Ethiop. J. Biol. Sci., **5(2): 117-135, 2006**
 ISSN: 1819-8678

SOME BASIC PHYSICAL AND MECHANICAL PROPERTIES OF THE VALUABLE *HAGENIA ABYSSINICA* TIMBER AND THEIR INTERACTIONS: IMLPICATION FOR ITS RATIONAL UTILIZATION

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ABSTRACT: Among the overlooked major causes in Ethiopia that led to the destruction of forests, inappropriate utilization and endangering of the valuable tree species such as *Hagenia abyssinica* are lack of technical information on basic properties of wood and its utilization methods. The objective of this study was, therefore, to determine the basic physical and mechanical properties of *H. abyssinica* at green and dry conditions, their interactions and effect on its timber utilization. The study showed that there was significant difference ($p<0.01$) in green and air dry values of moisture content (MC), density and mechanical properties namely, static bending, compression parallel and perpendicular to the grain, side hardness indentation and impact bending along height among the trees of *H. abyssinica*. Seasoning from green state (88%) to 12% MC has resulted in increase in mechanical properties of 41% in modulus of rupture, 13% in modulus of elasticity, 65% in compression parallel and 50% perpendicular to the grain and 30% in side hardness. The results show that MC affects density and in turn both strongly affect the mechanical property of *H. abyssinica* timber. The lower the MC, the lower the volume, the higher the oven dry density and the higher the mechanical properties of the species. Therefore, for lumber utilization and planning for sustainable management of *H. abyssinica*, it is appropriate to select the right density, dimension, mechanical properties and loading direction of this species.

Key words/phrases: Density; *Hagenia abyssinica*; Mechanical properties; Moisture content; Seasoning of wood; Uses.

INTRODUCTION

The wood of *Hagenia abyssinica*, like other woody species, is a hygroscopic and an anisotropic material. It has different properties on tangential, radial and longitudinal directions (Bodig and Jayne, 1982; FPL, 1999) and produces different products to satisfy human needs. Due to its attractive appearance, the demand of *H. abyssinica* for timber and veneer is increasing with time. Currently (2007), the price of *H. abyssinica* lumber (4 m length and > 15 cm

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wide) is about 5200 Birr/m^3 (1 USD = 9.224 Birr); the price of which has increased by about 9% compared to the year 2004. The estimated annual demand of wood including that of *H. abyssinica* in the country for the year 2006 was about 76 million m^3 and is projected to reach about 84.6 million m^3 in the year 2010 while the supply for both years is constant i.e., about 13 million m^3 (EFAP, 1994) with a deficit of about 63 and 72 million m^3, respectively.

Due to the high demand and large-scale destruction, unwise exploitation and inappropriate utilization of these renewable resources are taking place in the country faster than their regeneration even without knowing their timber properties and quality of products. Some of the traditionally valuable indigenous timber species such as *H. abyssinica*, *Podocarpus falcatus*, *Juniperus procera*, *Cordia africana*, *Pouteria adolfi-friederici* are over exploited and endangered. The first four species are proclaimed not to be harvested from both federal and regional forests in Ethiopia (TGE, 1994). These species need immediate and concrete measures to conserve, regenerate and determine the basic timber properties for rational utilization. The term 'timber' stands for wood other than fuel wood that can be potentially usable for lumber (sawn wood/saw timber) (Helms, 1998).

H. abyssinica is the commonest high-altitude rain forest tree, once dominant in the upper montane forest belts of Ethiopia but now remains scattered in moist semi-highland and highland agroclimatic zones where it is sometimes found in pure stands (Hedberg and Edwards, 1989; Azene Bekele *et al*., 1993; Thirakul, 1993; MacLachlan *et al*., 2002). The timber of *H. abyssinica* produces lumber having attractive appearance similar to *Kahya ivorensis* (mahogany) (FIAG, 1979). *H. abyssinica* is one of the eight species that produces high quality and decorative face veneer in Ethiopia (Melaku Abegaz and Demel Teketay, 2003). Due to this, the trees have been illegally harvested and pit sawed, and sold at high price.

The wood properties within and among trees is influenced by factors such as moisture content, location in a tree, location within a range of species, site conditions/environmental factors, growing space, growth rate, age and genetic/heritable variation of the species, etc (Bodig and Jayne, 1982; Desch, 1986; FPL, 1999), and processing and manufacturing defects.

