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Wood Properties of Eucalypt Hybrid Clones Growing in Tanzania

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Abstract Wood properties of nine year old Eucalypt hybrid clones grown at Lushoto, Kibaha, Kwamarukanga and Tabora in Tanzania were studied. Nine trees, three from each superior clone type representing small, medium and large trees were selected from each site. Samples were taken at breast height (1.3 m), 25% and 50% of tree height using standard procedures. Results of the study revealed overall mean basic density and fibre length values of 525.5–633.9 kgm^{-3} and 0.857–0.969 mm respectively. Modulus of elasticity and modulus of rupture ranged from 8525.2 to 12710.4 Nmm^{-2} and 72.6 to 108.5 Nmm^{-2} respectively. The cleavage in the radial and tangential directions ranged from 13.5 to 20.6 Nmm^{-2} and 14.9 to 22.0 Nmm^{-2} respectively. Compression ranged from 41.9 to 57.2 Nmm^{-2} and 7.8 to 13.7 Nmm^{-2} for shear strength. It is concluded that studied clones should be considered as a source of raw materials for pulp and paper production and for structural applications.

Keywords Eucalypt hybrid clones, Basic density, Fibre length, Mechanical properties, Tanzania

1. Introduction

Eucalypt hybrid clones in Tanzania were introduced from Mondi South Africa in 2003 through Tanzania Forestry Research Institute (TAFORI) in order to test their adaptability in the Tanzanian environment before large scale planting. Experiments started in 2004 using *Eucalyptus grandis* x *E. camaldulensis* (GC), *E. grandis* x *E. urophylla* (GU), and *E. grandis* x *E. tereticornis* (GT) hybrid clones to test their adaptability in the Tanzanian environment before large scale planting. Ten (10) GC, one (1) GT and one (1) GU clones were planted at 15 trial plots established at different agro ecological zones of Tanzania. The clones are preferred for their fast growth with a short rotation, wide adaptability to site conditions, produce better quality wood and more uniform stands than most indigenous trees Eucalypt hybrid clones are mainly used in house construction, production of fuel wood, poles, telecommunication posts, fencing posts, electricity transmission poles, pulping and timber [1]. The suitability of raw wood for various uses is determined by its properties. Some of the important properties for the above end uses include basic density, fibre length and mechanical properties.

Wood basic density is one of the most often studied wood quality traits because it determines the economic value and is under high degree of genetic control [2]. It affects properties of various wood products such as pulp and paper, wood strength and wood quality [3]. On the other hand, mechanical properties of wood are an expression of its behaviour under applied forces. It refers to the ability of the material to resist external loads or forces tending to cause change in its size and alteration of its shape [4]. The uses to which wood is put require ability to resist loads and thus it is appropriate to examine the behaviour of wood when subjected to various forces. They are the most important characteristics of wood products for structural applications. Structural uses of wood and wood products include tie beams, purlins in house construction, floor joists and rafters in wood-frame housing, power line transmission poles, plywood roof sheathing and sub-flooring and glue laminated beams in commercial buildings.

Previous studies have found that hybrid Eucalypt clones generally have wood properties that are intermediate to their parental taxa [5-7] in Brazil, Kenya and Uganda respectively. Bal and Bektaş [8] studied the mechanical properties of *E. camaldulensis, E. urophylla* and *E. grandis* and found that the wood of the species had better mechanical properties which were within the specified range needed for plywood and furniture production. However, there are no available studies on physical and mechanical properties of wood of Eucalypt hybrid clones grown in Tanzania. The aim of this study was therefore to determine physical and mechanical properties of Eucalypt hybrid clones growing in Tanzania. The results from this study will be used as a basis

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of making recommendations which will lead to efficient utilization of clonal wood.

2. Material and Methods

Study Area

The study was conducted in four agro ecological zones namely Lushoto (Highland), Kibaha (Coastal), Kwamarukanga (Lowland) and Tabora (Inland Plateux) (Table 1). Lushoto site is located within Lushoto District, Tanga Region. Kibaha site is located in Ruvu North Forest Reserve, Pwani Region. Kwamarukanga site is located within Kwamarukanga Forest Reserve, Handeni District, Tanga Region. Tabora site is located within Tabora Municipality. Lushoto, Kibaha and Kwamarukanga sites have dry spell between June and September, short rains from October to December and long rains from March to May while Tabora receives long rains between November and April.

