Variation in Wood Properties of Eucalyptus Hybrid Clones and Local Landraces Grown in Kenya

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Abstract
The wood properties of 5 to 6 years old *Eucalyptus grandis* X *E. camaldulensis* hybrid clones (GC) and local landraces of *E. grandis. E. tereticornis, E. camaldulensis and E. saligna* were studied at 4 sites in Kenya. Physical properties were determined using samples obtained at various heights, namely mechanical properties on butt logs and calorific values at tree DBH (diameter at breast height). Standard procedures of determination of wood properties were used. Results showed that site had significant effect (P<0.001) on basic density except in GC 15. The calorific values ranged from 4.9 to 5.1 for GCs and 4.9 to 5.0 for landraces. The mean Modulus of Elasticity (MOE) ranged from 7866 to 15080 MPa for GCs and 8335 to 11892 MPa for landraces. The mean Modulus of Rupture (MOR) ranged from 87.9 to 129.4 MPa for GCs and 67.9 to 106.7 MPa for landraces. The mean compression strength, shear strength and surface hardness varied significantly (P<0.05) with sites and tree type. It was concluded that at age 5 to 6years, wood from the GCs had the same or higher density, MOE, MOR, surface hardness, shear and compression strength, but the same or lower moisture content and volumetric shrinkage, compared to the landraces grown under similar conditions. However, the clones and landraces were similar in calorific values.

Keywords**: Eucalyptus, clones, mechanical properties, calorific value, wood density**

Introduction

Clonal forestry has been practiced in Kenya since 1996. Experiments were started in 1999 at seven sites: Karura, Hombe, Machakos, Timboroa, Embu, Laikipia and Naivasha to test the adaptability of *Eucalyptus grandis* Maid x *Eucalyptus camaldulensis* Dehn hybrid (GC) clones from South Africa. However, Laikipia and Naivasha sites were written off in 2000, due to severe game damage and harsh conditions, respectively. Eight GC clones were planted at these sites. Four local species, *E. grandis, Eucalyptus tereticornis* Sm, *Eucalyptus camaldulensis and Eucalyptus saligna* Smith were also included in the trials for comparative analysis.

It was expected that the clones would be suitable for withies at 2 years, fuelwood and building poles at 3 to 4 years, transmission poles at 6 to 8 years and timber at 10 years and above. The suitability of raw wood for various uses is determined by its properties. Some of the important properties for the above end uses include density, moisture content, mechanical properties and calorific value. It is therefore important to understand the variation in these properties between genotypes, different environments where trees were planted and the extent of genotype X environment interaction for improvement of wood quality (Panshin and de Zeeuw, 1980; Bowyer *et al.*, 2003). Understanding the patterns of variation within a tree provides useful information for tree improvement, wood processing and utilization. It was therefore necessary to evaluate these properties in order to give farmers and potential users the right information on the most appropriate end uses of the introduced hybrids.

Initial studies on wood properties had been done for seven hybrid clones and three local landraces at Karura when trees were four and half years old (Muga and Muchiri 2006). The results of this study showed that wood from GC clones had the same or higher density, crushing strength, Modulus of Elasticity (MoE), Modulus of Rupture (MoR), surface hardness and calorific values as the local landraces (Muga, 2003). However, it was yet to be established if site factors and the position on the stem would have any significant effects on the wood properties. The objectives of the study were to:

- Determine variation in moisture content and wood density with tree height among the GC clones and sites;
- Determine variation in the MoE, MoR, crushing strength, shear strength, surface hardness, calorific value and shrinkage amongst the hybrid clones and sites; and
- Compare properties of the hybrid clones with those of the local landraces growing under similar conditions.