Physical and mechanical properties of woods are strong bases to determine the quality and the basic stress values for construction and design purposes. Understanding the properties and the appropriate utilization methods of *H. abyssinica* will help to determine its sustainable regeneration and utilization.

This study was undertaken to generate technical knowledge on *H. abyssinica* timber and, thus highlight its economic importance. This may encourage regeneration and management of the species in large-scale plantations and hence contribute to its rational utilization in the country. The hypothesis of the study was that variation in moisture content (MC), density and mechanical properties existed at green and air dry states along height of the trees. MC has strong influence on density and both have strong influence on mechanical properties and utilization of *H. abyssinica* timber. Therefore, the main objectives of this investigation were to: (i) determine physical and mechanical properties as quality indicator for proper utilization of *H. abyssinica* timber, (ii) determine the variations and interactions of physical and mechanical properties of *H. abyssinica* timber at green and air dry states along the tree height within and among the trees, and (iii) compare *H. abyssinica* timber with other species and recommend its uses for different purposes.

MATERIALS AND METHODS

Description of *Hagenia abyssinica* (Bruce) J.F. Gmel.

Synonym. *Banksia abyssinica* Bruce

The genus name, *Hagenia* is named after a German botanist, 'Hagen' and the species epithet 'abyssinica' refers to the country 'Abyssinia', currently Ethiopia, from where the species was first collected. *H. abyssinica* belongs to the family Rosaceae. Its trade and local names are African Red wood, brayera, cusso, hagenia, kousso (English), kosso (Amharic), dusha, feto, hetu, heto (Afan Oromo), habbi (Tigre) (Breitenbach, 1963; Anonymous, 2006a), mdobore, mlozilozi (Swahili) and gora-gora (Agewgna) and shinchi (Awi) (MacLachlan *et al*., 2002).

H. abyssinica is a small to medium-sized tree with an average height of 25 m and a breast height diameter of 60 cm. It is characterized by typical parasol/umbrella-shaped crown and papery scaly bark (Grieve, 1995; MacLachlan *et al*., 2002). It is the monotypic species of the genus *Hagenia*. It is a tree native to the Afromontane regions with a disjunct distribution in the high mountains of East Africa from Sudan, Eritrea and Ethiopia in the North through Kenya, Uganda, Rwanda, Burundi, Democratic Republic of Congo and Tanzania, to Malawi and Zambia in the South and exotic to India (Anonymous, 2006a; 2006b). *H. abyssinica* is available in the Arsi, Bale, Gonder, Gojam, Kefa, Harerge, Sidamo, Shewa, Tigray, Welo and Welega regions of Ethiopia (Hedberg and Edwards, 1989).

In Ethiopia, it is generally found between altitudes of 2450-3250 m (Hedberg and Edwards, 1989), 2000-3300 m (Breitenbach, 1963; Azene Bekele *et al*., 1993; Thirakul, 1993; MacLachlan *et al*., 2002). It can be found growing mixed with *Podocarpus*, *Afrocarpus* and other tree species, and in drier afromontane forests and woodlands where *Hagenia* is dominant or in mixed stands of *Hagenia* and *Juniperus procera* (Azene Bekele *et al*., 1993; Thirakul, 1993; MacLachlan *et al*., 2002; Anonymous, 2006b).

Collection of test material

The material selected to prepare samples for wood property testing was the indigenous species, *H. abyssinica*. Sample logs were collected from Shashemene Forest Industry Enterprise area (Gambo) (Fig. 1), located in the sub-montane natural forest at an altitude of 2400 m, where there is an *H. abyssinica* disturbed forest so as to select defect-free trees. The altitude of Gambo ranges from 2160-3096 m. It has a mean annual rainfall of 1200 mm and mean annual maximum and minimum temperatures of 20°C and 15°C, respectively.

