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Investigation of Physical and Mechanical Properties and Their Relationship in *Senegalia caffra* Wood Grown in Northern Ethiopia

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ABSTRACT

This research focused on determining the physical and mechanical properties of *Senegalia caffra* collected from a *Gilgile Beles* site in Ethiopia and analyzing how these properties relate to the wood's performance. Fifteen (15) sample trees were selected and felled for the study. Sampling, specimen preparation, and conducting the different tests were achieved following ISO and British standards. In this study, the mean basic density of 594.40 Kg/m^3, modulus of elasticity (MoE) of 9,556.79 N/mm^2, modulus of rupture (MoR) of 105.69 N/mm^2, compression strength parallel to the grain of 53.15 N/mm, impact bending strength of 14,825.00 Nm/m^2, radial and tangential hardnesses of 4,958.67 N and 5,324.78 N, respectively, were obtained for the species. *Senegalia caffra* was superior to the high timber-value tree species of Ethiopia in most of the studied features. The bottom of the tree was highest in density, MoE, MoR, radial, and tangential hardnesses; whereas, the middle height was higher in compression and impact bending strengths. Heartwood was higher in density, MoE, compression strength, and radial and tangential hardnesses than sapwood. Density was moderately correlated with radial hardness (with an R of 0.605 and sig. of 0.000). Generally, higher properties were recorded at the bottom of the tree as well as in the heartwood.

INTRODUCTION

Forests provide various social, economic, and environmental services. Wood production is one of the key economic values of forests, which has subjected them to significant anthropogenic pressure, ultimately leading to deforestation (Louppe, 2008). The majority of forest products are derived from wood, which is the primary source of goods, particularly for low-income communities. In addition, it contributes significantly to job creation in these societies, as wood products can be easily produced and finalized using locally available and affordable materials (Hounlonon et al., 2021). This situation together with other factors has led to a heavy deforestation rate and endangering of tree species as well as associated plant and fauna species (IFAWI, 2024).

In Ethiopia to reduce and/or halt pressure on natural forests and high-value timber species; which have been identified as endangered tree species, plantations have been established. As it is the case in other parts of the world (Brancheriau, 2013), in our country too, plantations with exotic fast-growing tree species have been planted primarily to supply fuel wood and timber for local factories.

One of the exotic tree species established in the country is *Senegalia caffra* (Thunb.) P.J.H. Hurter & Mabb. that has widely been planted in the 'Amhara' regional state. The species is formerly known as *Acacia caffra, Mimosa caffra, Acacia fallax,* and *Acacia multijuga*. It is classified under the family of Fabaceae, or Leguminosae. The tree is a fast-growing deciduous shrub or tree, very attractive, upright, often flat-topped reaching a height of up to 14 m (SANBI, 2024). The Trunk is relatively straight, growing to a girth of around 60 cm. Matured trees change to grey from thick, rough, pale yellowish bark while they are young. The branch is whitish with silver hairs and as a result commonly known as a "white thorn". It is a lowland tree species found in the tropical and subtropical drier region distributed In Southern Africa, (only subspecies *campylacantha* is found); Zimbabwe, Botswana, Mozambique, Swaziland, South Africa, and as far north as Gambia and Ethiopia (Tropical Plants Database [TPD], 2024). It grows in deep, relatively moist soils or alluvial soils near rivers, in thorn veld/subtropical bushveld, and open parkland. It survives both dry weather and low temperatures with an elevation of sea level to 1500 m a.s.l. *Senegalia caffra* is tolerant of frost, drought, acidic, and sandy soil. The tree coppice well and regenerates quickly after burning (TPD, 2024).

The wood of the species is heavy, dense, hard, and seasoning with no serious defects and the grain is beautiful. The species traditionally has been widely used for agroforestry, fuel wood, medicine, tannin (From bark), basket making, furniture, and fencing poles (TPD, 2024 and SANBI, 2024).

The majority of the supply of wood for construction, furniture, hand tools, and others has been coming from mainly 'Addis Ababa' and some from 'Adama' for the lowland regions. Studies on wood for construction purposes were scarce for the lowland tree species. Some studies on the physical and mechanical properties of lowland tree species were conducted by the then WURC (Wood Utilization Research Center) and at present time, the center is known as Forest Products Innovation Center of Excellence only on *Acacia melanoxylon* and *Acacia decurrens*. In this study, many of the mechanical properties were considered. Researching lowland tree species could be crucial in alleviating wood scarcity for construction as well as reducing the expenditure of local currency by the inhabitants (who are most of them considered the poorest population in the country) to import wood for construction from the nearby available markets. The main objectives of this study were to determine the physical and mechanical properties of *Senegalia caffra* from *Gilgile Beles,* site in Ethiopia and observe the relation among the properties.

METHODS

The study was conducted on a natural stand of 37-year-old *Senegalia caffra* grown at the '*Gilgile Beles*' site in Ethiopia. 15 phenotypically vigorous sample trees were selected and felled for the study. Sample trees had a minimum diameter at breast height (DBh) of 19.45 cm and a maximum DBh of 37.64 cm averaging with a DBh of 30.55 cm and a mean height of 10.52 m ranging from 8.50 m to 12.67 m height.

