposes where high strength is required. Density is the main criterion for the prediction of clear wood strength properties [41].

In the case of both moisture conditions, the heartwood density was slightly higher than the corresponding sapwood density (Fig. 4). A similar variation to this finding was reported for the same species [42] in Australia. However, higher values of heartwood density compared to the corresponding sapwood density were reported for *Acacia burkea* and *Spirostachays africana* [43] and for *Albizzia julibrissin* [44]. The differences between the heartwood and sapwood may be extractives deposited in the heartwood.

A report showed that the phenol extractive content of heartwood was more than double that sapwood of *Acacia melanoxylon* [42].

The overall mean values of *Acacia melanoxylon* density in green and at 12% MC conditions were 0.695 g/cm^3 and 0.609 g/cm^3 respectively. The density at 12% MC was similar to with *Acacia melanoxylon* [45] in Argentina (0.604 g/cm^3) and also for the same species in the range of (0.515-0.710 g/cm^3) [8]. However, a higher magnitude than this finding was reported for this species with a value of 0.654 g/cm^3 at 12% moisture content [38]. The variation of this finding with other scholars conducted elsewhere may be attributed to genetics and local environmental factors that affect the growth of the trees such as soil characteristics, the density of stand, precipitation, solar radiation and age of the trees [46, 47].

In relation to commercially known and endangered tree species in Ethiopia, the density of *Acacia melanoxylon* was comparable with density at 12% moisture content of *Hagenia abyssinica* (0.56 g/cm^3) and *Pouteria adolfi-friederici* (0.60 g/cm^3); And superior than *Cupresus lustanica* (0.430 g/cm^3), *Pinus patula* (0.450g/cm^3), *Juniperus procera* (0.54 g/cm^3); and inferior than those of *Eucalyptus globulus* (0.780 g/cm^3) and *Eucalyptus camaldulensis* (0.853 g/cm^3) [3, 4]. According to Chudnoff [10], the density of *Acacia melanoxylon* was in the interval of medium density species and can be used for veneer, musical instruments, furniture, joinery, flooring, craft and decorative purposes.

Mechanical Properties: The results of the mechanical properties of *Acacia melanoxylon* along with the three stem height in green and at 12% moisture conditions are presented in Table 2 and Table 3 respectively. Table 4 and Table 5 show the statistical analysis of the mechanical properties in green and at 12% moisture content conditions respectively.

Modulus of Elasticity: Modulus of elasticity is the stress at the elastic limit. The mean values of modulus of elasticity (MOE) along with the three stem height in green and at 12%MC tests are shown in Table 2 and Table 3 respectively. The Analysis of variance revealed that the tree height had significant effects on MOE in the case of both MC conditions at $P<0.05$ (Table 4 and Table 5). However, the insignificant difference was found between the heartwood and sapwood at $P<0.05$ (Table 4 and Table 5). In the case of both MC conditions, the highest values of MOE found at the base of the stem and decreased from the base towards the tip along with the stem height of *Acacia melanoxylon* (Table 2 and Table 3). A similar pattern to this finding was reported for *Albizzia julibrissin* species [44] grown in Iran. In contrast, the insignificant decreasing value of MOE along with stem height from base upward has been reported for *Xylia xylocarpa* [48]. This result is similar to the trend of variation of wood density of the species. As reported by different scholars [7, 46], density was significantly correlated with the mechanical properties of wood. This noted that the density of the species can predict the values of the mechanical properties of the species.

The decreasing values of MOE along with the stem height was due to low density, short fibers, thinner cell walls and higher microfibril angles in juvenile wood and conversely, high in matured wood. The greater the MOE, the stiffer the timber and conversely, the lower the MOE the more flexible the timber will be Desch [49]. This implies that the bottom portion of *Acacia melanoxylon* has more stiffness than mid and top portions. The presence of knots, spiral grain and some environmental such as: moisture content and temperature also affect the mechanical properties of wood [50]. An important element of wood quality is that of stiffness or its modulus of elasticity [51]. The end-use of wood material, especially for structural timber is strongly related to the modulus of elasticity.

The results showed that the heartwood (13863.17 and 9400.50) N/mm^2 was insignificantly higher than sapwood (13479.62 and 9098.92) N/mm^2 for green and at 12% MC respectively (Fig. 5). Machado *et al.* [38] reported that the value of MOE decreased from 50% (heartwood) to 90% (sapwood) along with radial positions of *A. melanoxylon* stem. This finding is also in agreement with other hardwood of Oak species [52] and Silkwood (*Albizzia julibrissin*) [44]. In contrast to this finding, Hai *et al.* [53] reported that *Acacia auriculiformis* MOE at 12% MC (18800 and 20690 N/mm^2) for heart and sapwood respectively. The difference values of MOE of heartwood and sapwood are related to the chemical properties in heartwood and sapwood. A significant amount of extractives are deposited in the heartwood, up to two or three times more than in sapwood [46].

The overall mean values of MOE in green and at 12% MC conditions were (9249.70 and 13671.89) N/mm^2. The analysis of variance showed that MOE was a significant difference between green and at 12% MC condition (Fig. 5) of *Acacia melanoxylon* timber. This noted that below the FSP shrinkage or swelling occur thus increasing or reducing cohesion and stiffness [51].