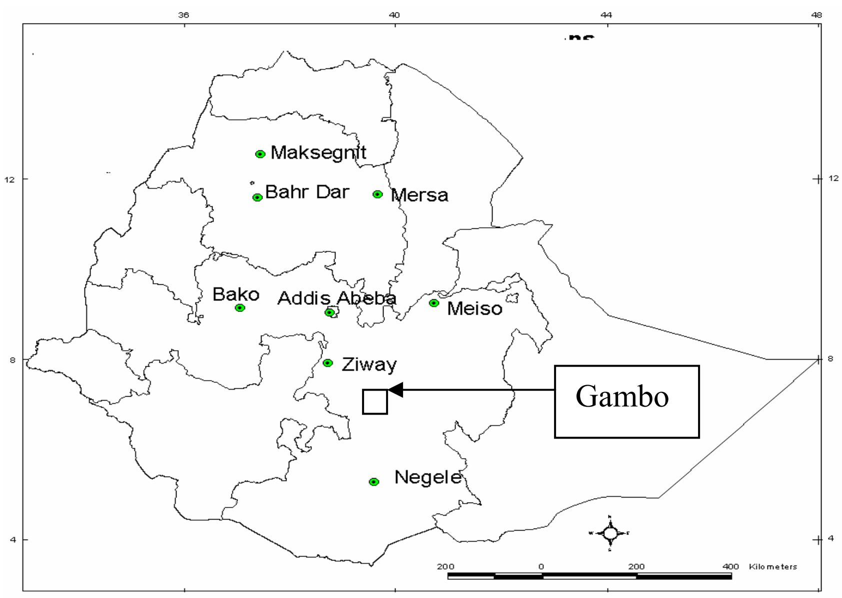

Fig. 1. Location of sample collection site, Gambo.

The sample trees had attained an average height of 15 (14-16) m and a breast height diameter of 40 (35-42) cm. Samples were collected in log forms of 2.5 m and up to 20 cm top diameter to obtain sufficient number of defect-free, clear-specimens for the different tests.

Sample preparation and seasoning

The preparation of small-clear specimens and methods of tests were mainly based on ISO standards, 2 x 2 cm small clear-specimens standard (ISO 3129, 1975; ISO 3130, 1975; ISO 3131, 1975; ISO 3133, 1975; ISO 3387, 1976; ISO 3348, 1975; ISO 3350, 1975; Burley and Wood, 1977; Lavers, 1983). In this case through-and-through sawing method was applied at the saw-mill in order to obtain approximately equal proportions of sapwood and heartwood and make the radial, tangential and longitudinal sections conspicuous.

Each log was sawn through-and-through to the pith and then 3 cm thick, 2.5 m long boards were chosen at a distance of 3-6 cm from the pith. This was done to obtain samples from both heartwood and sapwood parts. The boards were cross-cut into a series of 1.25 m long stringers (Burley and Wood, 1977). These were grouped and coded into odd and even numbers for the green and air dry tests, respectively. Boards for the drying tests were allowed to dry to less than 20% moisture content (MC) while the green test sample boards were plained parallel to the grain into 3 x 3 x 125 cm stringers, ripped and cross-cut into a series of standard right prisms having a cross-section of 2 x 2 cm and 1 m length. The 2 x 2 x 100 cm stringers at green (88% MC) and air dry (8% MC) conditions, respectively were then cross-cut into standard dimension specimens corresponding to each physical and mechanical property test (Table1). Thus, test samples were taken from each tree at about 1 m interval along the log height.

The air dry samples were stacked using stickers with four replications in air seasoning yard under shade without direct interference of sunlight and rainfall. Initial moisture content was determined from the samples distributed in the stacks. Current MC has been determined at three days interval. After two weeks of air drying, the three stacks possessing MC above 50% were transferred to artificial kiln seasoning to reduce the moisture to < 20%.

Typology of experiments and conditioning of specimens

The experimental design was Randomized Complete Block Design (RCBD). The experiments were designed into green (control) and air dry tests both for physical and mechanical properties (Table 1). Sample sticks were selected from the 1200 sticks prepared by eliminating defective ones. Nine hundred ninety three specimens were subjected to all tests, out of which 526 were for the green tests and 467 specimens for the air dry tests. Each specimen was used for testing and determination of MC, density and the corresponding mechanical property of the timber along the log length (Table 1).

Based on the experimental design and the type of measurements/parameters, all data were subjected to analysis of variance (ANOVA). The model $\chi ij= \mu+\alpha i+\beta j+\varepsilon ij$, where χij= ith observation in ijh block (bolts along log length), μ = general mean, αi = treatment i (trees), βj = effect of jh block, εij = error terms in ith observation in jth block has been used for the data analysis using SAS software. Excel and SAS software were applied for data management and analysis.

Table 1 Types of basic mechanical timber properties, number of specimens, rate and direction of loading for both green and air dry tests of *H. abyssinica*.