Materials and Method

The wood samples were obtained from eight GC clone trees 5 to 6 years old (GC 3, GC 10, GC 12, GC 14, GC 15, GC 522, GC 581 and GC 642) and four local landraces of the same age ((*E. grandis* (EG), *E. tereticornis* (ET), *E. camaldulensis* (EC) and *E. saligna* (ES)) at four experimental sites (Hombe, Embu, Machakos and Timboroa). The trials had three blocks and six trees per plot. One tree, (with diameter in the median range) per hybrid/local landrace was obtained from each site. From each tree, two 50-mm thick discs were obtained at various heights (0, 1.3, 4.8 and 9.6 m). From each disc, samples were obtained from bark to bark and used for the determination of basic density, green density, moisture content and shrinkage. The oven dry method was used for determination of basic density and moisture content (*Equation* 1 and *Equation* 3). The unit shrinkage was evaluated at the radial, tangential and longitudinal planes using *Equation 4* and total volumetric shrinkage computed by getting the sum of these three values. The disc at DBH of each tree was used for the preparation of samples for the determination of calorific values. An Adiabatic Bomb Calorimeter model 1013-B was used for calorific value tests. Calorific values were computed using formula in *Equation 7*. Strength tests were done on a universal strength testing machine (500 KN) using small clear specimens from butt logs prepared as per British Standard (BS 373) (Lavers, 1969). Tests were carried out at the Forest Products Research Centre, Kenya Forestry Research Institute (KEFRI).

Basic density = Oven dry weight/green volume (gcm^{-3}) -----------------------------*Equation 1*
Green density = Green weight/green volume (gcm^{-3}) ---------------------------------*Equation 2*
Moisture content = [Green weight-Oven dry weight/Oven dry weight] x100%---*Equation 3*
Percentage shrinkage =[(decrease in dimension)/original dimension] x 100%----- *Equation 4*
Modulus of rupture (MOR) = $3\ PL/2bd^2$ (MPa) ------------------------------------- *Equation 5*
Modulus of elasticity (MOE) = $P`L^3/4\Delta bd^3$ or $EL^3/4bd^3$ (MPa) ------------------ *Equation 6*
Where: b = width of specimen, d = thickness of specimen, l = loading span and span deflectometer,
P` = Load at Limit of Proportionality and P = maximum load

Calorific value ($Kcalg^{-1}$) = [water equivalent (g) x (rise in temperature ^{o}C+ water quantity of inner cylinder (g)) - correction value]/ Weight of sample (g) ----------------- *Equation* 7

Where: the correction value is the sum of the calorific values for the tissue paper and ignition wire used for in the test.
The water equivalent was computed as follows: -

Water equivalent = [calorific value of benzoic acid ($kcalg^{-1}$) x weight of Benzoic acid (g) – Water quantity of inner cylinder (g)]/ Rise in temperature ^{o}C

Sample means were used for the two-way analysis of variance using Statistical Programme for Social Scientists (SPSS) Version 11.

Results and Discussion

Moisture content

Moisture content (MC) is important when wood is purchased on a weight basis. It varies considerably among species and within a species depending on location, age, season of harvest and tree size] (Bowyer *et al* 2003**).** Variation in MC with site and with tree height at 0, 4.8 and 9.6 m are reported in Table 1 and Figure 1, respectively. The overall mean MC for trees and sites was 92.2 % ranging from 76.4 % for GC 14 at Embu to 122.3 % for *E. grandis* (EG) at Timboroa. GC 12, GC 3 and GC 642 had the highest overall mean MC, while GC 14, GC 15 and GC 10 had the least among the hybrids. GC 12 had higher mean than local landraces, except for *E. saligna*. GC 3, GC 642 and GC 581 had higher mean MC than *E. camaldulensis* (EC) and *E. tereticornis* (ET). Samples from Timboroa had the highest overall MC (100.9 %), while those from Embu had the least (86.7 %). There was a general tendency for MC to decrease with tree height for some local landraces and to decrease and then increase in *E. grandis*, GC 12, GC 581 and GC 15. However, in all the other cases, MC at the tree butt was higher than that at the top, except for GC 522 and GC.