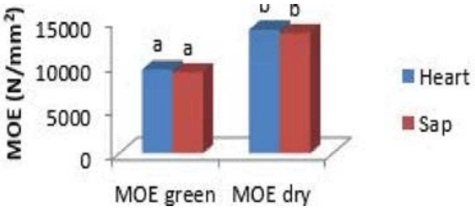

Fig. 5: The variation of MOE between the heart-sapwood and between green-dry conditions of *Acacia melanoxylon* timber

Note: Means having the same letters were not significantly different at $p<0.05$ level.

The overall mean value of this finding was greater than the mean values of MOE at 12% MC condition (13,000 N/mm^2) and less than in green condition (13,000 N/mm^2) for this species [54]. Igartùa *et al*. [55] reported less value of MOE in 12% MC condition (10900 N/mm2). On the other hand, Less value of MOE in green and air-dry condition (11781.9 and 14124.5 N/mm^2) respectively also reported for the same species [10]. However, greater than these findings have been reported for MOE, tested in green and air-dry conditions (9095 and 14400 N/mm^2) respectively [56].

In comparison with other Acacia species, the result of these findings was less than the values of MOE tested in green and air-dry conditions (14300 and 19700 N/mm^2) respectively for *Acacia schafneri* [57]. Similarly, a greater value of MOE tested in the air-dry condition for *Acacia deccurens* 14310 N/mm^2 [3]. However, MOE of *Acacia mangium* and *Acacia auriculiformis* in 12% MC conditions are less than these findings (9992 and 8214 N/mm^2) respectively [58].

In relation to commercially known in the country, the value of MOE of this finding tested at 12% MC was greater than *Cordia africana* (6996 N/mm^2), *Cupressus lusitanica* (6145 N/mm^2), *Eucalyptus globulus* (11655 N/mm^2) and *Prunus africana* (12070 N/mm^2) [3, 4].

Modulus of Rupture: The mean values of Modulus of rupture (MOR) in green and at 12% moisture condition tested are shown in Table 2 and Table 3. The analysis of variance showed that the tree height had significant effects on the modulus of rupture (MOR) at ($P< 0.05$) for both MC conditions (Table 4 and Table 5). However, the insignificant difference was found between the heartwood and sapwood for both MC conditions (Table 4 and Table 5). The results revealed that MOR was a decreasing trend from base to the tip of the tree in both MC conditions (Table 2 and 3). The variation MOR is similar to the trend of variation of wood density of the species. A similar variation to this finding was reported for Persian wood (*Albizzia julibrissin*) [44] grown in Iran. In-line with this finding has been reported for *Xylia xylocarpa* [48]. The decreasing values of MOR along with the tree height might be due to maturity at the base and juvenility at the tip of the tree. Different scholars [19, 40, 46] showed that maturity decreases from bottom to top of the tree and conversely, juvenility increases as the tree height increases. Due to the maturity of wood tissues in the bottom portion, the MOR was a high value at the base of *Acacia melanoxylon* timber. A higher value for MOR indicates a greater strength of timber [59].

The mean values of modulus of rupture (MOR) of heartwood (70.64 and 149.63) N/mm^2 was slightly higher than to the corresponding sapwood (68.34 and 146.78) N/mm^2) both in green and at 12% MC condition of *Acacia melanoxylon* timber respectively. This might be influenced by the presence of extractive materials found in the heartwood. A Decrease in MOR from 50% (heartwood) to 90% (sapwood) along the radial direction has been reported for *Acacia melanoxylon* timber [38]. Similar patterns to this finding reported for *Pseudolachnostylis maprounaefolia* [60] and for Persian Silkwood [44]. In contrast to this finding has been reported for *A. auriculiformis* MOR at 12% MC (132.10 and 150) N/mm^2 for heartwood and sapwood [53] respectively. Haygreen and Bowyer [20] noted that the presence of a higher concentration of extractives and infiltration materials in heartwood, the density and mechanical property of heartwood is often slightly higher than that of sapwood.

The overall mean values of Modulus of rupture (MOR) in green and at 12% MCs were 147.98 N/mm^2 and 69.49 N/mm^2 with a standard deviation of 12.05 N/mm^2 and 9.09 N/mm^2 respectively. Figure 6 depicted that, there was a significant difference between the green and at 12% moisture content condition tested of MOR of the tree.

The overall mean values of MOR in 12% MC condition was greater than others studies have been reported by several authors who found the values of MOR (89.9 N/mm^2) [55]; MOR (139 N/mm^2) [38] and MOR (129.9 N/mm^2) of the same species [56]. However, greater value than this finding of MOR in green condition has been reported for MOR (76.4 N/mm^2) of *Acacia melanoxylon* timber [56]. `

Comparisons with other Acacia species, the results showed that MOR value was greater than reported by Jusoh *et al.* [58], for *Acacia mangium* and *Acacia auriculiformis* tested at 12% MC (78 and 89)

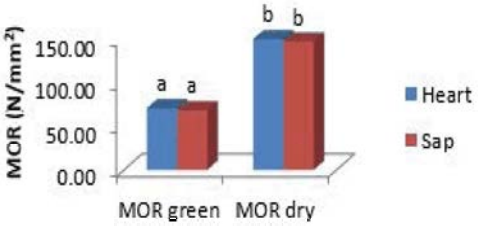

Fig. 6: The variation of MOR between heart-sapwood and between green-dry conditions of *Acacia melanoxylon* timber

Note: Means having the same letters were not significantly different at $p<0.05$ level.

