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Variation of Physical Properties of *Eucalyptus globulus* Grown in Ethiopia

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ABSTRACT

This study investigated the variability of density, shrinkage, and sap-heartwood proportion in different sites and within a tree. 10 trees of E. globulus from Menagesha Suba (M/Suba) and Debre Birhan (D/Birhan) forests were felled and 12 disks from each tree were collected along the stem. From each disk blocks of 2*2*3cm were taken at three locations from pith to bark. Then the block's green and oven dry weights as well as the three dimensions were measured. The result showed that the density and radial shrinkage of trees from M/Suba were significantly higher than D/Birhan forest. However, tangential, longitudinal shrinkage and sapwood proportion of trees from D/Birhan were significantly higher than M/Suba forest. Along the height, at both sites, density was increasing from bottom to top. In both sites, all shrinkages had shown a decreasing trend from breast height to 40%. Sap-heartwood proportions were irregular in trend along the height in both sites. Density shows an irregular pattern radially at both sites. At M/Suba, radial and tangential shrinkages increased from pith to bark. However longitudinal shrinkage exhibited a decreasing trend from pith to bark. At the D/Birhan forest, all shrinkages showed irregular patterns from pith to bark. Density was highly variable along the height in both study sites. Radially, density was more variable in the D/Birhan site. This study recommended that for end-uses requiring durable, denser, and stable wood, E. globulus from the M/Suba forest was better. For pulp wood, E. globulus from D/Birhan was recommended.

Introduction

Wood is a biological material that is highly variable within a tree and site (Zobel & Van Buijtenen, 1989). Being highly variable gives the wood be potential for genetic improvement as well as to be utilized for various end uses (Koga & Zhang, 2004). Hence, understanding wood variability within a tree along the height and across the stem from pith to bark is important for tree improvement, efficient wood processing, and efficient utilization of the material. Moreover, Huang et al., 2019 reported that to understand the structure and function of terrestrial ecosystems and improve our ability to assess and predict the response of forests to global climate change, it is important to conduct research on wood physical properties and identify influential factors of these properties.

Basic density is one of the physical properties of wood which is defined as the amount of dry matter available in a solid cubic meter of timber at 0 % moisture content (Kofman, 2010). For solid wood and fiber products of both softwood and hardwood species, density is the predominant indicator of quality (Kiaei & Sadegh, 2011). The basic density of wood is greatly influenced by tree species, site, and silvicultural practices employed in the forest (Listyanto et al., 2020). Furthermore, density is influenced by cell diameter, cell wall thickness, early wood-latewood ratio, and chemistry of wood. Generally, wood density is a better predictor of wood strength, stiffness, seasoning, machining, hardness as well as paper production potential of a species as noted by Kiaei and Sadegh (2011).

Wood density and shrinkage are often used as general indicators of the suitability of wood for manufactured products (Listyanto et al., 2020). Shrinkage determines wood stability that will be the outcome during and after drying (Listyanto et al., 2020). When the moisture content of the wood is above the fiber saturation point, then the wood will be dimensionally stable but when below that it will be prone to dimensional movement. Shrinkage is one of the dimensional movements when the wood loses its moisture. The outcome of this movement is warping, checking, and splitting of the woods which ultimately affect the utility of wood products. Wood is anisotropic material that shrinks more in the direction of the growth rings (tangentially). Radial shrinkage is about one-half of tangential shrinkage when the wood is dried from green to oven-dry condition. This makes the wood to be distorted when they are dried as well as when they are utilized for a given end use (Anonymous, 2010). According to Chavenetidou et al., 2020, the utilization of wood for various purposes is greatly influenced by the shrinkage and swelling of wood. The effects could be an alteration of wooden objects' shape, warping, opening or tightening of joints, change of cross-sectional shape, checking, or even collapse of wood.

Wood from most trees can be divided into sapwood and heartwood based on their color division (Cherelli et al., 2018). Heartwood is darker and more impregnated by tyloses than sapwood as a result of organoleptic and chemical differences between them (Gierlinger et al., 2004; Lourenço et al., 2010). Heartwood is formed by the secondary xylem differentiation process and the function of heartwood is regulated by tissue senescence (Fromm, 2013). For the pulp and paper industries, logs with wider sapwood are preferred. Trees with a high proportion of heartwood affect production costs and the quality of composite boards. There is a need for research on selected properties of eucalyptus spp and their silvicultural management to produce quality pulp and composite products.

