

**PHYSICAL AND NATURAL DURABILITY PROPERTIES OF PLANTATION GROWN  
ANOGEISSUS LEIOCARPA AND EUCALYPTUS CAMALDULENSIS IN THE  
SAVANNAH ECOLOGICAL ZONE, GHANA**

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**Abstract:**

*Physical properties of wood have significant influence on its natural durability and resistant to biodegradable factors while in service. Wood as a valuable and multipurpose renewable natural resource therefore is liable to degrade as biological agents may alter its behaviour, with negative effects on some of the physical and durability properties. As such, the major characteristics that validate wood adaptability for commercial utilization in the construction and furniture industries includes the physical and natural durability properties. The physical and natural durability properties of plantation grown exotic timber species (Anogeissus leiocarpa and Eucalyptus camaldulensis) were determined in accordance to BS 373 and EN 252 standards. Wood samples were prepared from three stem heights (butt, mid and top) as well as the heartwood and sapwood for the test. The results from the study showed that, moisture content increased from butt to the top. Where as the density decreased from the butt to the top. In terms of volumetric swelling, the tangential direction records the highest percentage, followed by the radial and the longitudinal direction. Percentage mass loss instigated by termites and other biodeteriorating agents was generally low as the decay intensity was not severe. The exotic timber species in-service would be highly resistant against termite attacks. As such, Anogeissus leiocarpa and Eucalyptus camaldulensis woods can be recommended for use in the furniture industry.*

**Key words:** moisture content, density, dimensional stability, biodeterioration, plantation grown timber.

**INTRODUCTION**

The high demand for commercial tropical timber species has momentarily contributed to the depletion of large areas of forest cover throughout the world (Amankwah et al. 2021). It is however acknowledged that, diversifying the forest resources is an indispensable way of ensuring their sustainability (Afele et al. 2022). As such, many developed countries adopted and expanded rapidly the area of plantations of fast-growing exotic species for use. The market impetus arising from the shortage of fodder, fuelwood and round wood for rural development activities also created the awareness of the need for tree planting in most developing countries. Financial support by donor agencies played a key role in stimulating the establishments of forest plantations in most tropical African countries (Uzu et al. 2022).

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It follows that, exotic timber species are planted throughout tropical Africa mainly in agroforestry development programs, for reduction of soil erosion, run-off control to combat desertification and rehabilitation of degraded lands. They also contribute to the production of fuelwood, sawn timber and in some cases for pulp and paper production (Appiah-Badu et al. 2022). The total area of tree plantations in the sub-Saharan region is about 21% of plantations (FAO 2003; Sarfo-Adu 2021). These plantations forest are mainly exotic species which has been extensively planted. As a result, exotic timber species dominate most of the forest plantations. The interest of forest plantation in Ghana dates back to the 1920s as timber is one of its most readily available resources (Kombat & Chen 2022). The general policy at the time was to plant mainly indigenous species in the high forest zone. The few exotic species that were planted in these zones were introduced mainly for fuelwood near large population centers and to fuel boilers for electricity generation or for mining use (Amankwah et al. 2021). However in the Savannah and dry semi-deciduous forest zones, a large number of exotic species were planted from 1951 to supply sawn, poles and fuelwood (Mensah et al. 2022). There has since been a substantial increase in the establishment of forest plantations over the last decade in the country.

Accordingly, forest plantations in the Northern part of the country in the Savannah ecological zone is estimated to cover 2,553 hectares and were primarily established for fuelwood production and environmental protection (Nero & Asuenabisa 2023). This zone therefore, is well endowed with magnanimous uncharacterized matured plantations timber species that when harnessed will forestall the under production, job losses and collapse of some wood processing and manufacturing industries due to lack of raw materials. Since, the material properties of most of these abundant plantation grown exotic timber species can be comparable to the commercial hardwoods that are in extinction (Appiah-Kubi et al. 2019).

But these matured plantation grown exotic timber species are not proficiently put to use in that, there is insufficient study on their material properties (Kyerem-Boateng & Marek 2021). As a result, most of these timber species have not been characterized and therefore cannot be recommended for effective and efficient use in the construction and furniture industries. Coupled with the high demand for commercial tropical timber species have not only reduced wood availability, but contributed greatly to making wood products too expensive in the Savannah ecological zone. This development does not in any way contribute to sustainable industrialization and growth in the ecological zone and the country at large.