N/mm^2 respectively. However, these findings were less than *Acacia schaffneri* (103.4 and 181.6 N/mm^2) has been reported by Machuca valesco *et al.* [57] in green and at 12% MC conditions respectively. In relation to commercially known and endangered tree species in the country, the result was greater than at 12% moisture content tested *Cordia africana* (64 N/mm^2), *Cupressus lusitanica* (64 N/mm^2) and *Juniperus procera* (87 N/mm^2) [4].

Static bending tests, including MOR and MOE indicated that *A. melanoxylon* timber can be a useful material for building construction due to the mechanical properties. The MOR and MOE values are used to characterize the strength of beams, joists, rafters, beams, tabletops, chair bottoms, trusses, furniture and timbers subjected to transverse bending [3].

Impact Bending: Impact bending is the resistance offered by wood specimens to sudden shocks. The mean impact bending values in green and at 12% MC condition tested specimens along the three stem heights are shown in Table 2 and Table 3 respectively. The statistical analysis revealed that the tree height had significant effects on specific impact resistance in both green and at 12% MC condition ($P<0.05$) along with the stem height (Table 4 and Table 5). However, the insignificant difference was observed along with the two radial directions i.e. between heartwood and sapwood in both MC conditions (Table 4 and Table 5). In contrast, Nicholas and Brown [7] reported that the mechanical properties of *Acacia melanoxylon* have little variation with tree height.

The results showed that the highest value of impact resistance was observed at the base and decreased from the bottom to top the tree height. A similar variation to this finding was reported for Black locust (*Robinia pseudoacacia*) [64]. This is also similar to other mechanical properties affected by the proportion of earlywood and latewood along with the stem height of the sample species. This variability may also be influenced by a combination of several other factors, including the inherent variability within trees [65], growth and environmental conditions and the presence of high extractive contents [66]. Different scholars [15, 67, 68] reports indicated that the heartwood proportion of *Acacia melanoylon* is high and markedly decreases with tree height. A large proportion of the heartwood means there is a large proportion of strong wood [67]. This noted that the *Acacia melanoxylon* mechanical properties were decreased with increasing tree height.

The results revealed that the mean values of specific impact resistance of heartwood (10071.11 and 9808.80) Nm/m^2 was to some extent higher than that of the sapwood (9690.60 and 9230.80) Nm/m^2 for green and at 12% MC conditions tested respectively. Aguilara and Zamora [42] reported that *A. melanoxylon* tree density of heartwood (0.583 to 0.987 g/cm^3) is higher than sapwood (0.494 to 0.740 g/cm^3). This noted that the heartwood is stronger than sapwood because the density and mechanical properties of *Acacia melanoxylon* are significantly correlated [7]. High amounts of extractives deposited in timber might influence the mechanical properties of wood. According to Santos *et al.* [69], the ethanol extractive content of blackwood heartwood is more than twice than that of the sapwood. As a result, the density and mechanical property of heartwood are often slightly higher than that of sapwood [20].

The overall mean values of specific impact resistance in green and at 12% MC conditions tested were 9880.81 and 9519.60 Nm/m^2 with standard deviations (1654.46 and 1660.71) Nm/m^2 respectively. The analysis of variance revealed that there was an insignificant difference between green and at 12% MC condition tested of specific impact resistance (Fig. 7). This was in agreement with this scholar [51]. This might be influenced by the moisture content of the specimens; it was difficult to suddenly break the fibers. A similar to this finding was reported for *Eucalyptus globulus, E. grandis* and *E. camaladulensis* [70].

The average value of impact bending obtained in this study was greater than at 12% MC tested of *Acacia decurrens* (7313 Nm/m^2) [3]. The result of this impact bending was greater than commercially known species in Ethiopia; For instance, *Cupressus lustanica* (5888 Nm/m^2) and *Pinus patula* (5187 Nm/m^2) and less than *E. saligna* (12873 Nm/m^2) and *Grevillea robusta* (18094 Nm/m^2) [3, 4].

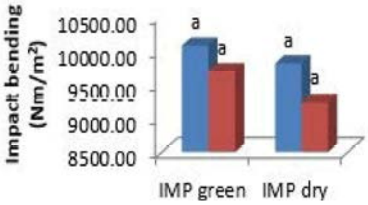

Fig. 7: The variation of impact bending between the heart-sapwood and between green-dry conditions of *Acacia melanoxylon* timber

Note: Means having the same letters were not significantly different at $p<0.05$ level.

Compression Parallel to the Grain: Compression parallel to grain (crushing strength) determines load a beam will vertically carry. The mean values of Maximum crushing strength (MCS) in green and at 12% MC condition tested along with the three stem height are shown in Table 2 and Table 3 respectively. The analysis of variance revealed that the stem height had significant effects on MCS in both green and at 12% MC condition of *A. melanoxylon* timber ($P<0.05$) (Table 4 and Table 5) respectively. However, the insignificant difference was observed along radial direction i.e. between heartwood and sapwood ($p<0.05$) (Table 4 and Table 5) for both green and at 12% MC condition respectively. In contrast, little variation along the stem height has been reported by different scholars [7, 38], for maximum crushing strength tested at 12% MC of blackwood grown in New Zealand and Portugal respectively.