Eucalyptus globulus could potentially be used for light and heavy construction works, boxes, piers and docks, ships, railway cars, decking, floors, and fire-resistant structures and over all could be used for all end-uses demanding hardwood species. Other than these, it could be used for furniture and cabinetwork, building, fencing, electric and telegraph poles and posts, piles, tool handles, veneer, cheap board, plyboard, particle board, short fiber pulp for paper making, fuel wood, and charcoal (Desalegn & Teketay, 2012; Tesemma et al., 1993).

Eucalyptus globulus has been studied in Ethiopia for its lumber characteristics by Desalegn and Teketay, 2012 and for pulp and paper by Gebeyehu et al., 2022. The species used as plywood is under investigation by the Forest Products Innovation Center. However, so far, no any study in the country concerning the variability of density, shrinkages, and sapwood-heartwood proportion of the species between sites and within a tree has been conducted. The major problem of *Eucalyptus globulus* is seasoning defects (like cup, bow, twist, crook, surface check, end check, and split). And these defects are associated with shrinking properties and studying the variability by site and within a tree is crucial.

The quality of any product that could be extracted from the wood of *Eucalyptus globulus* (Quality in visual appearance, physical property, strength, and durability) are highly influenced by site and within tree variability. Hence, studying the variability of basic density, shrinkages (Radial, Tangential, and Longitudinal), and sapwood and heartwood proportion in different sites and within the tree will be crucial for (1) Selecting an appropriate site and plus trees for the tree breeding program (based on intended end use), (2) Determining appropriate end-use that could be best in quality, (3) To supplement scientific knowledge on the species properties as well as generally for hardwood species. The aim of the study was to investigate the variability of basic density, shrinkages (Radial, Tangential, and Longitudinal), and sapwood and heartwood proportion at two different sites as well as variability within a tree along tree height and in radial direction from pith to bark.

METHODS

Eucalyptus globulus sample trees at eight years old were selected and harvested from M/Suba and D/Birhan. To investigate the variability of basic density, shrinkages, and sapwood-heartwood proportion between sites and within a tree a total of 7 and 10 trees were sampled from M/Suba and D/Birhan forests, respectively.

To determine basic density wood blocks of 2*2*3cm dimensions were extracted from a total of 12 disks/tree and cut from the heights of 30 cm, 70 cm, 130 cm (DBh), and from total heights at 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, and 90%. Shrinkages were determined from wood blocks (2*2*3cm) cut out of disks collected from DBh and 40% of the total height. Before re-cutting each disk, sapwood-heartwood dimensions were measured along two diameters crossing 90° on each disk at 30 cm, DBh, 20%, 40%, 60%, and 80% of total height (Jozsa, 1998).

Wood blocks of 2*2*3cm (For density and shrinkages) were cut from pith to bark and sample blocks were oven-dried at a temperature of 103±2 ^{0}C to get oven-dry weight and dimensions. Each sample block green and oven dry weights were measured using a digital sensitive balance with the precision of 0.01 as well as the three dimensions by a digital caliper. Weight and dimension measurement was continued until a constant weight loss from 0 to 0.02 was achieved. To determine basic density the techniques set by ISO 13061-2:2014/AMD 1:2017, 2017 were considered. Shrinkages were determined by ISO 13061-13:2016, 2016.

Data were decoded and summarized in Excel and statistical analysis was conducted by SPSS version 24. Descriptive statistics, ANOVA, and mean comparisons were conducted at a 95% confidence interval. Mean comparisons were undergone by standard tests for homogenous and non-homogenous variations.

RESULTS AND DISCUSSION

Basic Density

The mean basic density of *Eucalyptus globulus* trees collected from M/Suba and D/Birhan forests were 560.78 (81.82) and 541.00 (66.47) Kg/m3, respectively (In parenthesis is SD). The result showed that the mean basic density of E. globulus from the M/Suba forest was significantly higher than E. globulus from the D/Birhan forest ($P < 0.000$). For both sites, *E. globulus* is categorized as medium-density wood. Supporting our result, significant differences in basic density among various sites were reported for *Eucalyptus globulus* and *Eucalyptus nitens* (Raymond & Muneri, 2001); for six Eucalyptus species (Listyanto et al., 2020) and for Quercus petraea, Quercus cerris and Fagus sylvatica (Koman & Feher, 2015). Another study on different Eucalyptus species also observed that there was a strong correlation (>75%) of basic density with soil texture and moderately with temperature (Ribeiro et al., 2020). Contrarily, Miranda et al., 2001 found no significant difference in basic density among sites of *Eucalyptus globulus* stands.