Mechanical property	Dimension Lbh (mm)	Priority	Specimens per 1m stick	No. of green specimens	No. of air dry specimens	Span (mm)	Rate of loading (mm/sec) and direction /surface of loading
Static bending	300 x 20 x 20	1	1	110	106	280	0.11, Radial face
Compression parallel to the grain	60 x 20 x 20	2	1	110	103	Full span	0. 01, Parallel to grain
Side hardness	45 x 20 x 20	3	2	208	170	Full span	0.11, Radial and tangential faces
Impact bending	300 x 20 x 20	4	1	98	88	240	Few micro Sec., Radial face

NOTE: Lbh-length, width and thickness of specimens, respectively.

Conditioning of specimens is an essential task before and during conducting tests regardless of the species and kind of test (ISO 3129, 1975; Lavers, 1983). Experiments were conducted in a temperature range of 20-25°C and relative humidity of 60-80%. Humidifier machine was used to maintain such a laboratory condition. The specimens were conditioned to maintain the samples at green and air dry conditions, respectively, until testing was made. Specimens were tested one after the other. The green test samples were tested as soon as possible. Delay was unavoidable, thus the sticks for the green tests were arranged on a clean floor and watered daily. The air dry specimens were kept in the conditioning room.

Testing and determination of physical and mechanical properties of *H. abyssinica* timber

This study mainly focused on the basic mechanical properties of the timber which include (i) static bending (modulus of rupture (N/mm^2), modulus of elasticity (N/mm^2), work to maximum load (mmN/mm^3) and total work (mmN/mm^3)), (ii) compression parallel and perpendicular to the grain (maximum crushing strength (N/mm^2)), (iii) side hardness (tangential and radial steel ball indentation (N)), and (iv) impact bending (impact resistance, (Nm/m^2)) and the physical properties of *H. abyssinica*, namely MC (%) and density (kg/m^3). The term mechanical properties refer to strength, elasticity, compression, hardness and toughness properties of wood.

Tests were conducted at the former Wood Utilization and Research Center, now known as Forest Products Utilization Research Program (FPURP), where there are standard machines and equipment to convert, treat and carry out the small-clear specimens in the research laboratories. Each test has its own purpose and practical significance since wood is anisotropic material. This is useful for applying wood to specific design and construction purposes. Thus, different mechanical property tests of *H. abyssinica* were performed on radial, tangential and longitudinal surfaces. All mechanical tests except impact bending were conducted using the hydraulic Wolpert Universal Testing Machine (Fig. 2a) by adjusting speed and changing the force loading plates while impact tests were carried out using Wolpert Pendulum Impact Testing Machine (Fig. 2b). The machines are manufactures of Wolpert Werkstoffprüfmaschinen GmbH Schaffhausen, Switzerland.

Fig. 2a. Wolpert Universal Testing Machine (side view)

Fig. 2b. Wolpert Pendulum Impact Testing Machine (front view)

All specimens were primarily subjected to measurements of initial weight and dimensions (width, thickness and length) using triple beam-balance and caliper, respectively, followed by mechanical tests. At the end of each mechanical property test, all pieces were transferred to the oven drying machine maintained at 103°C ± 2 and weighed at four-hour intervals. Oven drying was continued until the difference between two successive weights of each specimen was between 0-0.2 g and the final weight was taken as the oven dry weight (ISO 3130, 1975; FPL, 1999). This was done to determine the moisture content, density and/or specific gravity and mechanical properties of the species at test from each single specimen. Moisture content (MC %) = Weight of water/ Oven dry weight = ((Initial weight/Oven dry weight)-1) x 100, and density was estimated using the formula: Density (kg/m^3) = Weight/Green volume (FPL, 1999).

Determination of mechanical properties for each sample involved force recording from the test machines and applying different engineering formulae for the different properties. Static bending and center loading tests additionally involved sketching of load-deflection curves to estimate the derivative/sub-properties of static bending strength namely, modulus of rupture, modulus of elasticity, work to maximum load and total work. The density and mechanical properties at test (green and air dry) were determined using different engineering formulae and the dry test values were converted/ adjusted to 12% MC for comparison of mechanical property and density values with similar studies. Compression strength perpendicular to the grain was estimated using a formula based on hardness value and given constants.

RESULTS AND DISCUSSION

Interactions of physical and mechanical properties of *H. abyssinica*

During the seasoning process, water/moisture loss for *H. abyssinica* above 30% MC was very rapid i.e., 24 -30% per three days. Below 25% MC, the progression of moisture loss from the specimens was very slow, about 5% per three days through air seasoning and 4-6% per day in kiln seasoning method. The kiln seasoning method took about three days to reduce the MC of the stacks below 20%. Slight bending and end check defects were observed in air and kiln seasoning methods. The appearance of the species sapwood and heartwood was undifferentiated, but mainly appeared white, creamy yellow merging into the dark-brown or dark-red heartwood. It had medium to fine grain with fine to medium texture.