Experimental Design

The experiments were established by TAFORI in 2004 using Eucalypt hybrid clonal material from Mondi South Africa. Randomized complete block design with four replications and 12 treatments (Eucalypt hybrid clones) was used to set up these experiments at Lushoto, Kibaha and Kwamarukanga sites and 10 treatments at Tabora site (Table 2). Each clone type was represented once in each block. Each plot comprised 16 trees spaced at 2.5 x 2.5 m in a 4 x 4 arrangement. The experiments have 2 guard rows planted to avoid edge effect.

Sample selection

Lushoto, Kibaha, Kwamarukanga and Tabora sites were subjectively selected for data collection which represent other sites within the studied agro-ecological zones. Wood samples were obtained from three superior Eucalypt hybrid clones in terms of survival, Dbh, height, basal area, volume and biomass production *i.e* GC 581, GC 584 and GU 608 from Lushoto site; GC 15, GC 167 and GC 940 from Kibaha site; GC 514, GT 529 and GC 940 from Kwamarukanga site and GC 15, GC 584 and GC 940 from Tabora site. Purposive sampling was applied to select three sample trees (small, medium and large in Dbh) from each clone type and from each site. In total, 36 sample trees were felled and cut into logs for basic density, fibre length and mechanical properties determination.

Physical properties determination

Wood Basic Density

Stem sectional discs measuring 5 cm thick discs were taken from each log at different level at breast height (1.3 m), 25% and 50% of tree height. A wedge running from pith to bark was cut from each disk. Samples were cut at 25% and 50% of wedges' total length. Wood basic density was determined in accordance with procedure described in BS. 373 [9]. The basic density of wood was calculated using water displacement for green volume determination.

Table 1. Study area description

Site characteristics	Sites			
	Lushoto	Kwamarukanga	Kibaha	Tabora
Latitude (S)	04°47'12 04°47'15	06°35'	6°33'- 6°43'	30°
Longitude (E)	038°17'40 038°17'41	38°55'	38°48'- 39°03'	33°
Altitude (ma.s.l)	1393 – 148	70	104	1175
Mean annual rainfall (mm)	1070	1000	900	700 – 1000
Mean temperature (°C)	7 – 30	19 – 32	23 – 35	18 – 28
Soil Ph	4.4 – 4.5	3.8 – 4.7	4.5 – 4.9	4.8 – 6.2
Soil Organic carbon (%)	2.7 – 3.6	1.8 – 2.6	0.68 – 1.7	1.7 – 2.9
Soil texture	Sandy	Sand clay	Sandy	Sandy

Table 2. Experimental design of Eucalypt hybrid clones

Blocks	Eucalypt hybrid clones (Treatments)											
B4	GC 940	GC 14	GC 10	GC 167	GC 581	GC 584	GT 529	GC 796	GU 608	GC 15	GC 785	GC 514
B3	GC 14	GT 529	GC 796	GC 584	GC 15	GU 608	GC 514	GC 785	GC 10	GC 167	GC 940	GC 581
B2	GC 785	GC 15	GU 608	GT 529	GC 581	GC 940	GC 10	GC 14	GC 514	GC 796	GC 584	GC 167
B1	GC 10	GT 529	GC 581	GU 608	GC 514	GC 785	GC 14	GC 167	GC 584	GC 940	GC 796	GC 15

Fibre length

Fibre length were measured in wood samples macerated with a 1:1 solution of glacial acetic acid and hydrogen peroxide solution for about 60℃ for 48 hours for cell dissociation. Thirty straight and unbroken fibres from each sample were randomly selected for measurement using a projecting microscope to obtain a mean fibre length for each Eucalypt hybrid clone.