Along the height, the highest basic density (620.36 and 569.87 Kg/m3) was observed at 70% of the total height both for the M/Suba and D/Birhan sites, respectively. The lowest density (510.72 and 517.88 Kg/m3) at both sites, respectively, was observed also at breast height (DBh). As shown in Figure 1, at both sites, the mean basic density increased from the bottom to the top of the tree.

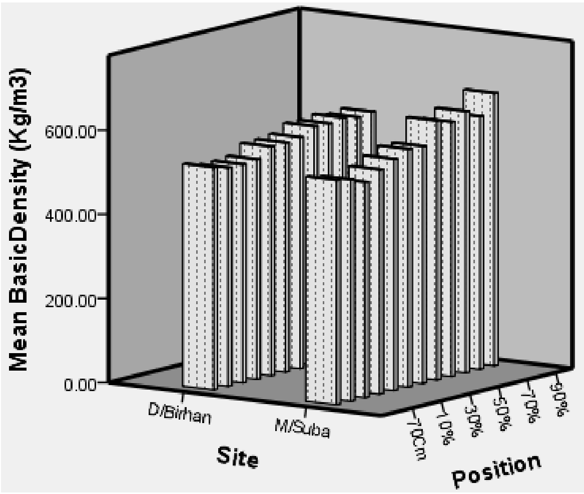

Figure 1. Trends of Basic Density along the Height of *Eucalyptus globulus* from D/Birhan and M/Suba Forests.

The mean comparison shown in Table 1 indicated that along the height for a considerable number of combinations between two positions significant difference in density was observed both for M/Suba and D/Birhan forests.

Table 1. Mean Basic Density along the Height for M/Suba and D/Birhan Forests and Significance Level.

Heigh	M/Suba	D/Birha
30Cm	533.07^{a}	527.81^{ac}
70Cm	525.52^{ad}	518.34^{a}
DBh	510.72^{d}	517.88^{a}
10%	532.61^{ad}	521.19^{a}
20%	549.02^{ac}	543.24^{b}
30%	564.20^{c}	544.25^{b}
40%	562.71^{c}	548.38^{bc}
50%	614.98^{b}	566.03^{d}
60%	603.56^{b}	564.34^{bd}
70%	620.36^{b}	569.87^{bd}
80%	599.92^{b}	562.61^{bd}
90%	593.94^{bc}	567.05^{bd}

Where values with similar subscript letters along the row are not significantly different at a 95% confidence interval. Similar to our study result, increasing trends and significant differences in basic density along the height was reported for *Eucalyptus grandis* by Githiomi and Kariuki, 2010; for *Eucalyptus globulus* by Tejedor, 2004, Quilhó and Pereira, 2001) and McKinley et al., 2002 as well as for *Eucalyptus globulus* and *Eucalyptus nitens* by Raymond and Muneri, 2001. Studies on other hardwood species (on *Alnus incana* and *Alnus glutinosa*) by Liepinš et al., 2023 also reported an increase in density along the height. And this is a general pattern for Eucalyptus species as noted by Zobel and Van Buijtenen, 1989. The reason behind the increase in density from the bottom to the top of the tree on *E. globulus* might be due to an increase in wall thickness in this gradient (Quilhó and Pereira, 2001). Contrary to our study, McKinley et al., 2002 (for *E. maidenii*) and Kiaei and Sadegh, 2011 (for *Tamarix aphylla*) reported decreasing trend whereas, McKinley et al., 2002 and Kube and Raymond, 2002 (for *E. nitens*) found irregular pattern in density along the height.

Radially, the highest basic density was obtained for the wood section taken close to the bark in the M/Suba stand but in the D/Birhan stand highest density was at the pith. The lowest density was recorded at the middle wood section in both study sites. Basic density was within 500s at M/Suba but at D/Birhan it was within the range of 400-500 Kg/m3 (Table 2). Basic density first decreased from the pith to the middle part of the stem diameter and then increased to the bark for both study sites (Figure 2).