Sampling was conducted following the ISO standard described in ISO 3129, 1975. Sample trees were cross-cut to 2.5 m logs from the bottom, middle, and top heights. Sample disks were taken from each log. Then the sapwood and heartwood boundaries were identified, measured, and recorded on each disk. Sample wood blocks with the dimensions of 2 cm*2 cm*3 cm were taken from each sapwood and heartwood to determine basic density following ISO standard (ISO 3131, 1975). Moisture content (MC) (%) was determined following ISO standard with sample sticks prepared from each log (ISO 3130, 1975). After drying sample sticks to around 12 % MC, clear wood specimens were prepared for the determination of static bending strength, compression strength parallel to the grain, impact bending, and radial and tangential hardness strengths by applying the respective procedures (ISO 3133, 1975, and BS373, 1957).

To determine static bending strength ISO 3133, 1975 standard was followed, and the test was conducted using the Universal Strength Testing Machine with maximum loads of 50 kilonewtons (kN). The load was applied to the center of the specimen, on the radial face, at a constant speed of 6.6 mm/min to carry out the tests using the samples' dimensions of 20 mm * 20 mm * 300 mm. Samples were loaded to failure in three-point loading over a span of 280 mm. The load of the force plate and the corresponding deflection were recorded from the dial gauge manually for each sample. Graphs were plotted for each specimen using Microsoft Excel to calculate MOE and MOR. From each plotted graph, MOE and MOR were calculated using the following formulae:

$$MoE = (p'*l^3)/(4*d*b*h^3) \quad \ldots\ldots\ldots\ldots (1)$$

$$MoR = (3p*l)/(2*b*h^2) \quad \ldots\ldots\ldots\ldots (2)$$

Where, MOE - Modulus of elasticity (N/mm^2), MOR - Modulus of rupture (N/mm^2), p' - Load at the limit of proportionality (N), p - Maximum Load (N), l - Span length (mm), d - Deflection at the limit of proportionality (mm), b - Width of specimen (mm), h - Thickness of the specimen (mm).

Impact bending resistance is the work required to cause total failure in impact bending and is determined according to BS 373, 1957. The specimens were tested using a pendulum hammer (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 using the following formula.

$$Im.Re. = {}^{P}\!/_{b*h}h \quad \ldots\ldots\ldots\ldots (3)$$

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

Hardness represents the resistance of wood to indentation. Hardness was comparatively measured by the force required to embed one-half the diameter of an 11.3 mm ball into the wood (FPL, 2010). Hardness values were obtained using the Janka method (BS 373, 1957). The specimens were tested using UTM with a rate of loading 6.35 mm/min for both radial and tangential faces.

Compression parallel to grain test was done based on (BS373, 1957) standard. The specimens were tested using a Universal Testing Machine with a speed of loading 0.635 mm/min. The load was applied by a spherical bearing block of the suspended self-aligning type. The test was discontinued when the maximum load is passed and the failure occurred. The Maximum crushing Strength (MCS) was calculated using the following formula:

$$MCS = {}^{C}\!/_{(b*h)} \quad \ldots\ldots\ldots\ldots (4)$$

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

Analysis was conducted using SPSS version 24 for descriptive statistics, analysis of variance (ANOVA), mean comparison and correlation, and regression analysis at 95% and 99% confidence intervals. Statistical results were reported using tables and figures.

RESULTS AND DISCUSSION

In this study the mean basic density of 594.40 Kg/m^3, MoE of 9,556.79 N/mm^2, MoR of 105.69 N/mm^2, compression strength // to the grain of 53.15 N/mm^2, impact bending of 14,825.00 Nm/m^2, radial hardeness of 4,958.67 N and tangential hardeness of 5,324.78 N were recorded for *Senegalia caffra* stand. When the species was compared to high timber value tree species of Ethiopia studied by Desalegn et al., 2012, the basic density, MoR and compression strength of *Senegalia caffra* were greater than *Cordia Africana, Ekebergia capensis, Hagenia abyssinica, Juniperus procera* and *Afrocarpus falcatus* but lower than *Acacia decurrens*. In MoE *Senegalia caffra* was higher than *Cordia Africana, Ekebergia capensis, Juniperus procera*, and *Afrocarpus falcatus* but lower than *Hagenia abyssinica* and *Acacia decurrens*.

Its impact bending and side/radial hardness were higher than all high timber value tree species of Ethiopia and *Acacia decurrens* (Table 1). In a study on *Acacia auriculiformis* it was found that the wood had a mean density of 540 Kg/m^3, MoE of 19,780 MPa, and MoR of 141.78 MPa (Hai et al., 2010). Another study by Makino et al., 2012 on the species *Acacia mangium* reported that the mean basic densities of the 5 and 7-year-old trees were 420 and 450 Kg/m^3 and their compression strengths were 30.00 and 32.80 MPa, respectively. The density of our study species was higher than the acacia species of the above two studies but lower than *Acacia auriculiformis* in MoE and MoR. By far greater density and MoE than *Senegalia caffra* was reported for three different ages of *Acacia auriculiformis*; densities of 825.16, 616.57, and 722.92 Kg/m^3 and MoE of 14,991.17, 14,066.78, and 13,164.47 N/mm^2, from Benin (Hounlonon et al., 2021).