In the case of both moisture conditions, the MCS was a decreasing trend from bottom to the top of the tree height as tableted in Table 2 and Table 3. This might be due to maturity at the base and juvenility at the tip of the tree height. Similar patterns were reported by Izekor *et al.* [61] who observed that a decreasing value of compression strength parallel to the grain from base to tip of *Tectona grandis* stem. A Similar variation also reported for Oriental beech and Caucasian fir species [33]. However, insignificance decrease along the stem height from base to upward has been reported for *X. xylocarpa* stem [48].

In contrast to this finding [38] has been reported in compression parallel to the grain of *A. melanoxylon* grown in Portugal, who found that an increase with tree stem height especially from 35% to 65% of tree height. Horacek *et al* [39] obtained that the increase in compression parallel to the grain was reported for softwood of Norway spruce. This indicates that most hardwood species have no common trend variations along with the stem height of the trees.

The MCS of this finding follows a similar declining trend of the density along with the stem height of the tree. Density is a significant correlation with compression strength [62]. Moreover, there is more material distributed internal stresses in a dense wood, so the mechanical properties of wood are also increasing [63]. In the present study, a declining trend from the bottom to top in density and compression strength for this wood species can be related to the above-mentioned correlation. According to Zobel and Van Buijtenen [16], the top logs contain mainly juvenile wood, which has low density and strength; bottom logs from the same tree consist predominantly of mature wood. Wood with high strength in MCS is suitable for timber used as columns, props, posts and spokes [3].

The maximum crushing strength (MCS) of heartwood (34.73 and 63.73 N/mm^2) was slightly higher than sapwood (33.26 and 62.23 N/mm^2) in green and at 12% MC condition tested specimens respectively. This variation might be due to the presence of a chemical in the heartwood and sapwood of the species. According to Machado *et al* [38], the MCS of *A. melanoxylon* timber decreased from 50% (heartwood) to the 90% (sapwood) radial direction. This difference between the heartwood and sapwood was the ethanol extractive content of blackwood heartwood is more than double that of the sapwood [42]. In addition, Haygreen and Bowyer [20] report indicated that a considerable amount of infiltrated material may somewhat increase the weight of wood and its resistance to crushing.

The whole mean values of MCS in green and at 12% MC conditions were (33.96 and 62.71) N/mm^2 with a standard deviation of (6.67 and 6.94 N/mm^2) respectively. There was a significant difference between green and at 12% MC tested samples of maximum crushing strength (Fig. 8) of *A. melanoxylon* timber.

The overall means of MCS obtained in this study were comparable with another study conducted elsewhere for the same species with the values of MCS (29.4 and 62.5 N/mm^2) for green and air-dry conditions [56] respectively. The same result also noted with the value tested at 12% MC condition was 61 N/mm^2 for the same species [38]. However, the results of these findings were greater than the values of MCS (33 and 48 N/mm^2) in green and air-dry condition respectively [54].

In comparison with other acacia species, the MCS values of *A. melanoxylon* timber tested in green and the air-dry conditions were less than (40.8 and 85.8 N/mm^2) for *Acacia schaffneri* [57] respectively; And less than air-dry condition of *A. ducurrens* (85 N/mm^2) [3]. In relation to commercially known and endangered tree species in the

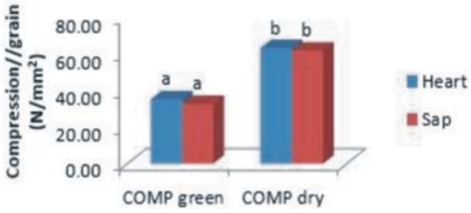

Fig. 8: The variation of maximum crushing strength between heart-sapwood and between green-dry conditions of *Acacia melanoxylon* timber

Note: Means having the same letters were not significantly different at p<0.05 level.

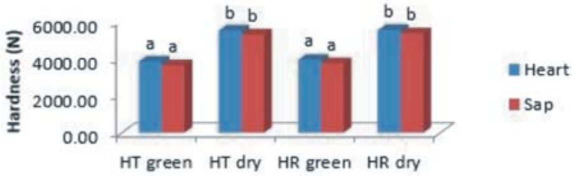

Fig. 9: The variation of hardness between heart-sapwood and between green-dry conditions of *Acacia melanoxylon* timber

Note: Means having the same letters were not significantly different at p<0.05 level. Where, HT: hardness tangential and HR: hardness radial.

country tested in air-dry condition were greater than *Juniperus procera* (38 N/mm^2), *Cordia africana* (29 N/mm^2), *E. globulus* (52 N/mm^2) and *E. grandis* (45 N/mm^2) [3, 4]. Based on the classification, compression parallel to the grain was in the interval of high maximum crushing strength and used for short columns, building pillars, trusts, chair legs, blocks, pillars, roof rafters and pit-props.

Hardness: The overall mean values of hardness tangential and radial in green and at 12% moisture content conditions tested along with the three stem height for the bottom, middle and top portions of the tree were summarized in Table 2 and Table 3 with other tested density and mechanical properties of these findings. The ANOVA table (Table 4 and Table 5) revealed that the tree height had significant effects on hardness tangential and radial for both green and at 12% MC conditions (P<0.05). However, the insignificant difference was observed along the radial direction i.e. between heartwood and sapwood in tangential and radial for both moisture conditions (Table 4 and Table 5).