Based on mathematical estimations, the values of mechanical properties of *H. abyssinica* declined with an increase in MC. A reduction of MC from 30% to 25% revealed a sharp increase in mechanical properties and the increase of mechanical properties from 30% to oven dry (0% MC) was relatively slow (Table 2). For instance, compression parallel to the grain increased with a magnitude of 2 N/mm^2 for each 1% MC reduction. There was a similar trend for the remaining mechanical properties below fiber saturation point (FSP). However, the extent in mechanical properties below FSP with a given change in MC varied among the mechanical properties of *H. abyssinica* (Table 2).

The results of *H. abyssinica* timber from green to air-seasoning condition of 12% MC revealed an increase in mechanical properties - 41% in modulus of rupture, 13% in modulus of elasticity, 2% in work to maximum load, 65% in compression parallel to the grain, 50% in compression perpendicular to the grain and 30% in side hardness indentation (Table 3).

Toughness properties such as total work and impact bending from green to 12% MC revealed a reduction of 39% and 27%, respectively (Table 3). The correlation between density and toughness properties in this study was very weak (Table 3). According to Gurfinkel (1981), mechanical properties such as toughness, which depend on the work done by the load during deformation or the energy absorbed by the member, do not increase with a decrease in MC. Thus, toughness properties (total work and impact bending) decreased from green to air dry condition (Table 3).

Compression strength parallel and perpendicular to the grain changed relatively more than modulus of rupture and hardness which, in turn, changed more than modulus of elasticity and work to maximum load (Tables 2 and 3). The lower the MC, the higher the oven dry density and the higher were most mechanical properties of *H. abyssinica* (Table 3). Most of the mechanical properties were inversely related to MC below the fiber saturation point (FSP). This was also in agreement with Haygreen and Bowyer (1996) who observed a strong influence of MC on density. The higher the MC, the higher the density of timber (Tables 2 and 3) but this does not mean that it is stronger. This is because the density becomes higher since it holds more water.

Table 2 Mean mechanical properties and density of *H. abyssinica* at different moisture content levels.

Mechanical properties and density	Unit	Moisture content (%) levels							
		30	25	20	15	12	10	5	0
Modulus of rupture	N/mm^2	11	32	53	74	86	95	115	136
Modulus of elasticity	N/mm^2	5063	6313	7563	8813	9563	10063	11313	12563
Work to maximum load	mmN/mm^3	0. 0126	0. 0356	0. 0585	0. 0814	0.0952	0. 1044	0. 1253	0. 1503
Total work	mmN/mm^3	0. 0164	0. 0452	0. 0576	0. 1058	0.1237	0. 1356	0. 1654	0. 1952
Compression // to the grain	N/mm^2	6	16	27	37	43	47	58	68
Compression ⊥ to the grain	N/mm^2	1	2	4	5	7	6	8	9
Impact bending	Nm/m^2	2276	2686	3096	3506	6436	3916	4327	4737
Side hardness	N	2350	2774	3197	3621	3814	4044	4468	4891
Density	Kg/m^3	630	610	600	580	560	570	550	540

NOTE: // -Parallel to the grain; ⊥- perpendicular to the grain.

The ANOVA revealed that there was significant difference ($p<0.01$) between green and air dry results in MC, density and mechanical properties such as static bending, compression parallel and perpendicular to the grain, side hardness indentation and impact bending along height within and among the trees of *H. abyssinica*.

There was no significant difference in MC, density and mechanical properties along log length of bolts of the trees. The possible reasons for the insignificant difference of most physical and mechanical properties bolts along log length in this study could be attributed to the fact that the sample trees were similar. The other reasons could be that sample logs were selected from the same geographic region, altitude, climate (rainfall and temperature) and edaphic conditions and it was thus, possible that no genetic variation existed among the trees selected for the tests.

The results at 12% MC indicated an approximate linear relationship between density and mechanical properties, namely modulus of rupture, modulus of elasticity and compression strength along the grain and hardness indentation (Table 3). The correlation values between density and mechanical properties at 12% MC revealed moderate correlation for modulus of rupture, modulus of elasticity and compression strength along the grain and total work (Table 3). Side hardness indentation on both radial and tangential surfaces indicated high correlation with density. Work to maximum load and impact bending revealed very low correlation between density and mechanical properties. As the oven dry density increased so did most mechanical properties of *H. abyssinica*.