According to the study conducted by Pollet et al., 2012 on the species *Robinia pseudoacacia* found that the average basic density of the wood was 606 kg/m^3; which was close to the density of *Senegalia caffra*, MoE of 15,700 MPa, MoR of 138 MPa, the compression strength of 63.3 MPa, impact bending of 172.1 KJ/m^2. Another study by Skarvelis and Mantanis, 2013 on *Fagus sylvatica* from four different sites reported the mean dry density of 640, 660, 640, and 600 Kg/m^3, MoR of 118.25, 81.50, 115.04, and 107.19 N/mm^2; compression strength of

56.62, 56.32, 59.68 and 49.11 N/mm^2; impact bending strengths of 708.08, 892.40, 832.65 and 704.28 KJ/m^2, respectively.

Table 1. Average Values of Physical and Mechanical Properties of Different Timber Species in Ethiopia

Timber Species	Density (Kg/m^3)	MoE (N/mm^2)	MoR (N/mm^2)	Comp. // to Grain (N/mm^2)	Impact Bending (Nm/m^2)	Radial/Side Hardeness (N)
Cordia africana	410	6,996	64	29	6,588	2,213
Ekebergia capensis	580	9,036	96	45	8,076	4,709
Hagenia abyssinica	560	9,563	86	43	6,436	3,814
Juniperus procera	540	9,081	87	38	-	1,910
Afrocarpus falcatus	520	6,704	77	40	4,680	4,081
Acacia decurrens	816	14,310	188	85	7,313	3,650

As shown in table 2, axially, almost all of the wood characteristics decreased slightly towards the top except MoE; which was observed to slightly increase in this gradient. The highest density, MoE, MoR, radial, and tangential hardnesses were recorded at the bottom of the tree while the middle height was higher in compression and impact bending strengths only. Compared to the two heights, the bottom height was superior to the middle and top heights in most of the properties whereas, most of the studied features were the lowest at the middle height (Table 2). Similar to our study, *Acacia melanoxylon* had shown a decreasing pattern in basic density for two moisture conditions from base to top of the tree as reported by Mussa and Bekele, 2019. Similarly, another study by Topaloglu and Erisir, 2018 observed a decreasing trend in basic density from the bottom to the top of the tree for the species named *Fagus orientalis* and *Abies nordmanniana*. Another study also reported that *Acacia mangium* had shown somewhat a decreasing pattern of basic density from the base to the top of the tree (Santos et al., 2023). Similar trends for MoR, compression strength, impact bending strength, radial and tangential hardnesses were reported by Gillah et al., 2008 on *Azadirachta Indica* and Mussa and Bekele, 2019 on *Acacia melanoxylon*.

In contrast to this study and other studies mentioned above, Machado et al., 2014 observed an increasing trend in density from 35% to 65% of the tree height for *Acacia melanoxylon*. Another study by Santos et al., 2013 also reported (a different trend to our result on density) for *Acacia melanoxylon* a decrease in basic density from the base to 5% of the height and then until the top it increased. Acacia hybrid (*A. auriculiformis* × *A. mangium*) in a study conducted by Duc Viet et al., 2020 was observed that basic density decreased when moving upward to a height of 9 m from the bottom of the tree and finally from 9 m onwards it increased for most of the studied sites. Although some studies have shown a different trend (from generally hypothesized) in density along the height, most studies including our study observed a trend in conformity to the hypothesized trend that such pattern might be due to having more matured wood/cells at the bottom and juvenile wood/cells at the top of the tree (Getahun et al., 2014). The other hypothesis for such a decrease in density axially could be due to having relatively few latewood and a high proportion of thin-walled cells at the top part of the tree (Haygreen and Bowyer 1996).

ANOVA in Table 3 detailed that there were significant differences in density, radial, and tangential hardnesses between positions along the height. The rest of the properties were not affected by axial position. In support of our result, on *Acacia melanoxylon* Mussa and Bekele, 2019 found that height had a significant effect on density, radial and tangential hardnesses for the two moisture conditions. However, their results on MoE, MoR, compression, and impact bending strengths were contrary to our findings. Another study on *Acacia melanoxylon* by Machado et al., 2014 found density was significantly different among three positions along the height. And in this study, MoE, MoR, and compression strength were not significantly different axially; which was similar to our finding. On the other hand, non-significant variability of density along the height was reported for *Acacia saligna* by Mmolotsi et al., 2013 and it was against our investigation.

In our study, pairwise comparison showed that there were significant differences in density, radial and tangential hardnesses between bottom and middle heights. Whereas, bottom and top height were significantly different in density and radial hardeness. On the other hand, middle and top heights were significantly different in radial and tangential hardnesses. The rest of the pairs were not significantly different (Table 2). According to a study by Nordahlia et al., 2014 on the species *Azadirachta excelsa* observed the bottom and middle height, as well as bottom and top height, were significantly different in the basic density of the stand established from the seedlot. On the other hand, the species planted from rooted cutting was significantly different for the pairs between bottom and middle, bottom and top as well as middle and top heights.