The mean values of hardness tested in both directions showed a decreasing trend from base to top of the stem height (Table 2 and 3) in green and at 12% MC conditions respectively. In line with this finding was reported for *Xylia xylocarpa* stem [48]. This finding is similar to the trend of variation of wood density of the species. Wood density is known to be closely related to the mechanical properties of wood [46]. The variation with the tree height might be due to the fact that the bottom bolt of the same tree has more mature-wood than the top bolt which consists mainly of juvenile wood [46]. Juvenile wood density and mechanical properties were lower than those of mature wood. The lower density and mechanical properties of the wood near the top may be due to the thin walls of cells of the wood, the lower cellulose content and crystallinity of the wood compared with that of the matured wood in the bolt at the butt [71].

The overall mean values of hardness tangential (3720.64 N and 5373.10 N) and radial (3825.80 N and 5415.40 N) in green and at 12% MC tested specimens respectively. There was a significant difference observed between green and air-dry condition tested specimens for both hardness tested in a tangential and radial directions (Fig. 9).

The results showed that the mean values of hardness in (tangential and radial) heartwood were slightly higher than sapwood in both green and at 12% MC conditions. Similar patterns have been reported for hardwoods of White and Red Oak species tested at 12% MC condition [52]. Significant differences in wood density between the heartwood and sapwood have been found in *Acacia burkea* and *Spirostachys africanum* species [72]. The change in weight is generally due to the deposition of extractives such as phenols and quinines [73]. These also result in enhanced durability of wood [18].

The whole mean values of hardness tested in green and air-dry conditions were less than (4600 and 5900 N) respectively [54] and also reported at 12% MC condition tested was 6600 N of the same species [7]. However, the overall value of this finding was greater than the value of *A. deccurens* that has been tested at 12% MC with the value of hardness is 3600 N. The average values obtained in this study also greater than commercially known tree species in the county tested at 12% moisture content for *Cupressus lustanica* (2761 N) and *Pinus patula* (2179 N) [4].

CONCLUSION

In this study, within-stem variation of several wood properties of *Acacia melanoxylon* in green and air-dried to 12% moisture contents were investigated. The density and mechanical properties were affected by stem height in both green and air-dry conditions. However, in both moisture conditions, the heartwood and sapwood had not affected the density and mechanical properties of *A. melanoxylon* timber. In both moisture conditions, the highest values of density and mechanical properties were observed at the base and lowest at the tip of *A. melanoxylon* tree. This noted that the bottom portion has the strongest than the middle and top portions of the tree. Whereas the heartwood density and mechanical properties were slightly higher than those of corresponding sapwood; this variation might be attributed to a concentration of extractives and infiltration material in the heartwood of *A. melanoxylon* tree. The overall mean values of mechanical properties tested at 12% moisture contents were increased more than twice in green condition tested of the tree. These variations between the green and at 12% moisture content (MC) condition tested samples were concerned with moisture content in the *Acacia melanoxylon* tree.

The density and mechanical properties of the timber found in this study were comparable with commercially known and endangered tree species in Ethiopia. Therefore, *Acacia melanoxylon* species could substitute thus over-harvesting species in the country. Since *A. melanoxylon* timber density was belonged into medium timber species, for this reason, it is suitable for veneer, musical instruments, furniture, joinery, flooring, craft and decorative purposes.

In regard to the findings emanated from this study the researcher recommends further studies should be conducted on tensile and shears strength, natural durability and treatability with preservatives, finishing and working properties of this lesser-known and lesser utilized of *Acacia melanoxyon* timber species in Ethiopia.

ACKNOWLEDGMENTS

First and foremost, my extraordinary thanks go to the Almighty, the provider, the protector, the cure and the creator Allah.

Thanks to Chencha Woreda Environment, Forest and Land Administration Office for allowing to harvest *Acacia melanoxylon* logs from the area.

I would like to express my gratitude to the Ethiopian Environment and Forest Research Institute (EEFRI) for sponsoring this study and the Forest Resources Utilization Research Directorate of EEFRI for allowing the *Acacia melanoxylon* tree and the logs harvested for my study. I would also like to thank the Wood Technology Research Center for allowing me to use woodworking and sample testing machines and laboratories for sample preparations and testing for this research.

Appreciation extended to Dr. Seyoum Kelemwork, Getachew Desalegn and Dr. Anteneh Tesfaye for their valuable technical guidance and suggestions during resource assessment and sample trees selection as well as for borrowing some reading materials which guide me for this research. Further thanks to Getachew Desalegn for reviewing and editing the initial draft of this manuscript.

My sincere thanks extend to my colleagues Worku Fekadu, Kebede Yimer and Demise Worku for their assistance in harvesting, sample preparation, testing the different wood properties. I also wish to express my appreciation to all Wood Technology Research Center staff members.

Last, but not least, I wish to acknowledge, Nebira Ebrahim, Fakia Abshiru, my parents, brothers, sisters and friends for the moral and material support and their patience during my studies; may Allah bless you abundantly.