Mechanical properties determination

Sample preparation of test specimens

Each log was cross cut into three 1.5 m long billets at breast height (1.3 m), 25% and 50% of the tree height and each billet was sawn into 45 - 65 mm thick radial planks for easy air drying and labelled to indicate tree number and position in the tree. The cants were re-sawn radially into 30 mm x 60 mm x 1500 mm planks. Planks were air dried to about 12% moisture content and re-sawn into 20 x 30 x 1500 mm scantlings which were then planed to 20 mm x 20 mm x 1500 mm.

Determination of Modulus of Elasticity (MOE) and Modulus of Rupture (MOR) parallel to the grain

MOE and MOR were determined according to the standard procedures described by ISO 3349 [10] for MOE and ISO 3133 [11] for MOR. Specimens measuring 20 x 20 x 300 mm were taken and loaded using centre loading method to the Monsantor Tensiometer wood testing machine using a feeding speed of 0.635 mm/min and 500 kg deflection beam. Graph plotting was done manually following the mercury column along the scale in Newton. The load at which failure occurred was recorded on graph paper. MOR was calculated from the maximum load at which each specimen failed. MOE was calculated using load to deflection curve plotted on a graph by the machine. MOE and MOR were calculated using the following equations.

$$MOR = 3PL/2BD^2 \tag{1}$$

$$MOE = P^1L^3/4YBD^3 \tag{2}$$

Where P = Maximum load in Newton (N)
L = Span (mm)
P^1 = Load in Newton (N)
B = Width (mm)
D = Depth (mm)
Y = Deflection in mm at mid length at limit of proportionality

Determination of radial and tangential cleavage

Cleavage strength was determined according to the standard procedure described by Panshin and De Zeeuw [12]. Test specimens measuring 20 x 20 x 45 mm were taken and then mounted on the Monsanto Tensiometer machine with a loading speed of 2.5 mm/min and a beam of 500 kg. The graph was manually plotted by following the rise of the mercury along its column until failure occurred. Maximum cleavage load was recorded at the point of failure. Cleavage strength was calculated by using the following equation

$$\text{Cleavage strength} = P/B \tag{3}$$

Where P = Maximum load in Newton (N)
B = Width (mm)

Determination of compression strength parallel to the grain

Compression strength parallel to the grain was determined according to the standard procedure described by ISO 3787 [13]. Each test specimens measuring 20 x 20 x 60 mm was taken and loaded on a parallel grain basis to the Monsanto Tensiometer machine using a feeding speed of 0.635 mm/min and 2000 kg deflection beam. Then, the maximum crushing load was recorded by plotting the graph following the rise of the mercury in the column until failure occurs. The maximum crushing strength was then calculated from maximum crushing load and recorded in N/mm^2. Crushing strength was calculated using the following formula:

$$\text{Crushing strength} = P/A \tag{4}$$

Where P = Maximum load in Newton (N)
A = Cross-sectional area (mm^2)

Determination of shear strength parallel to grain

Shear strength parallel to grain test was determined according to the standard procedure described by ISO 3347 [14]. Each test specimen measuring 20 mm x 20 mm x 20 mm was taken and mounted on the Monsanto Tensiometer machine with a 2000 kg deflection beam and a speed of 0.635 mm/min were used. Maximum shear strength was recorded graphically straight from the rise of the mercury along the column until failure occurred. Shear strength was calculated using the following equation:

$$\text{Shear strength} = P/A \tag{5}$$

Where P = Maximum load in Newton (N)
A = Area in shear (mm^2)

Statistical Analysis

Data were analysed using SAS software Version 9.1 for Windows. Analysis of variance (ANOVA) was done to compare wood basic density, fibre length, MOE, MOR, Cleavage, compression and shear strength parallel to grain between Eucalypt hybrid clones. Significant clone means were separated by Duncan's Multiple Range Test (DMRT).

3. Results and Discussion

Wood basic density

Wood basic density ranged from 525.5 to 633.9 kgm^{-3} among the evaluated clones (Table 3). Clone GC 584 and GC 581 had significantly higher basic density values than GU 608 at Lushoto site. Wood of GC 940 and GC 15 at Kibaha site had significantly higher ($p<0.05$) basic density values than GC 167. However, there were no significant differences in basic densities between clones from Kwamarukanga and Tabora sites. On the other hand, the average fibre length ranged from 0.857 mm to 0.969 mm for all clones (Table 3). Fibre length differed significantly ($p<0.05$) between clones at Kwamarukanga, Kibaha and Tabora sites. However, no significant difference in fibre length was recorded for clones at Lushoto site.