Table 2. Mean and pairwise comparison of wood properties at different heights along the bole and for different wood types of *Senegalia caffra*

Properties	Along The Height			Wood Type	
	Bottom	Middle	Top	Sapwood	Heartwood
Density (Kg/m^3)	611.67a	585.28b	586.24b	559.16b	629.63a
MoE (N/mm^2)	9660.68a	9488.95a	9520.73a	9358.87a	9754.70a
MoR (N/mm^2)	109.48a	103.08a	104.50a	112.89a	98.49b
Comp. Strength (N/mm^2)	53.61a	53.92a	51.92a	53.09a	53.22a
Impact (Nm/ m^2)	15,055.00a	15,108.33a	14,311.67a	16,911.11a	12,738.89b
Hardness (Rad) (N)	5248.67a	4674.33c	4953.00b	4454.44b	5462.89a
Hardness (Tan) (N)	5568.33a	5017.00b	5389.00a	4956.89b	5692.67a

Table 3. ANOVA of each Wood Property for axial direction and for wood types of *Senegalia caffra*

Source	Df	Sig.						
		Density	MoE	MoR	Comp	Impact	Rad.Hard	Tan.Hard
Position	2	0.024	0.820	0.377	0.299	0.455	0.000	0.000
Wood Type	1	0.000	0.098	0.000	0.907	0.000	0.000	0.000
Position*Wood Type	2	0.414	0.779	0.109	0.000	0.846	0.213	0.398
Error	84							
Total	90							

Heartwood was higher in density, MoE, compression strength, radial, and tangential hardnesses than sapwood but of significantly higher in density, radial, and tangential hardnesses. Whereas, sapwood was significantly higher than heartwood in MoR and impact bending strengths (Table 2). Basic density, MoE, compression strength, radial and tangential hardnesses were increasing from sapwood to heartwood. However, MoR and impact bending strengths had shown a decreasing trend from sapwood to heartwood gradients (Table 2), which was against the generalized pattern that matured wood has greater rapture and impact bending strength. Such a trend out of the normal pattern is common for hardwood tree species as discussed by many scholars. For instance, a study conducted by Bektas et al., 2020 found that MoE, MoR, impact bending, radial, and tangential hardnesses of sapwood were significantly higher than the heartwood for *Eucalyptus grandis*. In a study on *A. auriculiformis* by Hai et al. 2010 density, MoR, and MoE of the sapwood were higher than heartwood. Another study by Bal and Bektas 2013 on *Eucalyptus grandis* reported that MoE, MoR, and compression strength of the sapwood were higher than that of the heartwood. But supporting our findings, studies like Laskowska et al., 2021 on *Platycladus orientalis* heartwood density, MoE, MoR, and compression strength and study by Ayobi et al. 2011 on *Quercus castaneaefolia* heartwood MoR and compression strength greater than sapwood.

Results displayed in figures 1-7 are shown by considering a single wood type (sap or heartwood) at different heights. Generally, this study investigated that except MoE, all the other properties of both sapwood and heartwood decreased from the base to the top of the tree. When the trends were taken into account and compared to the generalized scientific knowledge, all the results supported this knowledge. Furthermore, figures presented from 1-7 tried to compare the two wood types at different heights. The finding showed that density, MoE, radial and tangential hardness of the heartwood taken from bottom, middle, and top heights were greater than the sapwood taken from these same heights (Figures 1, 2, 6, and 7). However, Mor and impact bending of the heartwood from the three heights were lower than the sapwood from different heights (Figures 3 and 5). Whereas, Sapwood and heartwood from the three locations were almost equal in compression strength (Figure 4).

Table 4 depicted that the mean density, impact bending, radial and tangential hardness of the sapwood and heartwood were significantly different at the bottom of the tree. Whereas, at the middle height, sapwood and heartwood were not significantly variable only for MoE. For the top height only density, MoE, impact bending, radial and tangential hardness of the two wood types were significantly different. Our study has shown the comparison of a single wood type but at different heights. This shows that sapwood of the bottom and middle heights were significantly different in density, compression strength, radial and tangential hardness. Sapwood at the bottom and top of the tree were significantly different only for radial hardness. On the other hand, compression strength, radial and tangential hardness of the sapwood at the middle and top heights showed significant differences. As to the heartwood, only radial and tangential hardness resulted in significant differences. Radial hardness of the heartwood from the bottom and top heights exhibited significant differences. Whereas, for tangential hardness heartwood of the middle height was significantly different among with bottom and top heights. As shown in Figure 1-7, all properties of the sapwood and heartwood decreased when height increased except MoE where both wood types were observed to increase in MoE as height increased. In a study on *Albizzia julibrissin* it was observed that heartwood density, MoE, and MoR were decreasing from the bottom to the top of the tree (Kiaei and Farsi, 2016). Another study by Duc Viet et al., 2020 reported that along the height at different locations basic density was increasing from pith to bark for all of the Acacia species and hybrids. *Acacia mangium* corroborated that at different heights along the stem of the tree, there was an increase in basic density from pith to bark direction and it was related to differentiation in cell types and fiber wall thickness within the wood (Da Silva et al., 2020 and Santos et al., 2023).