REFERENCES

1. Ministry of Environment, Forest and Climate Change, 2017. Ethiopia Forest Sector Review, Focus on commercial forestry and industrialization, Addis Ababa, Ethiopia, pp: 91.
2. Seyoum Kelemwork and Deribe Gurmu, 2000. The use of Agricultural residues for Cement Particleboards (in Amharic): In Matebu Tadesse and Mezegebu Abegaz (eds.), Postharvest Technology and Dissemination of Agricultural research Outputs. Proceeding of Ethiopian Agricultural Research Organization (in Amharic). pp: 192-196.
3. Getachew Desalegn, Melaku Abegaz, Demel Teketay and Alemu Gezahgne, 2012. Commercial Timer Species in Ethiopia: Characteristics and Uses - A Handbook for Forest Industries, Construction and Energy Sectors, Foresters and Other Stakeholders. Addis Ababa University Press, Addis Ababa, pp: 324.

4. Getachew Desalegn, Seyoum Kelemwork and Daniel Gebeyehu, 2015. Forest Products Utilization Research in Ethiopia: Highlights on Major Achievements and Contributions. Ethiopian Environment and Forest Research Institute, Addis Ababa, pp: 122.
5. Demel Teketay, Mulugeta Lemenih, Tesfaye Bekele, Yonas Yemshaw, Sisay Feleke, Wubalem Tadesse, Yitebetu Moges, Tesfaye Hunde and Demeke Nigussie, 2010. Forest Resources and Challenges of Sustainable Forest Management and Conservation in Ethiopia: In Bongers. F and T. Tennigkeit, (eds.), Degraded forests in Eastern Africa management and restoration. Earthscan, UK. PP: 19-63.
6. Bekele-Tesemma, A., 2007. Useful trees of Ethiopia: identification, propagation and management in 17 agroecological zones. Nairobi: RELMA in ICRAF Project, pp: 552.
7. Nicholas, I. and I. Brown, 2002. Blackwood: A Handbook for Growers and Users. Forest Research Bulletin No. 225, New Zealand.
8. Lemmens, R.J., 2006. *Acacia melanoxylon* R.Br. In: Louppe D, A.A. Oteng-Amoako, M. Brink, (eds), Prota 7(1): timbers/Bois d'oeuvre 1. [CD-Rom]. PROTA, Wageningen, Netherlands.
9. Orwa, C., A. Mutua, R. Kindt, R. Jamnadass and S. Anthony, 2009. Agroforestree Database: A tree reference and selection guide. Version, pp: 4.0.
10. Chudnoff, M., 1980. Tropical timbers of the world. Forest Products Laboratory, Forest service. US Department of Agriculture, USA.
11. Boland, D.J., M.I.H. Brooker, G.M. Chippendale, N. Hall, B.P.M. Hyland, R.D. Johnston, D.A. Kleinig and J..D. Turner, 1984. Forest Trees of Australia. Nelson and CSIRO, Melbourne.
12. Bradbury, G.J., B.M. Potts and C.L. Beadle, 2010b. Phenotypic variation in wood colour in *Acacia melanoxylon* R. Br. Forestry, 83: 153-162.
13. Searle, S.D., 2000. *Acacia melanoxylon*, a review of variation among planted trees. Australian Forestry, 62: 79-85.
15. Knapic, S., F. Tavares and H. Pereira, 2006. Heartwood and sapwood variation in *Acacia melanoxylon* R. Br. Trees in Portugal. Forestry, 79: 371-380.
14. Monteoliva, S., D.V. Igartúa and E.J. Matta, 2009. Color de la madera de Acacia melanoxylon implantada en Buenos Aires, Argentina. Bosque, 30(3): 192-197.
16. Zobel, B. and B. Van Buijtenen, 1989. Wood Variation: Its Causes and Control. Springer Verlag, New York, pp: 363.
17. Desch, H.E. and J.M. Dinwoodie, 1996. Timber: Structure, Properties, Conversion and Use, 7th ed, Macmillan Press Ltd., London, pp: 306
18. Searle, S.D. and J.V. Owen, 2005. Variation in basic wood density and percentage heartwood in temperate Australian Acacia species. Aust. For., 68(2): 126-136.
19. Forest Products Laboratory, 2010. Wood handbook-Wood as an engineering material. General Technical Report FPL-GTR-190. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, pp: 508.
20. Haygreen, J.G. and J.L. Bowyer, 1996. Forest Products and Wood Science. An introduction. (3rd ed), USA, pp: 484.
21. ISO 3129 (International Organization for standardization), 1975. Wood-sampling methods general requirements for physical and mechanical tests. ISO, no.3129. (1st ed), Switzerland, pp: 4.
22. Getachew Desalegn, 2006. Some basic physical and mechanical properties of the valuable Hagenia abyssinica timber and their interactions: Implication for its rational utilization. Ethiop. J. Biol. Sci., 5: 117-135.
23. Moya, R., E. Urueña, C. Salas, F. Muñoz and O. Espinoza, 2013. Kiln drying behavior of lumber from ten fast-growth plantation species in Costa Rica. In: Wood Material Science & Engineering, 8(1): 37-45.
24. Yewubdar Melese and Aseffa Abagaz, 2017. Determination of Soil nutrient balance on barley farm land in Chencha District, Southern Ethiopia. M.Sc. Thesis, Addis Ababa University, pp: 66.
25. Burley, J. and P.J. Wood, 1977. A Manual on the Species and Provenance Research with Particular Reference to the Tropics. (eds.), Tropical forestry paper No. 10A. Department of Common wealth Forestry Institute. University of Oxford, UK.
26. ISO. 3131 (International Organization for standardization), 1975. Wood-Determination of density for physical and mechanical tests. ISO, no.3131. Switzerland, pp: 2.
27. ISO 3133 (International Organization for standardization), 1975. Wood determination of ultimate strength in static bending. ISO, no. 3133. Switzerland, pp: 2.
28. ISO 3348 (International Organization for standardization), 1975. Wood-determination of impact bending strength. ISO, no.3348, Switzerland, pp: 2.