The interaction of physical and mechanical properties for this species has been determined by estimating the air dry density and mechanical properties at the moment of test in the range 30-0% MC (Tables 2 and 3). Removal of MC below FSP from *H. abyssinica* timber resulted in shrinkage whereby fibers became compact and increase in most of the mechanical properties was observed (Tables 2 and 3). The experiments revealed that MC significantly influenced the mechanical properties and density of the species. The effects of MC were markedly observed when the MC of the specimens was further reduced from the FSP.

Panshin and De Zeeuw (1980) stated that the removal of free water located in cell lumens held by weak forces had no effect on mechanical properties of timber; instead it was arrival at the FSP. At this state, the cells are not compact since there is much water in the lumens. Reduction of MC in the cell wall of wood (i.e., bound water) held more tightly by chemical forces (surface adsorption) have strong influence on properties of timber (Panshin and De

Zeeuw, 1980; Haygreen and Bowyer, 1996). The range of MC in wood influences mechanical properties, density, quality and resistance of wood against decay and bio-deteriorating agents (Haygreen and Bowyer, 1996). When wood is dried below FSP, the walls of individual cells become more and more compact and the fibers consequently become stronger and stiffer. Furthermore, as the volume of wood decreases, the specific gravity and mechanical properties of wood increases (Panshin and De Zeeuw, 1980; Gurfinkel, 1981; Haygreen and Bowyer, 1996). This would explain the observed increase in the values of mechanical properties with a decrease in MC. Thus, the mechanical properties and density at each level of MC is required for the specific application of the species.

Increment in mechanical properties is an implication for an increase in quality, durability and service life of the timber. This also implies that when planning structural design work and appropriate utilization of the species, it is important to consider the increase or decrease of properties, the extent and other influencing factors of density and mechanical properties.

The density varies with the amount of water held in it and has a pronounced effect on mechanical properties of the species (Tables 2 and 3). The nominal specific gravity (based on oven dry weight and green volume) of *H. abyssinica* at 12% MC was 0.56. This means that it is 0.56 times as heavy as pure water. The theoretical value above which 99% of the nominal specific gravity values of *H. abyssinica* will fall is 0.40 (Getachew Desalegn, 1989). This means that only 1% of the specific gravity values of the species will fall below 0.40, which is a good indication of design work and other purposes for utilization of the species. If the specific gravity value of *H. abyssinica* falls below 0.40, it is considered weak for structural work that involves carrying heavy load for a long period. Specific gravity indicates the lower limit for a species below which a specimen will be weak compared with the average material of that species (Desch, 1986).

Thus, when the mechanical properties of the species is stated, it is important to indicate the MC and density at which determination was made since the density of the species varies with the amount of water held in it. This is useful for comparison of density and mechanical property values and deciding on the appropriate utilization of the species at specific MC and environment for specific purpose.

Table 3 Comparison of mechanical properties and density change between green and air dry tests.

Condition	Density (Kg/m³)	Modulus of rupture (N/mm²)	Modulus of elasticity (N/mm²)	Work to maximum load (mmN/mm³)	Total work (mmN/mm³)	Compression // (N/mm²)	Compression ⊥ (N/mm²)	Impact (Nm/m²)	Side hardness (N)
Green (88%) MC	910	61	8500	0.0934	0.2013	26	4	11660	2939
Air dry (12% MC)	560	86	9563	0.0952	0.1237	43	6	5342	3814
Classification density and mechanical properties at 12% MC	Medium	Medium	Low	Medium	Low	Medium		Low	Medium
Correlation Coefficient (r)		0.4948	0.3671	0.0199	0.3516	0.2075		0.4112	0.7300; 0.627
Classification of r		Medium	Medium	Low	Medium	Medium		Low	High
Air dry (8% MC)	550	104	10625	0.1147	0.1480	52	7	6436	4168
Percentage change at 12% MC		41	13	2	-39	65	50	-45	30
Percentage change at 8% MC		70	25	23	-26	100	75	-53	42

NOTE: The relationships/correlations at 12 % MC between density and the respective mechanical property has been indicated as L= low correlation, M= moderate, H= high correlation between density and mechanical properties. The correlation values for hardness are for the radial and tangential directions, respectively.