The examination of table 3 show that the mean basic density of the studied clones varied between clones within a site. The differences might be a result of differences in the anatomy of wood such as vessel characteristics, type of cells, their proportions and arrangements as well as the accumulation of extractives in heartwood from individual hybrids [7, 15]. It may also be affected by intrinsic differences in growth rates of the individual trees sampled in Kenya [6]. The studied hybrid clones show basic density similar to other Eucalypt clones of 7-9 year-old [6, 7, 16, 17] in Kenya, Uganda, India and Brazil respectively. However, study results are slightly higher than those reported by Zanuncio et al. [18] for 7 year-old for *E. urophylla* clone. The present values are within the range reported for pulp and paper production *i.e* 480 to 650 kg m^{-3} [19, 20], 400 - 750kg m^{-3} timber for structural use [21] in Uganda and higher than 500 kgm^{-3} ideal for charcoal production [17, 22] in Brazil. According to FAO [23] wood with basic density less than 400 kg/m^3 at 12% MC are termed as weak, 401 to 500 kg/m^3 fairly strong; 501 to 640 kg/m^3 strong; 641 to 800 kg/m^3 very strong and more than 801 kg/m^3 exceptional strong. Based on the FAO standards, all studied eucalypts clones are under the range of strong strength category indicating that they are potential for timber at age of 9 years.

Table 3. Wood basic density and fibre length of 9 year old Eucalypt hybrid clones

Site	Treatment	Basic density ($kg\ m^{-3}$)	Fibre length (mm)
Lushoto	GC 581	572.9d	0.925b
	GC 584	587.8d	0.934ab
	GU 608	525.5e	0.954a
Kibaha	GC 15	585.9b	0.921d
	GC 940	598.5b	0.969c
	GC 167	532.9c	0.942d
Kwamarukanga	GC 514	633.9a	0.959e
	GC 940	593.1a	0.898f
	GT 529	616.7a	0.916f
Tabora	GC 584	537.1f	0.857h
	GC 940	532.1f	0.942g
	GC 15	540.6f	0.922g

Values followed by the same letter within column are not significantly ($p<0.05$) different based on DMTR.

On the other hand, the fibre length values of Eucalypt hybrid clones as revealed in this study compares well with findings reported for *E. grandis* × *E. urophylla* hybrid trees [16, 24], *E. grandis* parent trees [25] from India, *E. camaldulensis* clones and other *E. camaldulensis* trees from Brazil [5] whose fibre length ranged between 0.95 mm to 1.06 mm. Findings in this study were higher than mean fibre length of 0.67 mm to 0.75 mm for Eucalypt hybrid clones [26] in India, 0.72 mm to 0.81 mm for Eucalypt clones and 0.70 mm for *E. camaldulensis* [27] in Morocco. According to Miranda et al. [20] and Jorge et al. [28] Eucalypt clones with fibre length between 0.87 to 1.04 mm are suitable for pulp and paper production, therefore wood of the clones studied are therefore suitable for pulp and paper production.

Mechanical properties

Modulus of Elasticity (MOE) and Modulus of Rupture (MOR)

The overall means of MOE and MOR across the four studied clones ranged from 8525.2 to 12710.4 Nmm^{-2} and 72.6 to 108.5 Nmm^{-2} respectively (Table 4). ANOVA results indicated significant ($p<0.05$) difference in MOE values for Eucalypt hybrid clones growing at Kibaha and Kwamarukanga sites. However, there were no significant differences in mean MOE for clones at Lushoto and Tabora sites. In addition, MOR differed significantly ($p<0.05$) between clones at Kwamarukanga site. No significant difference in MOR was recorded for clones at Lushoto, Kibaha and Tabora sites. GU 608 growing at Lushoto site showed higher MOR values than GC 581 and GC 584 while GT 529 growing at Kwamarukanga site showed higher MOR than GC 940 and GC 514. However, GC 940 at Kibaha site showed higher MOR values than GC 167 and GC 15 while GC 940 growing at Tabora had higher mean MOR values than GC 167 and GC 584.