29. ISO 3387 (International Organization for standardization), 1976. Wood-determination of ultimate stress in static compression parallel to the grain. ISO, no. 3787, Switzerland, 2p.
30. ISO 3348 (International Organization for standardization) 1975. Wood-determination of impact bending strength. ISO, no.3348, Switzerland, pp: 2.
31. IBM Corp. Released, 2011. IBM SPSS Statistics for Windows, version 20.0. Armonk, NY: IBM Corp.
32. Igartúa, D.V. and S.Monteoliva, 2009. Densidad básica de la madera de *Acacia melanoxylon* R. Br. en relación con la altura de muestreo, el árbol y el sitio. Invest Agrar: Sist Recur For, 18: 101-110.
33. Topaloglu, E. and E. Erisir, 2018. Longitudinal Variation in selected Wood Properties of Oriental beech and Caucasian fir. Maderas. Ciencia y Tecnología, 20(3): 403-416.
34. Kord, B., A. Kialashaki and B. Kord, 2010. The within-tree variation in wood density and shrinkage and their relationship in Populus euramericana. Turk J. Agric For, 34: 121-126.
35. Kiaei, M. and A.B. Sadegh, 2011. The influence of stem height on wood density and shrinkage of Athel wood. American-Eurasian j. Agric. & Environ. Sci., 11: 45-48.
36. Moya, R. and F. Muñoz, 2010. Physical and Mechanical Properties of eight Fast growing plantation Species in Costa Rica. Journal of Tropical Forest Science, 22(3): 317-328.
37. Chowdhury, M.Q., A.Z.M.M. Rashid, M.S. Newaz and M. Alam, 2007. Effects of height on physical properties of wood of jhau (Casuarina equisetifolia). Australian Forestry, 70: 33-36.
38. Machado, J.S., J.L. Louzada, J.A. Santos, L. Nunes, O. Anjos, J. Rodrigues, M.S. Rogério, R. Simões and H. Pereira, 2014. Variation of wood density and mechanical properties of blackwood (*Acacia melanoxylon* R. Br.) Mater Des, 56: 975-980.
39. Horáček, P., M. Fajstavr and M. Stojanović, 2017. The variability of wood density and compression strength of Norway spruce (Picea abies /L./ Karst.) within the stem. Beskydy. 10 (1, 2): 17-26.
40. Getahun, Z., P. Poddar and O. Sahu, 2014. The Influence of physical and mechanical properties on quality of wood produced from Pinus patula tree grown at Arsi Forest. Adv. Res. J. Plant Ani. Sci., 2(4): 32-41.
41. Ishengoma, R.C., P.R. Gillah and M.O. Andalwisye, 1998. Some physical and strength properties of lesser-known Milletia oblate sub.spp. Stozii from Tanzania. Faculty of Forestry Record. Sokoine University of Agriculture, 67: 54-60.
42. Aguilera, A. and R. Zamora, 2009. Surface roughness in sapwood and heartwood of Blackwood (Acacia melanoxylon R. Br.) machined in 90-0 direction. Eur J. Wood Wood Prod., 67(3): 297-301.
43. Mmolotsi, R.M., O. Chisupo, W. Mojeremane, M. Rampart, I. Kopong and D. Monekwe, 2013. Dimensional Relations and Physical Properties of Wood of Acacia saligna, an Invasive Tree species growing in Botswana. Vol. 1(6). Res. J. Agriculture and Forestry Sci. Department of Crop Science and Production, Botswana College of Agriculture, Private Bag 0027, Gaborone, Botswana.
44. Kiaei, M. Desch M. Farsi, 2016. Vertical variation of density, flexural strength and stiffness of Persian silk wood. Madera y Bosques, 22: 169-175.
45. Igartúa D.V. Desch S. Monteoliva, 2009. Densidad básica de la madera de *Acacia melanoxylon* R. Br. en relación con la altura de muestreo, el árbol y el sitio. Invest Agrar: Sist Recur For., 18(1): 101-110.
46. Panshin, A. and C. De Zeeuw, 1980. Textbook of Wood Technology. (4th ed.), McGraw-Hill, New York, USA, pp: 722.
47. Gebeyehu, D.W., 2019. Review on the Effects of Silivicultural Practices on Some Selected Wood Properties of Softwoods and Hardwoods Species. Ethiopian Environment and Forest Research Institute, Wood Technology Research Center, Addis Ababa, Ethiopia, Academic Journal of Plant Sciences, 12(2): 37-42.
48. Josue, J., 2004. Some wood properties of Xylia xylocarpa planted in Sabah. Sepilok Bulletin 1: 1-15.
49. Desch, H.F., 1986. Timber, its structure, characteristics and utilization. (6thed), HMSO, London.
50. Huang, C.L., H. Lindstrom, R. Nakada and J. Ralston, 2003. Cell wall structure and wood properties determined by acoustics-a selective review. Holzals Roh-und Werkstoff, 61: 321-335.
51. Kollmann, F. and W. Côté, 1968. Principles of Wood Science and Technology. Solid wood. Springer-Verlag Publishers, Berlin, pp: 592.