Besides, the unutilized overgrown matured plantation timber species are instigating dramatic changes in the habitat as the matured trees covered a lot space from the earth's surface leading to restriction of activities of the forestry personnel. In perilous storms, the overgrown trees often suffer damage and fall in between the matured trees leading to most areas of the forest easily getting burned by bush fires during the harmattan seasons (Asori et al. 2020). All these negative ecological impacts have not only made the regular upkeep of the plantations forest extremely difficult but expensive as well. Their non-usage does not facilitate their full contribution to Ghana's national development agenda. These coupled with the depletion of the natural forest calls for an urgent need to drastically shift from the current attention of only relying on the tropical hardwoods in order to enhance the pattern of timber utilization in the country without further delay.

The quest therefore to minimize the extinction of the primary commercial timber species in the forest and to improve industrialization and sustainable development in Ghana is to encourage the usage of the plantation grown exotic timber species (Asamoah et al. 2023). Their utilization will in no doubt lessen the demand on the few commercial primary species. It will also serve as a major incentive for the woodworkers and the construction firms in the zone to rely on locally available raw materials for their construction activities, probably at comparatively low cost. The need therefore, for the usage of the exotic plantation grown timber species for construction is very much on the increase as they are sustainable, renewable, fast growing, pest free and good for reconversion for manufacturing purposes.

However, their acceptability in the wood manufacturing and construction industries is extremely possible when their material properties are determined and made known for stakeholders to appreciate their utilizable characteristics. The provision of scientific knowledge on the physical and natural durability properties of the plantation grown exotic timber species is therefore indispensable for recommending their wood for construction and furniture production. This is necessary, due to the fact that, wood service life is largely limited due to its susceptibility to destruction by biological agents.

Among the numerous exotic timber species in the forest plantations within the Savannah ecological zone are *Anogeissus leiocarpa* and *Eucalyptus camaldulensis*. These species are generally long-lived and evergreen that belongs to the Fabaceae and Myrtaceae family respectively. *Anogeissus leiocarpa* is locally known as kane and *Eucalyptus camaldulensis* known as white oak. They are exotic timber species, native to tropical regions of Asia and are widely used as medicinal plants (Salih et al. 2020; Stackpole et al. 2011). Currently, the wood of *Anogeissus leiocarpa* and *Eucalyptus camaldulensis* are structurally used only for fencing and thatch roofing. But they are locally exploited for wide range of non-timber products such as fodder, medicine, fire wood, charcoal, farm input handles and planted as ornamental plants on the streets as well as around government departments in the Savannah zones. According to Lata et al. (2023) and

Maqsood et al. (2023) *Anogeissus leiocarpa* and *Eucalyptus camaldulensis* fit into patterns of rapid growth, and most importantly are considered promising for reforestation, reaching 30-60 and 40-70 meters in height respectively. Undoubtedly, diversifying their use will in no small way improve wood supply for the timber sector in Ghana. The aim of this study therefore, was to determine the physical and natural durability properties of two plantation grown exotic timber species (*Anogeissus leiocarpa* and *Eucalyptus camaldulensis*) in the Savannah ecological zone.

## MATERIALS AND METHODS

### Materials

The materials used for this study was obtained from the Tamale plantation reserve in the Savannah ecological zone Ghana. Five (5) mature plantation grown *Anogeissus leiocarpa* and *Eucalyptus camaldulensis* trees each were sampled for the study. The age of the plantation timber species was about 53 years. Purposive sampling technique was adopted based on, the diameter at the breast height greater than 60cm, the overall straightness of the trunk and defect free in order to minimize tree-to-tree variation. Trees with similar diameters (61-65cm) at breast height (1.3m) from the ground level were felled with the aid of a chain saw. The merchantable length of the clear bole of each tree was measured and divided into three equal parts and labelled as butt, mid and top for the bottom, middle and top portions respectively.

### Determination of Physical Properties

Preparation of the wood test specimens was carried out at the Tamale Technical University Wood and Architectural Technology workshop. The physical properties, thus percentage (%) moisture content, oven-density, percentage (%) volumetric shrinkage and swelling were determined in accordance to British Standards BS 373 (1957). Using clear samples from a stem sectional discs extracted from the middle portion of each section of the three axial locations (butt, mid, and top) and radial locations (heartwood and sapwood) of each tree. For the physical property, a total of nine-hundred (900) cubes (20mm x 20mm x 20mm) were planed, trimmed and carefully cut out of both heartwood and sapwood portions for the physical properties' determination of each species {i.e. (30 samples x 3 stem sections (butt, mid and top) x 5 trees x 2 wood portions (heart and sap) = 900}. During the cross-cutting of each strip into the required length, a pencil mark was place on the face to enable easy identification of the three directional sections of each cube. After the preparation of the test specimen, they were immediately weighed on an ELE International digital electronic balance with precision 0.001g to obtain the initial mass (Fig. 1).