Table 4. MOE and MOR of 9 year old Eucalypt hybrid clones in four sites

Site	*Treatment*	*MOE ($N\ mm^{-2}$)*	*MOR ($N\ mm^{-2}$)*
Lushoto	GU 608	10252.8a	100.7a
	GC 581	9620.2ab	89.5a
	GC 584	8880.3b	92.2a
Kwamarukanga	GT 529	11498.5c	108.5b
	GC 514	10368.9cd	92.5c
	GC 940	9110.4d	72.6d
Kibaha	GC 15	12701.4e	74.9e
	GC 940	8525.2f	83.6e
	GC 167	9096.3f	74.4e
Tabora	GC 584	9048.9g	95.2f
	GC 940	8960.7g	96.5f
	GC 15	9090.4g	91.3f

Values followed by the same letter within column are not significantly ($p<0.05$) different based on DMTR.

MOE of Eucalypt hybrid clones studied compare favourably with some Eucalypt hybrid clones and other *Eucalyptus* species. For instance, 7866 to 15080 Nmm^{-2} for Eucalypt clones and 8335 to 11892 Nmm^{-2} for *E. grandis*, *E. tereticornis*, *E. camaldulensis* and *E. saligna* for local landraces in Kenya [6]. Olufemi and Malami [29] reported MOE for *E. camaldulensis* (9048.49 to 19388.71 Nmm^{-2}) and *E. paniculata* (12100 Nmm^{-2}) in Nigeria. GT 529 and GC 581 had the highest MOR values, implying that they can withstand relatively higher bending stresses while in service.

These findings were supported by Thelandersson and Hansson [30] who reported that MOR values of 93.4 Nmm^{-2} can withstand relatively higher bending stresses while in service. Based on Kityo and Plumptre, [21] classifications, MOE ranged from 6860 to 14700 N mm^{-2} and MOR of 39 to 132 Nmm^{-2} are suitable timber for structural applications. Wood of Eucalypt hybrid clones studied had MOE values within the specified ranges and thus can be used for making structural elements such as tie beams, rafters and purlins in house construction.

Radial and Tangential Cleavage

The mean cleavage strength values in the radial and tangential directions for Eucalypt hybrid clones from all studied sites are presented in Table 5. The overall mean radial cleavage strength ranged from 13.5 to 20.6 N mm^{-2} while tangential cleavage strength ranged from 14.9 to 22.0 Nmm^{-2}. Wood of studied clones at Tabora site showed higher cleavage strength in radial and tangential directions for GC 584 and GC 15 respectively.

Table 5. Radial and Tangential Cleavage strength of wood of 9 year old Eucalypt hybrid clones from four sites

Sites	Treatments	Cleavage	
		Radial	Tangential
Lushoto	GC 581	15.9a	14.9b
	GC 584	15.8a	19.1a
	GU 608	13.5a	15.6b
Kwamarukanga	GC 514	19.9b	19.9c
	GC 940	16.6b	16.7c
	GT 529	19.2b	20.4c
Kibaha	GC 15	16.99c	20.2d
	GC 940	17.2c	18.9d
	GC 167	16.5c	17.2d
Tabora	GC 584	20.6d	21.4e
	GC 940	15.6e	16.5f
	GC 15	18.2de	22.0e

Values followed by the same letter within a site and column are not significantly ($p<0.05$) different based on DMTR.

There were significant ($p<0.05$) differences in cleavage strength in the radial direction for wood of clones at Tabora site and significant ($p<0.05$) differences in tangential cleavage strength for wood from Lushoto and Tabora sites. Findings revealed that, tangential cleavage from Eucalypt hybrid clones wood was higher than in radial direction. This was probably due to the relationship between air-dry density and the cleavage strength of timber along the fibres [31]. The results were confirmed by Moya and Muñoz [32] and Ismaili et al. [33] that, cleavage strength at tangential direction possessed higher strength than radial direction for both green and an air-dry condition. The cleavage strength values obtained in this study are similar to those reported by Turinawe et al. [7], who documented cleavage strength ranging from 18 to 20 Nmm^{-2} for Eucalypt hybrid clones and 16 to 33 Nmm^{-2} for *E. camaldulensis* in Uganda.