Table 1. Moisture content of Eucalyptus GC hybrid clones and local landraces at four sites

Landrace/ Clone	Embu	Machakos	Hombe	Timboroa	Overall Mean
EC	83.4	-	100.6	-	92.0
EG	92.6	84.6	85.1	122.3	96.1
ES	78.3	94.9	109.4	121.2	101.0
ET	99.7	-	92.4	84.5	92.2
GC 581	85.1	95.1	92.9	101.3	93.6
GC 14	76.4	-	83.2	93.8	84.5
GC 642	86.3	104.2	87.4	103.8	95.4
GC 15	91.6	93.8	79.3	84.1	87.2
GC 10	-	89.8	87.5	-	88.6
GC 12	-	99.5	-		99.5

GC 522	-	99.0	85.4	-	92.2
GC 3	-	-	-	95.9	95.9
Overall mean	86.7	95.1	90.3	100.9	93.3
Std. Deviation	14.7	15.0	13.8	21.3	16.2
Coefficient of variation (%)	16.9	15.8	15.3	21.2	17.4

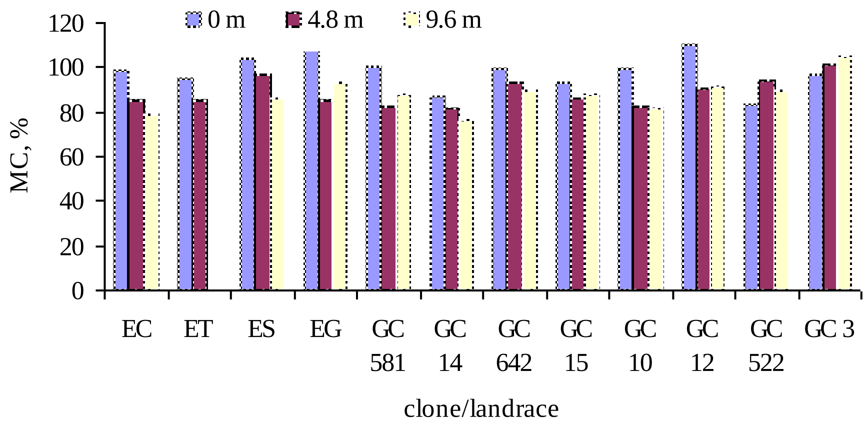


Figure 1. Variation of moisture content of Eucalyptus GC hybrid clones and local landraces.

Density

The lowest mean basic density was that of *E. grandis* at Machakos (0.45 gcm^{-3}) while the highest was that of GC 15 (0.60 gcm^{-3}) at Timboroa (Table 1). The basic density of hybrid clones was generally higher than that for local landraces although some were lower or the same. All the hybrids had higher basic density than *E. saligna* (0.48 gcm^{-3}) and *E. grandis* (0.45 gcm^{-3}). These results indicate that GC clones and local landraces were light to moderately heavy (Chikamai *et al*., 2006). The basic density values for *E. saligna* (0.48 gcm^{-3}) and *E. camaldulensis* (0.54 gcm^{-3}) are slightly lower than those of 19-year-old trees of the same species at Turbo (0.52 gcm^{-3} and 0.59 gcm^{-3}), respectively) (Muga and Githiomi, 1996).

All the hybrid clones studied had comparable green density (0.98-1.05 gcm^{-3}) to that of *E. tereticornis* (1.04 gcm^{-3}) and *E. camaldulensis* (1.04 gcm^{-3}), but higher than that for *E. saligna* (0.88 gcm^{-3}) and *E grandis* (0.95 gcm^{-3}).

Basic and green densities varied significantly (P<0.001) among the GC clones and local landraces. Results of Tukey's pairwise comparison indicated that all the hybrid clones, except GC 12 had basic density significantly higher than that of *E. grandis*. All the hybrid clones, *E. camaldulenis, E. tereticornis* and *E. saligna* had higher green density than *E. grandis.* The basic and green density of *E.camaldulenis, E. tereticornis,* GC 15, GC 10 and GC 14 were higher than that of *E. saligna*.

Site had significant effect (P<0.05) on the basic density of all the hybrid clones and local landraces except GC 15, and green density of all the hybrid clones and local species except *E. camaldulensis* and *E. tereticornis.* The higher density for *E. tereticornis* (0.54 gcm^{-3}) and *E. camaldulensis* (0.54 gcm^{-3}) than that of *E. saligna* (0.48 gcm^{-3}) and *E. grandis* (0.45 gcm^{-3}) and variation within sites were probably due to intrinsic differences in growth rates of the individual trees sampled. Generally, *E. saligna and E. grandis* have higher growth rates than the other local landraces.