52. Merela, M. and K. Čufar, 2013. Density and Mechanical properties of sapwood versus heartwood, in three different oak species. Drvna industrija, 64(4): 323-334, Ljubljana, Slovenia.
53. Hai, P.H., B. Hannrup, C. Harwood, G. Jansson and D.V. Ban, 2010. Wood stiffness and strength as selection traits for sawn timber in Acacia auriculiformis A. Cunn. ex Benth. Canadian Journal of Forest Research, DOI: 10.1139/X09-19.
54. Bootle, K.R., 1983. Wood in Australia: Types, Properties and Uses. McGraw-Hill Book Company, Sydney.
55. Igartua, D.V., K. Moreno, J.C.Piter and S. Monteoliva, 2015. Density and mechanical properties of Argentinean *Acacia melanoxylon* (in Spanish). Maderas Cienc Tecnol, 17(4): 809-820.
56. Haslett, A.N., 1986. Properties and utilisation of exotic speciality timbers grown in New Zealand. Part II, Australian blackwood *Acacia melanoxylon* R.Br. New Zealand Forest Service, Forest Research Institute, FRI Bulletin No. 119(2).
57. Machuca-Velasco, R., A. Borja de la Rosa, A. Corona-Ambriz, I. Zaragoza-Hernández, J.G. Arreola-Avila and J. Jiménez-Machorro, 2017. Xilotecnia of the wood of Acacia Schaffneri from the State of Hidalgo, Mexico. Maderas. Ciencia y Tecnología, 19(3): 293-308.
58. Jusoh, I., F.Z. Abu and N.A. Syazni, 2014. Wood Quality of Acacia Hybrid and Second-Generation Acacia mangium. BioResources, 9: 150-160.
59. Dinwoodie, J.M., 1981. Timber Its Nature and Behavior. Van Nostrand Reinhold Company Ltd., Molly Millars Lace, England, pp: 190.
60. Uetimane, J.r.E. and A.C. Ali, 2010. Relationship between mechanical properties of ntholo (Pseudolachnostylis maprounaefolia Pax) and selected anatomical features. Journal of Tropical Forest Science, 2(4).
61. Izekor, D.N., J.A. Fuwape and A.O. Oluyege, 2010. Effects of density on variations in the mechanical properties of plantation grown *Tectona grandis* wood. Arch. Appl. Res., 2(6): 113-120.
62. Gindl, W. and A. Teischinger, 2002. Axial compression strength of Norway spruce related to structural variability and lignin content. Composites Part A: Applied Science and Manufacturing, 33(12): 1623-1628.
63. Baar, J., J. Tippner and P. Rademacher, 2015. Prediction of mechanical properties - modulus of rupture and modulus of elasticity of five tropical species by nondestructive methods. Maderas-Cienc Tecnol, 17(2): 239-252.
64. Adamopoulos, A., C. Passialis and E. Voulgaridis, 2007. Strength Properties of Juvenile and mature wood in Black locust (*Robinia pseudoacacia* L.). Wood and Fiber Science, 39(2): 241-249.
65. Harzmaln and H. Koch, 1982. Structural development of Tropical hardwoods. Holztechnologie, 23: 8-13.
66. Tsoumis, G., 1991. Science and Technology of Wood; Structure, Properties and Utilization. Van Nostrand Reinhold, New York.
67. Santos, A., R. Simões and M. Tavares, 2013. Variation of some wood macroscopic properties along the stem of *Acacia melanoxylon* R. Br. Adult trees in Portugal. Forest Syst., 22(3): 463-470.
68. Igartúa, D.V., K. Moreno and S.E. Monteoliva, 2017. *Acacia melanoxylon* in Argentina: heartwood content and its relationship with site, growth and age of the trees, Forest Systems, (26): 1 e007.
69. Santos, A., A. Alves, R. Simões, H. Pereira, J. Rodrigues and M. Schwanninger, 2012. Estimation of wood basic density of *Acacia melanoxylon* (R.Br.) by near infrared spectroscopy. J Near Infrared Spec, 20(2): 267-274.
70. Getachew Desalegn and Alemu Ggezaghne, 2010. Timber properties of Eucalyptus species. Research Report No. 81. Ethiopian Institute of Agricultural Research, Addis Ababa, Ethiopia.
71. Zobel, B.J. and J. Sprague, 1998. Juvenile wood in trees. Springer- Verlag, New York.
72. Mmolotsi, R and K. Kejekgabo, 2013. Physical Properties of Wood in Selected Lessor Known Tree Species in Botswana. Agriculture, Forestry and Fisheries, 2(2): 105-109.
73. Kokutse, A.D., H. Bailleres, A. Stokes and K. Kokou, 2004. Proportion and quality of heartwood of Togolese teak (*Tectona grandis* LF). For. Ecol. Man, 189: 37-48.