Table 4. Variation in Physical and Mechanical Properties of Sap and Heartwood at Different Heights for *Senegalia caffra*

Phys. and Mech. Properties	Wood Types	Position along Height		
		Bottom	Middle	Top
B. Density (Kg/m^3)	Sapwood	B571.11a	B547.22b	B559.14ab
	Heartwood	A652.22a	A623.33a	A613.33a
MoE (N/mm^2)	Sapwood	A9,399.27a	A9,409.19a	B9,268.13a
	Heartwood	A9,922.08a	A9,568.71a	A9,773.33a
MoR (N/mm^2)	Sapwood	A114.52a	A116.10a	A108.04a
	Heartwood	A104.43a	B90.06a	A100.98a
Comp // to Grain (N/mm^2)	Sapwood	A51.93b	A57.21a	A50.13b
	Heartwood	A55.30a	B50.64a	A53.72a
Impact Bending (KJ/ m^2)	Sapwood	A17,266.67a	A16,958.33a	A16,508.33a
	Heartwood	B12,843.33a	B13,258.33a	B12,115.00a
Rad. Hardeness (N)	Sapwood	B4,633.33a	B4,165.33b	B4,564.67a
	Heartwood	A5,864.00a	A5,183.33b	A5,341.33b
Tang. Hardeness (N)	Sapwood	B5,140.67a	B4,756.67b	B4,973.33a
	Heartwood	A5,996.00a	A5,277.33b	A5,804.67a

Small letters compare mean differences along the height and similar letters indicate not significantly different at 95% confidence interval. Capital letters compare mean differences between sapwood and heartwood and similar letters indicate not significantly different at a 95% confidence interval.

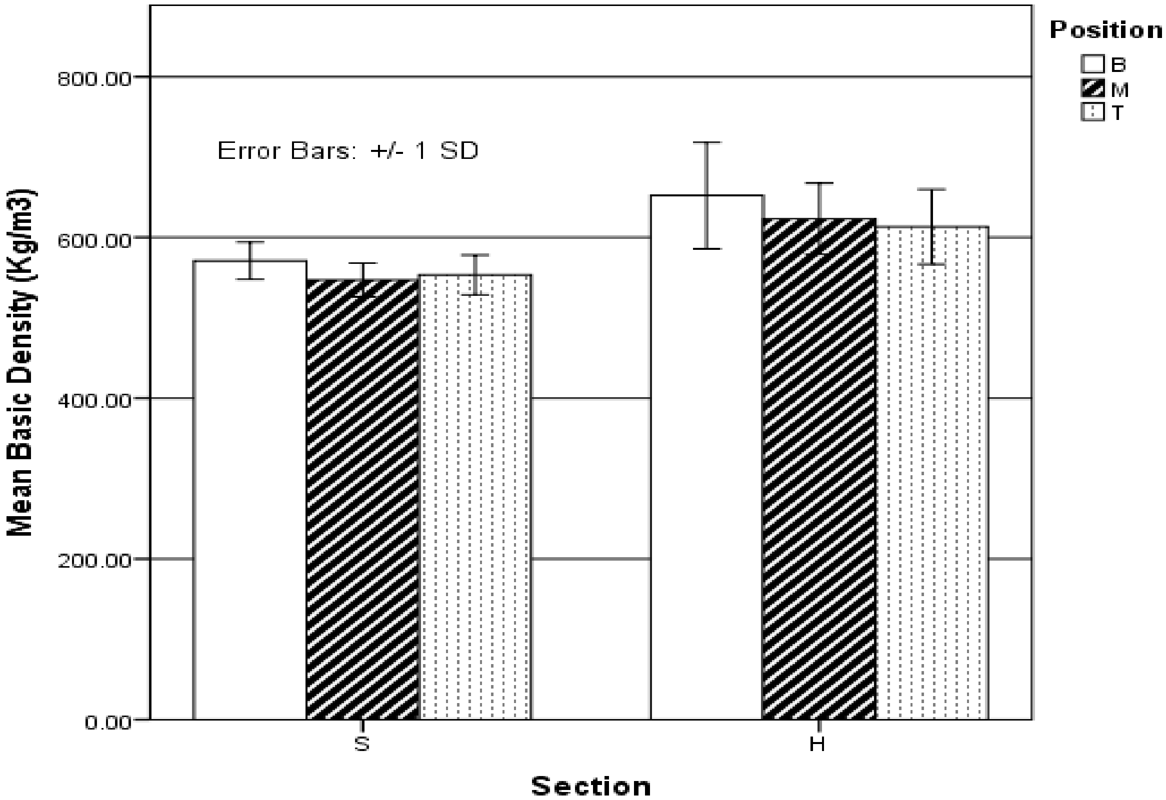

Figure 1. Trends in Basic Density at Different Heights for Each Wood Type of *Senegalia caffra*
Where, b - Bottom, M - Middle, T - Top, S - Sapwood and H - Heartwood