Comparison of *H. abyssinica* timber with other timber species

Classification of density and mechanical properties at standard 12% MC for the species revealed that density and all mechanical properties fell in the medium range while impact bending and modulus of elasticity fell in the low range (Table 3). The results showed that *H. abyssinica* had lower density and hardness values when compared with the results of Bryce (1967) from Tanzania. It was, however, similar in the remaining properties.

The results of *H. abyssinica* timber at 12% MC were compared with nine hardwood and five softwood timber species (Table 4). Based on the values and standard classification of density and mechanical properties at 12% MC (Farmer, 1987), *H. abyssinica* was relatively similar to *Ocotea kenyensis, Podocarpus falcatus* and *Ekebergia capensis* in all mechanical properties and density. It was also comparable with *Trilepisium madagascariense* (formerly *Bosqueia phoberos*), *Albizia gummifera*, *Albizia schimperiana*, *Milica excelsa* (formerly *Chlorphora excelsa)* and *Juniperus procera*. However, it was lower in modulus of elasticity and impact bending properties. Compared to *Albizia species* and *M. excelsa,* it had high density and low impact values. *H. abyssinica* had high compression strength and side hardness values when compared with *J. procera*; it was also higher in density and all mechanical properties when compared with home grown exotic softwoods namely *Cupressus lusitanica, Pinus patula* and *Pinus radiata* (Table 4).

Comparative suitability values based on *H. abyssinica* was equal to 100 and with an accuracy of ± 10%, the density of which was similar to *Croton macrostachyus*, *Eucalyptus grandis*, *T. madagascariense*, *O. kenyensis*, *J. procera*, *P. falcatus*, *A. schimperiana*, *M. excelsa*, *Allophylus abyssinicus*, *A. gummifera*, *E. capensis*, *A. grandibracteata*, *Pouteria* (formerly *Aningeria*) *adolfi-friederici* and *Acrocarpus fraxinifolius* but it was higher than *Polyscias fulva*, *P. patula*, *P. radiata*, *Antiaris toxicaria*, *Cordia africana* and *C. lusitanica*. When considering bending strength (modulus of rupture), *H. abyssinica* was similar to *J. procera*, *P. falcatus*, *P. patula*, *P. radiata*, *A. schimperiana*, *C. macrostachyus*, *E. grandis*, *T. madagascariense*, *O. kenyensis*, *A. gummifera*, *E. capensis*, *A. grandibracteata*, *P. adolfi-friederici* and *A. fraxinifolius* but higher than *C. africana*, *P. fulva*, *A. toxicaria*, *M. excelsa* and *C. lusitanica*.

Table 4 Comparison of *H. abyssinica* timber with other timber species using density and mechanical property value at 12% MC.

No.	Potential timbers	Density (Kg/m³)	Modulus of rupture (N/mm²)	Modulus of elasticity (N/mm²)	Compression parallel (N/mm²)	Compression ⊥ (N/mm²)	Impact resistance (Nm/m²)	Side hardness (N)
1	*Albizia gummifera* [a]	580	85	12689	46	8	11331	4994
2	*Albizia schimperiana* [a]	530	80	12729	41	6	9254	3343
3	*Cordia africana* [b]	410	64	6996	29	4	6588	2213
4	*Cupressus lusitanica* [a]	430	64	6145	33	5	5888	2761
5	*Ekebergia capensis* [a]	580	96	9036	45	8	8076	4709
6	*Hagenia abyssinica* [c]	560	86	9563	43	7	6436	3814
7	*Juniperus procera* [d]	513	87	9081	38	4		1892
8	*Milica excelsa* [a]	570	74	8252	41	7	6050	3689
9	*Ocotea kenyensis* [a]	560	91	9163	44	7	8289	4281
10	*Pinus patula* [a]	450	73	8428	36	4	5187	2179
11	*Pinus radiata* [a]	450	77	8983	40	6	5624	3168
12	*Podocarpus falcatus* [a]	520	77	6704	40	7	4680	4081
13	*Pouteria adolfi-friederici* [a]	600	93	10029	46	8	8677	4535
14	*Trilepisium madagascariense* [a]	560	93	9997	44	7	8087	3693

a =WUARC (1995), b = Truneh Kide (1987), c = Getachew Desalegn (1997), d= Bryce (1967).
NOTE: Density (Kg/m^3) classification at 12% MC: exceptionally light< 300), light = 00-450; medium= 50-650; heavy = 650-800; very heavy = 80-1000; exceptionally heavy> 1000 (Farmer, 1987). Mechanical properties (N/mm²) classification at 12% MC are very low, low, medium, high and very high, respectively. Modulus of rupture: < 50, 50-85, 85-120, 120-175, > 175, respectively.
Modulus of elasticity: < 10000, 10000-12000, 12000-15000, 15000-20000 and > 20000, respectively.
Compression parallel to the grain: < 20, 20-35, 35-55, 55-85, > 85 (Farmer, 1987).