Compression and shear strength parallel to grain

The results for compression and shear strength parallel to grain are presented in Table 6. The overall compression strength (CS) and shear strength values of studied Eucalypt hybrid clones across all sites ranged from 41.9 to 57.2 Nmm^{-2} and 7.7 to 13.7 Nmm^{-2} respectively. Significant ($p<0.05$) difference in CS was observed for clones at Tabora site. Wood from Lushoto site showed the lowest and highest mean CS values for GU 608 and GC 581 respectively. Wood of clones growing at Kwamarukanga site showed the lowest and highest mean CS values for GT 529 and GC 514 respectively. Wood from Kibaha site showed the lowest and highest mean CS values for GC 167 and GC 15 respectively. However, wood from Tabora site showed the lowest mean CS values for GC 15 and highest mean CS values for GC 584 and GC 940. ANOVA showed significant ($p<0.05$) differences in shear strength between Eucalypt hybrid clones in all sites. Clone GC 581 and GC 584 growing at Lushoto site showed significantly higher shear strength values than GU 608. Clone GT 529 showed significantly higher mean shear strength values than GC 514 and GC 940 for Kwamarukanga site while GC 940 showed significantly higher mean shear strength values than GC 15 and GC 167 at Kibaha site. GC 15 and GC 584 showed significantly higher mean shear strength values than GC 940 at Tabora site.

Table 6. Compression and Shear strength parallel to grain of 9 year old Eucalypt clones

Site	Treatment	Compression Force (N mm^{-2})	Shear at MC (N mm^{-2})
Lushoto	GC 581	57.2a	13.2a
	GC 584	57.2a	13.1a
	GU 608	56.6a	11.5b
Kwamarukanga	GC 514	50.4b	9.3d
	GC 940	50.3b	7.9e
	GT 529	49.7b	11.6c
Kibaha	GC 15	53.2c	11.2g
	GC 940	50.7cd	13.7f
	GC 167	46.9c	9.9g
Tabora	GC 584	48.8e	11.3h
	GC 940	46.2e	10.2i
	GC 15	41.9f	11.6h

Values followed by the same letter within a site and column are not significantly ($p<0.05$) different based on DMTR.

Eucalypt hybrid clones have shown compression strength similar to those reported by Moya and Muñoz [32]; Acosta et al. [34]. The mean compression strength of this study was somewhat greater than those reported previously by Lima et al. [35] for 8 year old Eucalypt clones and 20 year old *E. camaldulensis* in Nigeria [36]. According to Muga et al. [6], Eucalypt hybrid clones have significantly higher compression strength values than *E. grandis* and *E. tereticornis* progenies in Kenya. The results showed significant shear strength between clones within a site. This could be attributed to genetic differences and other localized site factors. Madsen [37] found that, the shear strength does appear to be affected somewhat by moisture content between green and air-dry condition. Shear strength values obtained in this study are in keeping with results reported by Santos et al. [17]; Lima and Garcia [38] with shear strength values ranged from 10.7 to 13.8 Nmm^{-2} for *E. grandis* and *E. resinifera*. Wood from GC 584 and GC 581 at Lushoto site and GC 940 at Kibaha site have good shear values implying that they could be used as substitutes for structural purposes where toughness is desired.

4. Conclusions

There were significant variations in wood basic density between clones at Lushoto and Kibaha sites while at Kwamarukanga and Tabora sites showed no significant variation. Significant variation in fibre length was observed for Eucalypt hybrid clones at Kibaha, Kwamarukanga and Tabora sites while Lushoto site showed no significant difference. On the other hand, mechanical properties values for the studied Eucalypt hybrid clones meet the minimum requirements needed for different structural applications. Wood properties values obtained in this study placed Eucalypt hybrid clones wood at a better position of suitability enabling the wood to compare favourably with other Eucalypt clones and *Eucalyptus* species for pulp and paper and timber for structural use. Therefore, it can be concluded that, Eucalypt hybrid clones should be considered as source of raw materials for pulp and paper production, timber for structural use and for structural elements.

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