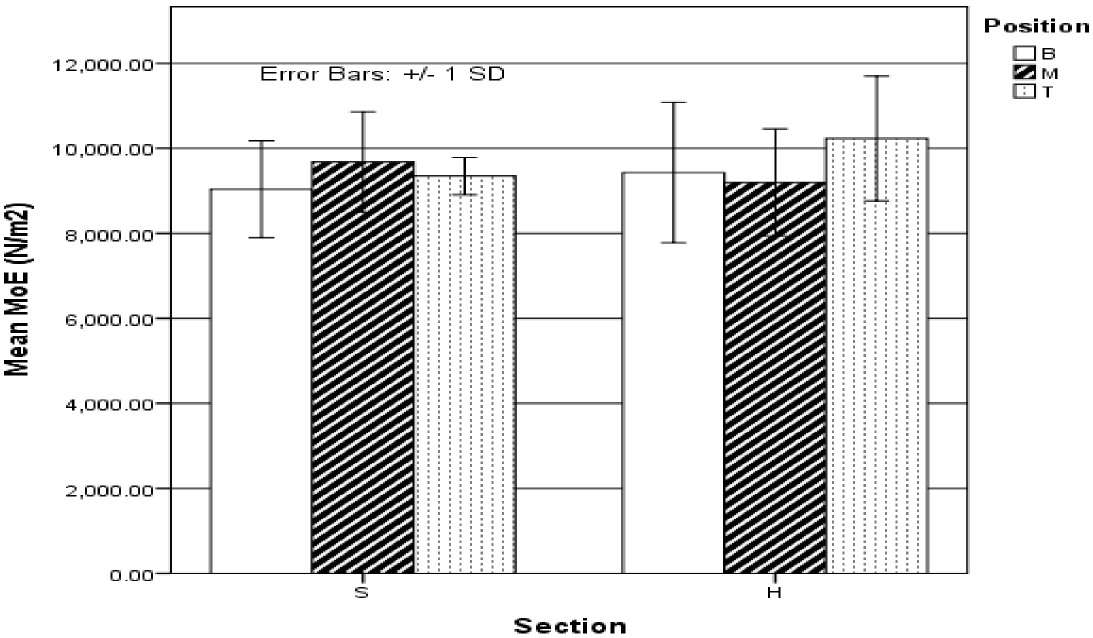

Figure 2. Trends in MoE at Different Heights for Each Wood Type of *Senegalia caffra*
Where, b - Bottom, M - Middle, T - Top, S - Sapwood and H - Heartwood

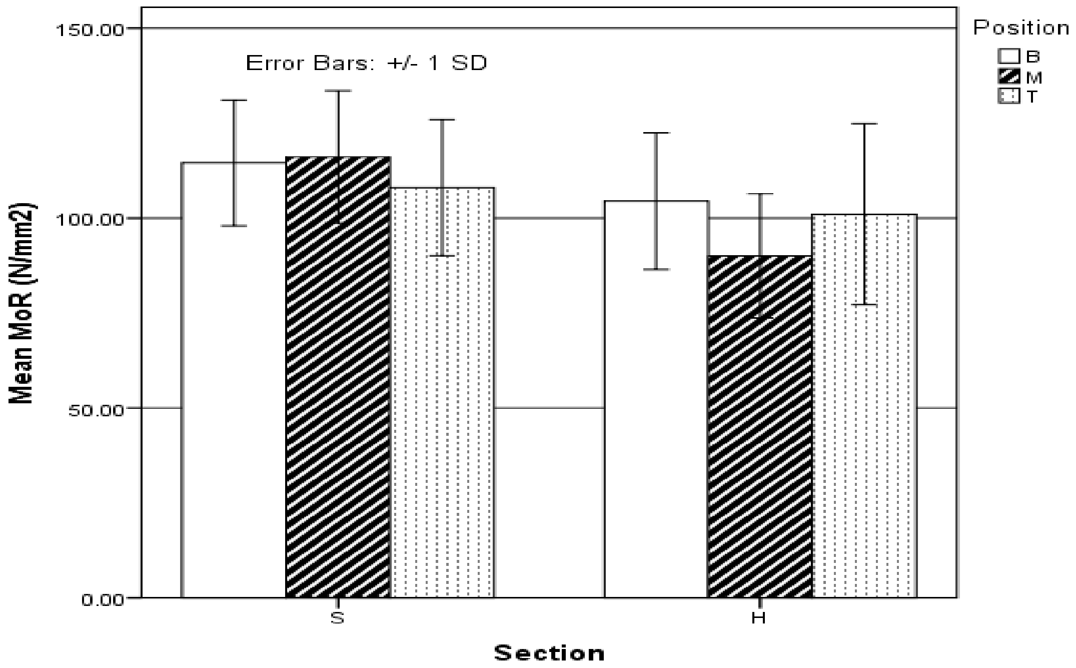

Figure 3. Trends in MoR at Different Heights for Each Wood Type of *Senegalia caffra*
Where, b - Bottom, M - Middle, T - Top, S - Sapwood and H - Heartwood