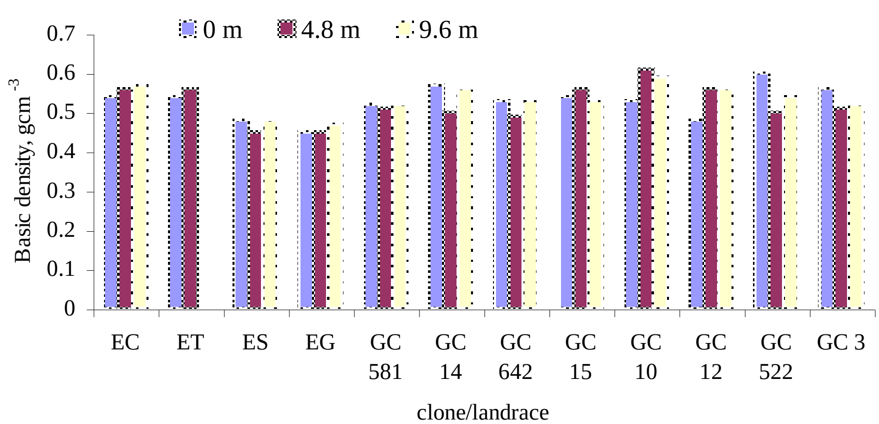
A general linear model showed significant effect (p<0.05) of the interaction of height*site and site*tree type on basic and green densities. However, the interaction of height*site*tree type did not have any significant effect on green and basic densities. The basic density of the wood from the 6 year old Eucalyptus GC clones and local landraces was the same or higher than that for mature *Cupressus lusitanica* Mill (0.3-0.49 gcm^{-3}) and *Pinus patula* Schlect. & Cham, (0.3-0.49 gcm^{-3}), (Bryce, 1967; Chudnoff, 1984; Prospect database 1997). *Cupressus lusitanica* is the main commercial timber species in Kenya.

Table 2. Variation in Basic Density (BD) and Green Density (GD) Eucalyptus GC hybrid clones and landraces at 4 sites

Landrace/ Clone	Site								Overall mean	
	Embu		Machakos		Hombe		Timboroa			
	BD (gcm^{-3})	GD (gcm^{-3})	BD (gcm^{-3})	GD (gcm^{-3})	BD (gcm^{-3})	GD (gcm^{-3})	BD (gcm^{-3})	GD (gcm^{-3})	BD (gcm^{-3})	GD (gcm^{-3})
EC	0.57	1.05	-	-	0.51	1.03	-	-	0.54	1.04
EG	0.45	0.85	0.41	0.76	0.47	0.88	0.47	1.04	0.45	0.88
ES	0.43	0.76	0.52	1.01	0.48	0.99	0.47	1.04	0.48	0.95
ET	0.51	1.02	-	-	0.54	1.03	0.58	1.06	0.54	1.04
GC 581	0.49	0.90	0.51	0.99	0.54	1.04	0.49	0.98	0.51	0.98
GC 14	0.52	0.91	-	-	0.56	1.03	0.54	1.05	0.54	1.00
GC 642	0.51	0.96	0.48	0.97	0.56	1.04	0.52	1.06	0.52	1.01
GC 15	0.51	0.97	0.54	1.04	0.59	1.06	0.60	1.04	0.56	1.03
GC 10	-	-	0.55	1.03	0.57	1.05	-	-	0.56	1.04
GC 12	-	-	0.52	1.03	-	-	-	-	0.52	1.03
GC 522	-	-	0.50	0.99	0.55	1.01	-	-	0.53	1.00
GC 3	-	-	-	-	-	-	0.54	1.05	0.54	1.05
Overall mean	0.50	0.93	0.50	0.98	0.54	1.02	0.53	1.04	0.52	0.99
[3]Sd	0.05	0.10	0.07	0.11	0.06	0.07	0.08	0.04	0.07	0.08
[4]Cv	10.00	10.90	13.80	11.60	10.40	6.90	15.70	4.10	12.50	8.30