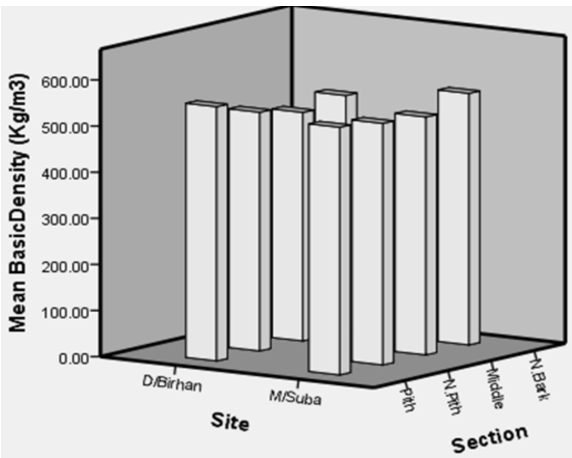

Figure 2. Basic Density across the Stem of *Eucalyptus globulus* from D/Birhan and M/Suba Forests.

A pairwise comparison of basic density among different wood sections taken at various points across the stem of both sites was presented in Table 2. Radially, at the M/Suba site, significant differences in basic density were observed for the sections between the middle and N. bark, middle and pith, and near pith and near bark wood sections. As to the D/Birhan forest, significant differences were observed between pith and N. pith, pith and middle, pith and N. bark, N. pith and middle, and middle and N. bark wood sections (Table 2).

Table 2. Mean basic Density across the Stem and mean Comparison for M/Suba and D/Birhan Forests.

Forest	Radial Locations			
	Pith	N. Pith	Middle	N. Bark
M/Suba	537.00^{ac}	527.02^{bc}	516.15^{b}	545.51^{a}
D/Birhan	551.25^{c}	517.54^{a}	495.55^{b}	510.60^{a}

Where N. Pith= Near Pith and N. Bark= Near Bark. Values with similar subscript letters along the row are not significantly different at a 95% confidence interval. Studies by Tejedor, 2004 on *Eucalyptus globulus* and Mckinley et al., 2002 on *Eucalyptus globulus* and *E. maidenii* observed that basic density was increasing from pith to bark. In the same study by Mckinley et al., 2002 but on *E. nitens* and by Bala and Seth, 1992 on *Cedrus deodara* observed that basic density was constant radially. In a study of *Parkia velutina* density was observed to strongly vary from inner to outer wood across the stem (Morel et al., 2018). Similarly, for *Alnus glutinosa* a more distinct variability of density across the stem was indicated by Liepiņš et al., 2023.

Shrinkages

The overall means for radial, tangential and longitudinal shrinkages of *E. globulus* collected from M/Suba forest were 5.98 (2.28), 6.23 (2.21) and 0.44% (0.48), respectively (In parenthesis is St.Dv). Whereas, *E. globulus* collected from D/Birhan site shown the mean radial shrinkage of 4.06% (1.41), tangential shrinkage of 8.44% (2.78) and longitudinal shrinkage of 1.42% (0.80). As homogeneity of variance was violated between mean shrinkages of the two sites, a non-homogenous test was conducted using the Games-Howel test at a 95% confidence interval. ANOVA shown that radial shrinkage of *E. globulus* collected from the M/Suba site was significantly higher than the radial shrinkage of *E. globulus* collected from the D/Birhan site ($P < 0.000$). However, tangential and longitudinal shrinkages of *E. globulus* from the D/Birhan site were significantly higher than that of *E. globulus* from the M/Suba forest ($P < 0.000$). In a study on six Eucalyptus species and their hybrids it was observed that radial and tangential shrinkages were different among three sites; showing a direct relation with an increase in site quality (Listyanto et al., 2020). Other studies on *E. globulus* showed that radial and tangential shrinkages (Yang et al., 2002) and tangential shrinkage (Washusen and Ilic, 2001) were significantly influenced by site. More or less similar figures for all shrinkages of the M/Suba forest were reported by Sejdiu et al., 2013 for *Fagus sylvatica* grown in four regions. Contrary to our result, no significant differences in all shrinkages among the three sites of *Fagus sylvatica* were found by Skarvelis and Mantanis, 2013.

All shrinkages at M/Suba and D/Birhan forests showed a decreasing trend when moving from breast height to 40% of the total height (figure 3). As shown in Figure 3 below, none of the pairs between the two heights were significant in both sites (M/Suba and D/Birhan) except for tangential shrinkage of *Eucalyptus globulus* at D/Birhan forest. As tangential shrinkages both at M/Suba and D/Birhan forests have not met homogeneity of variance, a non-homogenous test using the Games-Howel test was conducted.