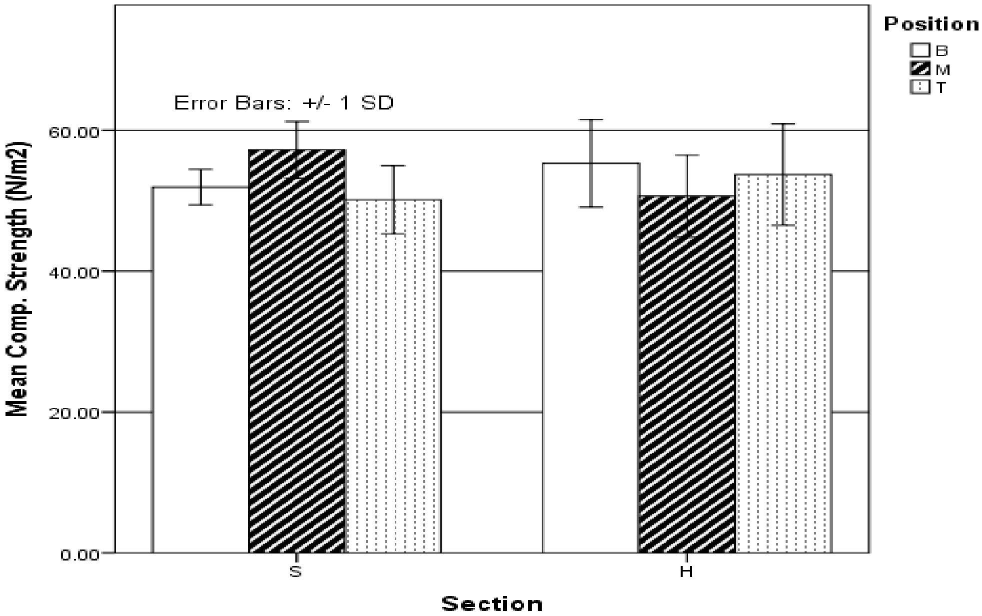

Figure 4. Trends in Compression Strength // to Grain at Different Heights for Each Wood Type of *Senegalia caffra*
Where, b - Bottom, M - Middle, T - Top, S - Sapwood and H - Heartwood

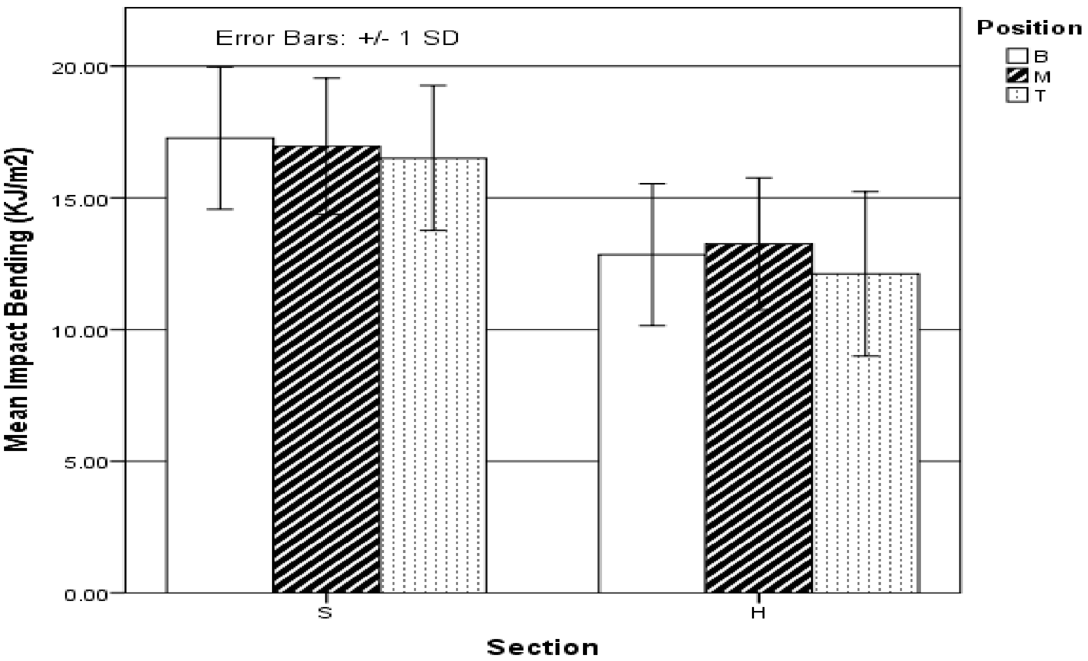

Figure 5. Trends in Impact Bending at Different Heights for Each Wood Type of *Senegalia caffra*
Where, b - Bottom, M - Middle, T - Top, S - Sapwood and H - Heartwood

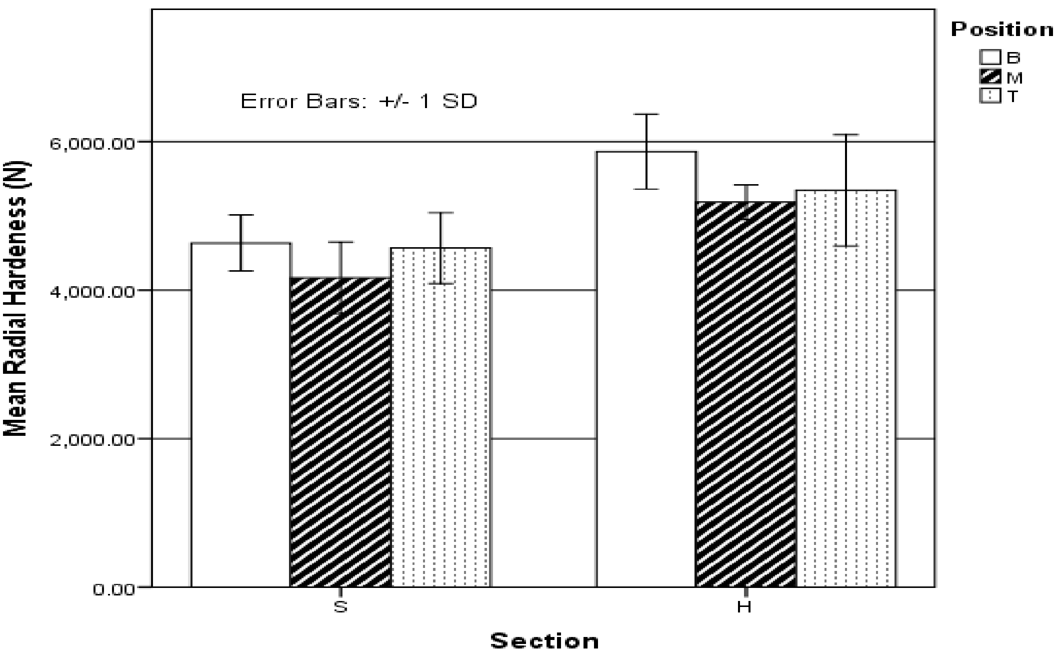

Figure 6. Trends in Radial Hardness at Different Heights for Each Wood Type of *Senegalia caffra*
Where, b - Bottom, M - Middle, T - Top, S - Sapwood and H - Heartwood