The initial weight of the wood specimens was determined and oven-dried at 103±°C until constant mass was obtained. Moisture content of the specimens were then determined using the formular:

$$\text{Percentage (\%)} \text{ Moisture Content} = \frac{\text{Initial weight of wood} - \text{Oven dry weight of wood}}{\text{Oven dry weight of wood}} \times 100 \quad (1)$$

For the determination density at 12% MC, the specimens of each species were oven-dried at 103±1°C to constant weight and conditioned to 12% MC in constant humidity atmosphere for their oven-dry masses to be determined. The samples were then cooled in desiccators and reweighed on the electronic balance. The procedure was repeated until constant weight was obtained as the final weight, and the oven-dry density for each sample was calculated using the formular:

$$\text{Density} = \frac{\text{weight of oven-dry wood (kg)}}{\text{volume of wood (m}^3\text{)}} \quad (2)$$

where: Volume of wood = Length x Width x Height

In terms of wood shrinkage, square strips were extracted from the three axial locations (butt, mid and top) for all trees. Clear samples were obtained for each wood species and dried at room temperature for 21 days before the specimens were then oven dried at varied temperatures as they were weighed periodically and their dimensional changes in length, width and thickness were moitored by using a micrometer screw gauge in the radial and tangential directions and digital veneer calipers to the nearest 0.001mm in the longitudinal direction. It follows that, shrinkage due to drying at various stages, thus from green to oven-dry 12% moisture content state were calculated for the tangential, radial and longitudinal dierctions using formular:

$$\text{Percentage (\%)} \text{ Volumetric Shrinkage} = \frac{\text{Initial volume of wood(dimensiuni)} - \text{Final volume of wood}}{\text{Initial volume of wood}} \times 100 \quad (3)$$

To determine the percentage volumetric of swelling, oven dried samples were soaked in clear water for about 72 hours in order to allow the specimens to get soaked and submerge in the water. And a digital veneer calipers was used to take various measurements. Thus, tangential, radial, and longitudinal sections of each sample were measured with a pair of digital calipers and the volumetric swelling determined using the formular:

$$\text{Percentage (\% Volumetric Swelling)} = \frac{\text{Final volume of wood} - \text{Initial volume of wood}}{\text{Initial volume of wood}} \times 100 \quad (4)$$

This experimental study was carried out at the at the Timber Mechanics and Furniture Testing laboratory of the Council for Scientific and Industrial Research (CSIR) of the Forestry Research Institute of Ghana (FORIG), Kumasi – Ghana.



**Fig. 1.**  
**Cubes packaged for weighing on scale (A), saturated samples removed from water for volume measurements (B).**

### Determination of Natural Durability

For the graveyard test, stakes from both the heartwood and sapwood portions obtained from three stem sections (butt, mid, and top) of each tree were prepared from the billet sampled from the timber species. The test specimens were critically examined to ensure that they are clear specimens and free from both natural and artificial defects. Each billet was further converted into lumber stripes and air-dried to an appreciable moisture content for machining. A total of one-hundred and eighty (180) test specimen were planed and cut into 500mm x 50mm x 25mm for both heartwood and sapwood portions of each species for the natural durability determination {i.e. (6 specimen x 3 stem sections (butt, mid and top) x 5 trees x 2 wood portions (heart and sap) = 180)}. The natural durability analysis followed the standard procedures of EN 252, (2014).

All the specimens were first labelled with a permanent marker and then weighed using an electronic balance. The final weight of each test specimens was appropriately recorded, and then inserted into the soil to cover one third of their length at the termite prone demonstration field of the Faculty of Renewable Natural Resources, Kwame Nkrumah University of Science and Technology, Kumasi - Ghana. Cutlass was used to remove the vegetation predominantly made of long and creeping grasses. The test specimens were arranged in the field with a spacing of 50cm x 60cm as the distance between columns and rows respectively for twelve (12) months of field exposure (Fig. 2). According to Acheampong (2013), the demonstration site lies within the semi-deciduous vegetation zone [6° 40'N and 1° 33'W] with moderate temperature (25°C) and high relative humidity of 83%. The site soil is not only dominantly made up of Ochrosol soil, but contains many termite mounds and has a high decay hazard index. According to Usher (2020), *Anobium* spp., *Ancistrotermes* spp. and *Nasutitermes latifrons* are among the common subterranean termites that are on the site.