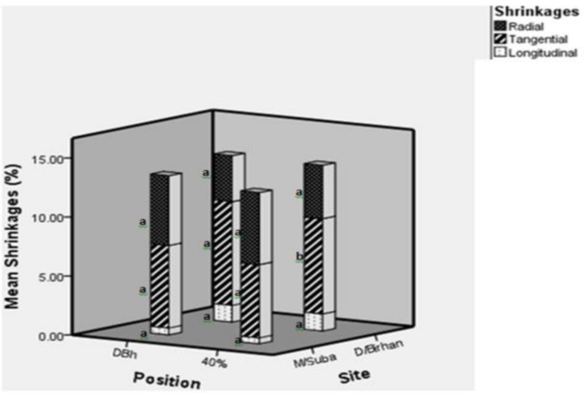

Figure 3. All Shrinkages along the Height of *Eucalyptus globulus* from M/Suba and D/Birhan Forests. Bars of a given shrinkage at two positions within a site having similar letters are not significantly different ($P>0.05$).

Radial shrinkages at breast height and 40% of the total height at the M/Suba forest were higher in magnitude compared to radial shrinkages at the two positions for the D/Birhan site. Whereas, tangential shrinkage and longitudinal shrinkage recorded at the two heights in the D/Birhan forest were higher than values registered at the two heights in the M/Suba forest (Figure 3). Supporting our result, Kiaei and Sadegh, 2011 observed a decrease in all shrinkages along the bole of *Tamarix aphylla* but contrary to our study, a significant difference was reported for all shrinkages in this gradient. Some studies have shown various trends for radial, tangential, and longitudinal shrinkages; McComb et al., 2004 for instance reported that for Eucalyptus hybrid (*E. globulus* and *E. camaldulensis*) radial and longitudinal shrinkages decreased along the height but tangential shrinkage increased in this gradient. Against our study, for *Eucalyptus globulus* significant linear increase in radial shrinkage axially was reported by Gonya, 2020. In another study on *Ziziphus mauritiana* it was observed that decrease in radial shrinkage, irregular trend for tangential shrinkage, and increasing pattern for longitudinal shrinkage (Riki et al., 2019). In a research by Van Duong and Matsumura, 2018 no significant difference in tangential shrinkage was indicated axially for *Melia azedarach*

At the M/Suba stand, radial and tangential shrinkages increased from pith to bark. On the other hand, longitudinal shrinkage had shown a slight decrease from the pith to the bark. At the D/Birhan forest, radial shrinkage increased from pith to near pith, then decreased to the middle, and finally increased and reached its highest value at the bark. Tangential shrinkage first increased from the pith to the middle wood section but then decreased to the bark. The highest tangential shrinkage was observed in the middle wood section. Longitudinal shrinkage increased from the pith to the near pith, then from the near pith to the middle it dramatically decreased and finally increased to the bark showing the highest value at the near pith wood section (Figure 4).

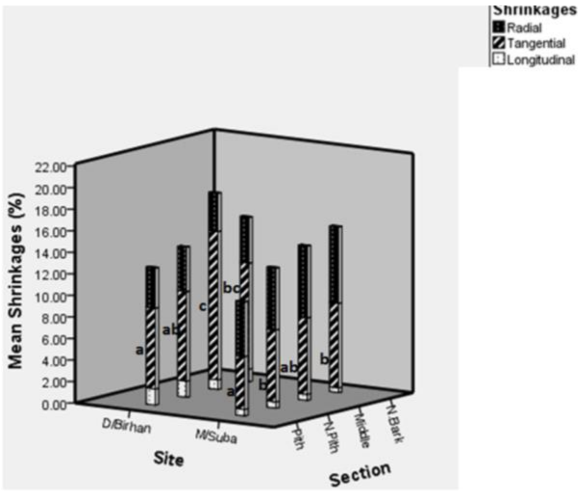

Figure 4. All Shrinkages across the Stem of *Eucalyptus globulus* from D/Birhan and M/Suba Forests. Similar letters of tangential shrinkages within a site but at various locations radially indicate they are not significant (P>0.05).