Range for hybrids: 0.40 – 0.71 gcm^{-3} (BD); 0.74 – 1.20 gcm^{-3} (G.D)

Range for local species: 0.36 – 0.66 gcm^{-3} (BD) and 0.63 – 1.16 gcm^{-3} (GD)



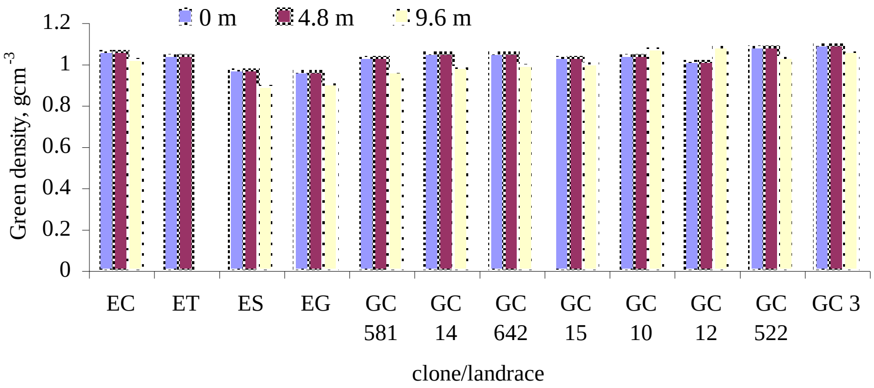


Figure 2. Variation of basic and green density of Eucalyptus GC hybrid clones and local landraces.

Shrinkage

Wood dries below the fibre saturation point (28-30 %) resulting in loss of bound water and it shrinks. Conversely, as water enters the cell wall structure, the wood swells. This dimensional change is a completely reversible process in small pieces of stress free wood but may not be completely reversible in large pieces of wood because of internal drying stresses. Table 3 shows that the radial shrinkage was moderate to large, while tangential shrinkage was fairly large to large (Prospect database, 1997). The high shrinkage could probably be due to a high proportion of tension wood (Washusen *et al*, 2002). The results obtained are comparable to those obtained for *E. grandis* at 10-25 years old which were 0.45 %, 6.1 % and 10.4 % for longitudinal, radial and tangential planes, respectively (Silva *et al*, 2006). The tangential shrinkage values are comparable to those for *E. globules (*12%) and for *E. maidenii (*10%) but lower than for *E. nitens* (17%) (McKinley *et al*, *2002*). The ratio of tangential and radial shrinkage was highest for GC 522 (2.56) and lowest for *E. camaldulensis* (1.15) (Table 3). GC10, GC 14, GC 15 and GC 642 had values higher than those for all the four local landraces. *E. grandis* and *E. saligna* had values higher than those for GC 12, GC 3 and GC 581 (Table 4). The ratio of tangential and radial shrinkage of *E. grandis* in this study (1.63) is similar to(1.71) reported by Silva *et al,* (2006).

E. camaldulensis, *E. tereticornis* and *E. saligna* tended to have higher or the same volumetric shrinkage values than all the hybrid clones. However, GC 522, GC 581, GC3, GC10 had much lower values as compared to the local species. The volumetric shrinkage values obtained are comparable to those of *E. globulus* (18.9 %) and *E. nitens* (15.6 %) (Rozas, *et al*, 2003). The differences in the volumetric shrinkage values could be attributed to possible differences in wall proportion, ray parenchyma proportion, and micro fibril angle (YiQiang *et al*, 2006).

The high shrinkage requires careful drying of the wood to avoid excess loss and special design features in finished products to allow for the movement that is likely to be encountered. As long as the high unit shrinkage is taken into account, high quality products can still be manufactured. The high shrinkage can be reduced by debarking 80 % of the trees' circumference 24 months before felling (Acar *et al*, 1979). This can reduce the proportion of tangential and radial shrinkage to about 1%.