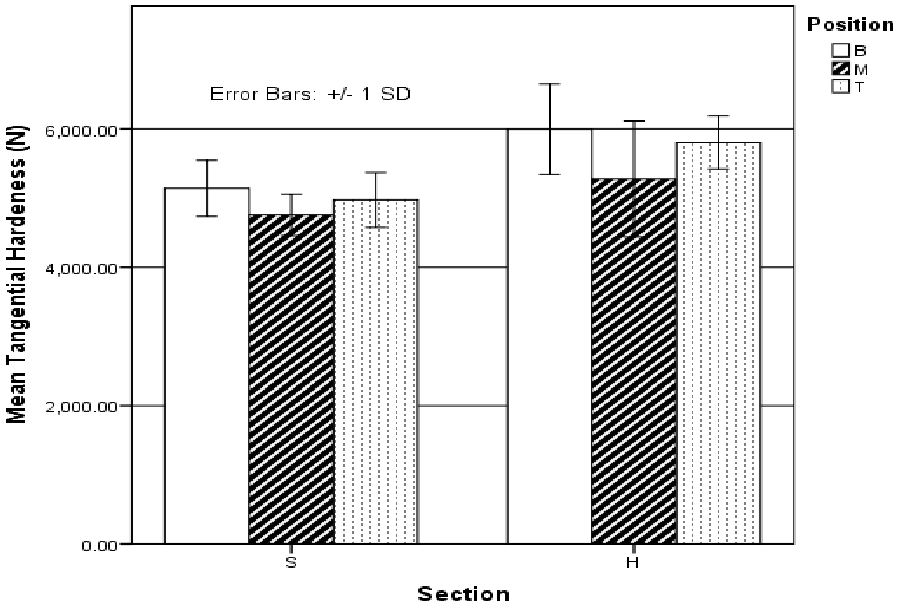

Figure 7. Trends in Tangential Hardness at Different Heights for Each Wood Type of *Senegalia caffra*
Where, b - Bottom, M - Middle, T - Top, S - Sapwood and H - Heartwood

No correlation was observed for density with MoR (R was 0.056 with a significance level of 0.601) and compression strength parallel to the grain (with an R of 0.065 and sig of 0.545). Low correlation was observed for basic density with MoE; very significantly (0.005) and positively correlated (R=0.295), impact bending; very significantly (0.000) and positively correlated (R of 0.413), and tangential hardness; very significantly (0.003) and positively correlated (R=0.305). On the other hand, moderately and positively correlated (with an R of 0.605) properties were basic density with radial hardness and the correlation was very significant (P=0.000).

A study conducted by Makino et al., 2012 on the species *Acacia mangium* reported a significant positive correlation between basic density and compression strength with correlation coefficients (R) of 0.790 and 0.583 for 5 and 7-year-old stands, respectively. *Ficus Exasperata* which was studied by Sarogoro and Emerhi, 2021 exhibited a significant positive correlation with an R of 0.832 between basic density and impact bending strength at the significance level of 0.041. Whereas, MoE and basic density were strongly and positively correlated with an R-value of 0.909 but not significantly having p value of 0.151. Basic density and MoR were found to be not significantly correlated (R=0.140) with the significance level of p=0.151. A study that related density with MoE, MoR, and compression strengths of the wood of angiosperm species indicated that all the strength properties studied were highly related to density with R^2 of 0.737, 0.859, and 0.812, respectively ((Niklas and Spatz, 2010). Another research conducted by Bal and BektaŞ, 2013 showed oven-dried density was positively and strongly related to MoE, MoR, compression, and impact bending strengths with R^2(p-value) of 0.8422($p<0.001$), 0.8372($p<0.001$), 0.758($p<0.001$) and 0.6496 ($p<0.001$), respectively.

CONCLUSION

When *Senegalia caffra* was compared to endangered high timber value tree species of Ethiopia, it was found that the species was superior to almost all of the highly valued species in all properties studied except for its MoE where *Hagenia abyssinica* was greater than *Senegalia caffra*. Radial hardness strength was highly and significantly variable along the height among all the three heights studied. Basic density and tangential hardness were also moderately variable in this height gradient.

MoE, MoR, compression strength parallel to the grain, and impact bending strength were uniform all along the height. Only MoE and compression strength parallel to the grain of the sapwood and heartwood were similar but the rest of the wood properties greatly and significantly vary between the two wood types (Sapwood and Heartwood).

Generally, wood properties were highly variable in the radial direction when compared to the axial direction. Along the stem wood properties were almost uniform. Generally, higher properties were recorded at the bottom of the tree as well as in the heartwood; which were in the matured parts of the stem. It was suggested from this study that it is better to use the inner wood (Part of wood close to the pith) for end-uses those requiring higher mass and strength.

CONFLICTS OF INTEREST

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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