In this study, significant differences were observed only for tangential shrinkages of *Eucalyptus globulus* from both D/Birhan and M/Suba forests. Hence, in Figure 4, only significant differences in tangential shrinkages of both forests were displayed by letters. The rest of the pairs were not significantly different. As tangential shrinkages both at M/Suba and D/Birhan forests have not met homogeneity of variance, a non-homogenous test using the Games-Howel test was conducted. At M/Suba forest significant differences in tangential shrinkages were observed; pith among with near pith and near bark wood sections. Whereas, at the D/Birhan forest, tangential shrinkages of pith and near bark and middle among with pith and near pith were significantly different (Figure 4). Gonya 2020 studied *Eucalyptus globulus* and observed that radial shrinkage significantly (P<0.0001) increased linearly from pith to outer wood. Another study by McKinley et al., 2002 observed that for conditioned and unconditioned wood samples of *Eucalyptus nitens, E. globulus* and *E. maidenii* radial and tangential shrinkages and *E . globulus* longitudinal shrinkage increased from pith to bark. But longitudinal shrinkage of *E. nitens* (both for conditioned and unconditioned wood samples) decreased from pith to bark and of *E. maidenii* conditioned wood showed increasing and the unconditioned wood showed decreasing trend in this gradient. A study conducted to examine radial and tangential shrinkages from pith to bark of different cultivars of *Cryptomeria japonica* found that radial and tangential shrinkages decreased from pith to bark at the stem base, but increased from pith to bark in the upper stem for some of the cultivars. For the other cultivars tangential shrinkage was constant at a height of 0.4 m, but increased and then decreased from pith to bark above 2.6 m height. Contrary to tangential shrinkages, in the other four cultivars, radial shrinkage was observed to increase from pith to bark (Yamashita et al., 2009). Another study on *Melia azedarach* by Van Duong and Matsumura, 2018 found that the pattern of tangential and radial shrinkages was a gradual increase from pith to bark in the two sites.

Sapwood (SW) and Heartwood (HW) proportions

SW proportion of 53 and 68% and HW proportion of 47 and 32% were recorded for M/Suba and D/Birhan sites, respectively. SW proportion of *E. globulus* collected from the D/Birhan forest was significantly higher than *E. globulus* collected from the M/Suba forest (P< 0.000). However, the heartwood proportion of *E. globulus* of the M/Suba site was significantly higher than that of *E. globulus* from the D/Birhan site (P < 0.000). According to Morais and Pereira, 2007 study on *E. globulus* from four sites reported that there was significantly higher difference in heartwood proportion among sites. Research conducted on *Eucalyptus globulus* planted with different spacing proved that a statistically significant difference was found between narrower and wider spacing in heartwood areas (Miranda et al., 2009). Another study by Almeida et al., 2020 on Eucalyptus species and their hybrids found that sites from higher and more humid latitudes had recorded the highest heartwood percentage which was between 61 and 67%. A study by Rodríguez-Pérez et al., 2022 on *Dipteryx panamensis* showed that heartwood diameter had ranged from 3.5 to 7.2 cm of different families and it was significantly different across provenances. Another study conducted in different stands of the species named *Robinia pseudoacacia* revealed that habitat fertility does not affect the formation of heartwood (Klisz and Wojda, 2015). Different forest types were studied for the dynamics of heartwood formation and it was found that fresh mixed forest types had the highest dynamics of heartwood formation (Nawrot et al., 2008).

Along the height the highest sapwood (SW) proportion was observed at 40% of total height and the lowest at DBh in the M/Suba forest. Whereas, at D/Birhan forest highest SW proportion was observed both at 20% and 80% of total height, and the lowest was at stump height (30Cm). On the other hand, the highest heartwood (HW) proportion was registered at DBh and the lowest at 40% of the total height for the M/Suba site. For the D/Birhan forest highest HW proportions were obtained at 30Cm and the lowest HW at 20% and 80% of total height (Table 3). The mean comparison shown in Table 3 indicated that both SW and HW from both sites were highly significant variables all along the stem.

Table 3. Sapwood-Heartwood Proportions (%) along the Height for M/Suba and D/Birhan Forests and their Significance Level.