Table 3. Mean shrinkage values for Eucalyptus GC hybrid clones and local landraces at four sites

Landrace/ Clone	Longitudinal Shrinkage (%)	Radial Shrinkage (%)	Tangential Shrinkage (%)	Tangential/ Radial ratio (%)	Volumetric Shrinkage (%)
EC	0.9	10.4	12.0	1.15	23.2
EG	0.6	7.8	12.7	1.63	21.1
ES	0.6	8.9	13.6	1.53	23.1
ET	0.9	9.4	13.3	1.41	23.6
G.C 10	0.2	4.9	10.5	2.14	15.6
GC 12	0.4	9.4	12.4	1.32	22.2
GC 14	0.7	7.8	12.8	1.64	21.3
GC 15	0.5	7.5	12.4	1.65	20.4
GC 3	0.5	6.2	9.0	1.45	15.7

GC 522	0.3	4.1	10.5	2.56	14.9
GC 581	0.4	6.8	8.9	1.31	16.1
GC 642	0.5	6.8	12.1	1.78	19.4

Mechanical properties

Mechanical properties of wood refer to its resistance to imposed loads or forces. Mechanical properties of wood are most important when wood and wood products are used for structural building applications. Structural uses of wood and wood products include 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 (Haygreen & Bowyer, 1989). The mechanical properties of hybrid clones (GC) tended to be same or higher in stiffness (MOE) and bending strength (MOR) as compared to the local species (Tables 4 and 5). Compression strength, shear strength and surface hardness varied significantly ($P<0.05$) with sites and hybrid clones/landrace. Samples from Hombe had higher compression strength, shear strength and surface hardness than those from the other sites. The hybrids tended to be same or higher in compression strength, shear strength and surface hardness in comparison to the local landraces.

Based on the classification by Chikamai *et al.*, (2006, the wood of GC hybrid clones varied from strong to very strong, while that of the local landraces was moderately strong to strong. Most of the hybrids fall in strength groups S_2 and S_3 and compare well in MOR with mature *Eucalyptus globulus* Labill (106.3 MPa), *E. saligna* (110.6 MPa), *Acacia melanoxylon* R.Br. (108.3 MPa), *Milicia excelsa* (Welw.) *C.C* Berg (101.8 MPa) and higher than *Cupressus lusitanica* (68 MPa). The local landraces were in S_3 and S_4 categories indicating that, the wood of 5 to 6 years old hybrid GC clones and local landraces studied can be used for construction poles and posts (Bengough, 1971; Chikamai *et a*l., 2006). The relatively higher wood strength properties of the hybrids are due to higher basic density, which is in line with results of studies by Bowyer *et al* (2003); and Panshin and de Zeeuw, (1980)**.**

Calorific values

From Tables 6 and 7, samples from from Hombe had the highest overall mean calorific value (5.00 kcalg^{-1}) while those from Machakos had the least (4.94 kcalg^{-1}). However, these differences were not significant indicating that site and tree type (hybrid or local landraces) did not affect the caloric value of the wood.

The calorific values of hybrids were relatively higher than those of mature *Acacia. mearnsii* (3.5-4.0 kcalg^{-1}) and *A. melanoxylon* (4.31 kcalg^{-1}), and similar to those of mature *A. nilotica* (4.8-4.95 kcalg^{-1}), *E. grandis* (4.97 kcalg^{-1}), *E. saligna* (4.95 kcalg^{-1}) and *E. globulus* (4.8 kcalg^{-1}).

Table 4. Overall Mean Modulus of Elasticity (MOE) and Modulus of Rupture (MOR) Eucalyptus GC hybrid clones and local landraces