Based on observations of sawn wood and results of timber properties at 12% MC, the high quality *H. abyssinica* timber of the Shashmene (Gambo) area is recommended for decorative and artistic work, high-class furniture, cabinet making, light flooring, toys and novelties and especially for veneer owing to its attractive appearance, fine texture and color. This recommendation is in agreement with Getachew Desalegn (1997), MacLachlan *et al*., (2002) and Melaku Abegaz and Demel Teketay (2003). According to Bolza and Keating (1972), the products of *H. abyssinica* were also recommended for construction, joinery, lumber, tools, agricultural implements, utensils, bowls, cutting boards, fences, fuel wood, vehicle body, pulpwood, interior trim, core stock, hardboard and particleboard production.

CONCLUSIONS AND RECOMMENDATIONS

H. abyssinica is a very important species that provides timber with medium class density and mechanical properties as well as its decorative appearance and texture. Results revealed that there was significant difference ($p<0.01$) between green and air dry values in moisture content, density and most mechanical properties along height among trees of *H. abyssinica* timber. Most of the mechanical properties were inversely related to MC. However, MC and density did not affect all properties to the same extent. It varied from one property to other both within and among trees of *H. abyssinica*.

The results of *H. abyssinica* timber from green to air-seasoning condition of 12% MC revealed an increase in mechanical properties, 41% in modulus of rupture, 13% in modulus of elasticity, 2% in work to maximum load, 65% in compression parallel to the grain, 50% in compression perpendicular to the grain and 30% in side hardness indentation. Compression strength along and across the grain changed more relatively than modulus of rupture and hardness on side grain which in turn changed more than modulus of elasticity and work to maximum load. *H. abyssinica* was relatively better and comparable to *Ocotea kenyensis*, *Podocarpus falcatus* and *Ekebergia capensis* in all mechanical properties and density.

The results will have practical implication for the appropriate utilization of the species provided that *H. abyssinica* timber is used under protected conditions. Forest industries including saw-millers and joineries and other wood-using firms can use these results for defect-free material, which will be beneficial to those who select *H. abyssinica* from Shashmene (Gambo) and similar agroecological zones. Utilization of *H. abyssinica* wood without taking into consideration the basic timber properties and other limitations would be seen as waste of design, time, economy and resource (material).

Based on the results and development activities on *H. abyssinica*, the following points are recommended: (i) density is affected by MC and in turn both strongly affect its mechanical properties. Thus, it is wise to select the right density, mechanical property, dimension, rate and loading direction of wood when planning *H. abyssinica* timber for specific use at specific MC and environment; (ii) the current utilization trend has to abandon *H. abyssinica* and focus on alternative/substitute species until its resource base is well stocked and sustained in the country; and (iii) further applied research is recommended to cover all properties and the factors that determine/influence wood properties so as to improve its quality and rational utilization with immediate intervention of appropriate genetic material selection, adequate regeneration and silvicultural treatments. This will be relevant to fill the information gap for future development and rational utilization of this economically valuable and one of the top critically endangered species of Ethiopia.

ACKNOWLEDGEMENTS

The contributions of the following individuals has been acknowledged: Dr. Dag Rudin, Mrs. Helen Parker, Håkan Wennerholm, Dr. Alemu Gezahgne, Melaku Abegaz, Gunnar Rutegard, Negussie Jiru and Deshu Mamo. Thanks to the laboratory technicians Ms. Medhin Desta, Aysheshim Tebeje, Worku Fekadu, Mesekerem Reta, Gemechu Kaba, the late Wakgari Kebede, Abiy Getahun and Kassahun Guluma who very kindly assisted me during specimen preparation and conducting the tests by devoting their part time both day and night. Thanks to Abbas Kedir for his support in the data analysis work. Many thanks to all Forest Products Utilization Research Program (FPURP) staff, Shashemene Forestry Industry Enterprise and Wondo Genet College of Forestry.

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