Position	Site / Wood Type	M/Suba SW Prop.	M/Suba HW Prop.	D/Birhan SW Prop.	D/Birhan HW Prop.
30 Cm		44[c]	56[af]	60[c]	40[a]
DBh		42[c]	58[f]	63[b]	37[c]
20%		51[a]	49[b]	72[ad]	28[bd]
40%		65[b]	35[c]	69[d]	31[b]
60%		60[d]	40[d]	71[ad]	29[bd]
80%		57[e]	43[e]	72[a]	28[d]

SW-Prop.= SapWood Proportion and HW-Prop.= Heartwood Proportion in %. Values with similar subscript letters along the column are not significantly different at a 95% confidence interval. At M/Suba forest, the SW proportion showed an increasing trend from stump height to 40% of the height and then it decreased when moving to the top of the tree. In this site, HW proportion decreased to 40% of the height and then it increased to the top of the tree. Whereas, in the D/Birhan forest, the SW proportion was shown to have an increasing trend from the bottom to the top of the tree. However, HW proportion decreased along the height in this site. At the D/Birhan site, the SW proportion was higher compared to the M/Suba site. But At M/Suba, the HW proportion was higher compared to the D/Birhan forest (Figure 5).

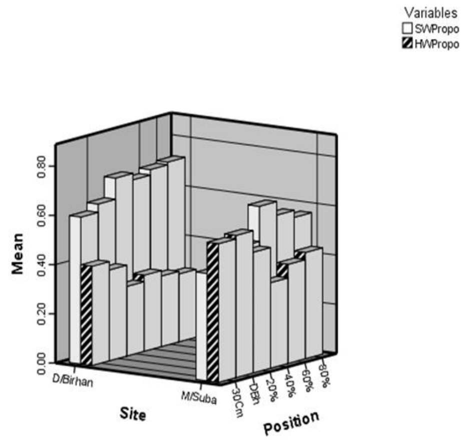

Figure 5. Sapwood-Heartwood Proportions (%) along the Height of *Eucalyptus globulus* from D/Birhan and M/Suba Forests.

In studies by Gonya, 2020; Miranda et al., 2015 and 2007 heartwood diameter of *Eucalyptus globulus* showed a decreasing trend from the bottom to the top of the tree. A study by Morais and Pereira, 2007 on *E. globulus* from four sites investigated that the proportion of heartwood and sapwood declined along with an increase in tree height in all sites. Moreover, Morais and Pereira observed that the heartwood area was higher than sapwood at the base and 5% height levels but above this height heartwood area had decreased. Another study on *Eucalyptus nitens, E. globulus,* and *E. maidenii* also reported that heartwood had shown a decreasing trend from the bottom to the top of the tree for all species aged 8 and 11 years old (McKinley et al., 2002, and Raymond and Muneri, 2001). Sapwood and heartwood proportions of *Ziziphus mauritiana* were significantly different along the height as reported by Riki et al., 2019. This study also observed that from the bottom to the top of the tree sapwood proportion increased whereas heartwood decreased. A study by Knapic, 2006 observed that five trees formed heartwood to 85% of the total height and no trees formed heartwood to 90% of the total height in a study on the species named *Acacia melanoxylon*. According to this research, heartwood decreased from the base to the top of the tree. Another study by Nawrot et al., 2008 reported that heartwood formation decreased with an increase in height for all age classes of *Larix decidua*.

CONCLUSION

Wood from the *Eucalyptus globulus* of the M/Suba stand was denser than the *Eucalyptus globulus* from the D/Birhan stand. At M/Suba and D/Birhan forests, the basic density of E. globulus was increasing from the bottom to the top of the tree and some significant differences among different heights had been noticed. Similar results were reported by many authors as to the trend along the height and with a number of significant variability in this gradient. From this, it could be concluded that density was highly variable along the height in both study sites. Radially, basic density was more variable in the wood of E. globulus from the D/Birhan site. Generally, E. globulus from the D/Birhan site was more variable in b. density within the tree.

At M/Suba, all shrinkages were uniform all along the height. Moreover, E. globulus from the D/Birhan forest was more variable in general in all shrinkages radially from pith to bark. From this, it could be concluded that the variability of E. globulus from the D/Birhan forest was more pronounced in both axes. Sapwood and heartwood proportions from the M/Suba forest have shown somewhat a high degree of variability when moving from the bottom to the top of the tree compared to the D/Birhan forest. Furthermore, the *Eucalyptus globulus* from the D/Birhan forest had more sapwood proportion compared to the *Eucalyptus globulus* from the M/Suba forest. And Eucalyptus globulus from the M/Suba forest had more heartwood proportion.

Generally, this study concluded and recommended that for tree breeding with respect to (1) End-uses requiring durable wood, more dense wood, and highly stable (in dimensional movements) wood would be better from M/Suba forest, (2) Pulp wood, as D/Birhan forest had shown high sapwood proportion, wood of Eucalyptus globulus from D/Birhan forest is better recommended for this purpose.

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