Species/clone	*N*	*Mean MOE (MPa)*	*S.D*	*C.V (%)*	*Mean MOR (MPa)*	*S.D*	*C.V (%)*
EG	**4**	**10,674.3**	**1,352.0**	**12.7**	**96.8**	**8.2**	**8.4**
ES	4	9,522.7	**1,459.4**	**15.3**	**92.8**	**11.6**	**12.5**
ET	4	9,453.7	**382.0**	**4.0**	**79.9**	**17**	**21.3**
EC	2	9,222.3	**772.0**	**8.4**	**99.1**	**3.7**	**3.7**
GC 3	1	11,120.4	**-**	**-**	**110.8**	**-**	**-**
GC 10	2	12,016.4	**2,573.3**	**21.4**	**116.9**	**14.2**	**12.1**
GC 12	1	15,079.8	**-**	**-**	**127.0**	**-**	**-**
GC 14	1	11,607.9	**2,856.4**	**24.6**	**110.8**	**18.2**	**16.5**
GC 15	4	11,173.8	**2,369.3**	21.2	109.9	13.8	12.6
GC 642	4	10,144.2	2,101.6	**20.7**	**98.6**	**10.1**	**10.2**
GC 522	2	9,231.2	**977.9**	**10.6**	**98.1**	**3.2**	**3.3**
GC 581	4	11,258.5	**1,025.2**	**9.1**	**103.8**	**10**	**9.6**

Table 5. Mean MOE and MOR for Eucalyptus GC hybrid clones and local landraces for each site

Site	Timboroa		Embu		Hombe		Machakos	
Property	MOE	MOR	MOE	MOR	MOE	MOR	MOE	MOR
Mean (MPa)	9,553.5	93.1	10,233.1	98.4	10,977.2	108.5	11,837.1	107.3
Sd	1,187.3	12.24	1,396.0	9.4	2,376.2	15.5	1,839.7	13.2
Cv (%)	12.4	13.15	13.6	9.6	21.7	14.3	15.5	12.3

Table 6. Mean calorific values (kcalg^{-1}) for Eucalyptus GC hybrid clones and local landraces across sites (C.V-Coefficient of variation and S.D-Standard deviation)

	Tree type

Statistics	ES	ET	EG	EC	GC 14	GC 581	GC 642	GC 15	GC 3	GC 10	GC 522
Mean	4.96	5.00	4.97	4.86	4.95	5.04	4.94	4.95	4.87	5.07	5.13
Sd	0.07	0.05	0.14	0.02	0.05	0.06	0.09	0.03	-	0.03	0.03
Cv (%)	1.4	1.0	2.9	0.4	1.10	1.1	1.9	0.7	-	0.6	0.6

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Table 7. Overall mean calorific values (kcalg^{-1}) for Eucalyptus GC hybrid clones and local landraces for each site (C.V-Coefficient of variation and S.D-Standard deviation)

Site/statistic	Timboroa	Hombe	Embu	Machakos	Overall mean
Overall Mean	4.98	5.01	4.96	4.94	4.97
Sd	0.12	0.15	0.07	0.06	0.10
Cv (%)	2.3	2.9	1.4	1.2	2.1

Conclusion

From the results, the following conclusions were made:

- Eucalyptus hybrid clones have the same or higher basic and green densities than local landraces. In addition they have the same or lower moisture content than the local landraces grown under similar conditions. Butt logs tend to have higher moisture content than logs from middle and top of the trees except in GC 3 and GC 522;
- Variation in density for GC hybrid clones and local landraces with tree height is sma;
- Site has an effect on the basic and green density of GC hybrids and local landraces. Trees grown in Hombe and Timboroa generally have higher densities than those in the other sites, except for *E. saligna* and GC 642. Samples from Embu tend to have lower densities except for *E. camaldulensis.* Site has an effect on moisture content of the wood of the hybrids and the local landraces. Samples from Timboroa generally had higher moisture content than those from the other sites except for GC 15 and *E. tereticornis*;
- The interaction of height, site and site tree type seem to have an effect on basic and green densities of the hybrids and the local landraces. However, the interaction of height*site*tree type has no effect on their green and basic densities;
- GC hybrids are the same or higher in all strength properties tested [MOE (stiffness) and MOR (bending strength), shear strength, compression strength and surface hardness than the local landraces grown under similar conditions. The interaction of site*tree type seem to have an effect on shear strength, compression strength and surface hardness of the hybrids and the local landraces. Wood from trees grown in Hombe tends to have higher values for these strength properties than those from the other sites while those from Embu tend to have lower values;
- Eucalyptus hybrid clones and local landraces have similar calorific values irrespective of site; and
- Eucalyptus hybrid clones have lower or similar volumetric shrinkage compared with the local species.

Recommendation

It is recommended that further studies be carried out at 10 years.

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