The site was inspected quarterly to observe the rate of attack without tempering the stakes in order not to district the activities of the termites on the test specimens. After the set period (one year), the test specimens were harvested, thoroughly cleaned with a brush to remove the sand particles and dirt before they were oven dried at 105±°C for 72 hours. The test specimens were weighed at every 12 hours intervals

until a constant weight was obtained as the final weight. This weight was used to estimate the percentage mass loss to the nearest 0.001g to find out the degree of degradation.

**Percentage (%) mass loss was determined as follows:**

$$\text{Percentage (\%)} \text{ Mass loss} = \frac{\text{Initial weight} - \text{Final weight}}{\text{Initial weight}} \times 100 \quad (5)$$

where:

Initial weight = Final weight before exposure

Final weight = Final weight after exposure

### Visual Degradation Rating

After 12 months of field exposure, all the test specimens were carefully examined to ascertain the potency of termite's attack. The ratings follow CEN (2005) /TS, 15083-1 standard (Table 1).

Table 1

<i>Visual durability rating</i>		
Rating	Description	Definition
0	sound	No evidence of attack by bio-degrader
1	Slight attack	Limited evidence of attacks by bio-degraders
2	Moderate attack	Significant evidence of attacks by bio-degraders
3	Severe attack	Strong evidence of attacks by bio-degraders
4	Failure	Total failure



a



b



c



d

**Fig. 2.**

**Test specimens labelled and buried at the graveyard, *Anogeissus leiocarpa* (A, B) and *Eucalyptus camaldulensis* (C, D).**

### STATISTICAL ANALYSES

Variance of the physical properties between heartwood and sapwood within trees stem height was analyzed, and percentages recorded. One-way repeated measure analysis of variance (ANOVA) was conducted to test the significance levels of mean values at confidence level ( $p < 0.001$ ). A follow up test was done by Duncan Multiple Range Test for where there is significant difference among means. Descriptive statistics consisting of means with standard deviations were presented for each tree section used for the study. The statistical tool used for the analyses was SigmaPlot version 14.0.

## RESULTS AND DISCUSSION

### Physical properties of plantation grown *Anogeissus leiocarpa* and *Eucalyptus camaldulensis* Percentage (%) moisture content (MC)

The amount of moisture in wood is termed moisture content, expressed as a percentage of its dry weight. According to Horbelt et al. (2021), the actual amount of water varies between tree species and within individual trees depending on location, age, harvesting season, and tree size. Apparently, changes in wood moisture content lead to changes in the strength, density and durability. Table 2 reports the variance of percentage (%) moisture content and oven-dry density of *Anogeissus leiocarpa* and *Eucalyptus camaldulensis*. Moisture content percentage (%) in wood helps in determining the water retaining nature of the wood, and its effects on the overall strength and performance of the wood material.

It was observed that the mean moisture content of all the five trees of the plantation grown *Anogeissus leiocarpa* recorded overall mean percentage of 41.39 ( $\pm 3.96$ ) and 67.08 ( $\pm 1.55$ ) for the heartwood and sapwood portions respectively. The sapwood portions recorded higher values than that of the heartwood. These values are in line with Kaba and Desalegn (2020) findings, who stated that the moisture content of *Eucalyptus* species may range from 43-75% due to variations in site and the seasons of felling.

Among all the species, the heartwood recorded less % MC than the sapwood portions. Moisture content varied along the bole of both species. The variation of the moisture content within and between species was slightly low (Table 2) Since the timber samples were subjected to the same period of seasoning, results affirm that *Eucalyptus camaldulensis* has the highest moisture content than *Anogeissus leiocarpa*.

### Density at 12% moisture content

Density is the most significant physical property in the characterization of wood for furniture and other constructional purposes. The average mean axial density variation of plantation grown exotic timber species is reported in Table 2. Mean oven-dry density of all the sampled *Anogeissus leiocarpa* and *Eucalyptus camaldulensis* trees was 724.74kg/m<sup>3</sup> and 589.93kg/m<sup>3</sup> respectively. Stem position and wood portions were found to be significant sources of variation of the mean oven-dry density. The heartwood portions of the exotic timber species had higher density values (818.51kg/m<sup>3</sup> and 629.09kg/m<sup>3</sup>) than the sapwood portions (630.97kg/m<sup>3</sup> and 550.76kg/m<sup>3</sup>) for *Anogeissus leiocarpa* and *Eucalyptus camaldulensis* respectively, signifying good strength and durability for construction purposes. The analysis of variance revealed that differences between average oven-dry densities of the species studied were highly significant at P <0.001. This strongly suggests that there was significant differences between the heartwood and sapwood portions, as well as along the axial direction of all the trees. The density of the plantation grown timber species studied decreases from the bottom portion of the trees to the top portion (Fig. 3) The higher density at 12% moisture content in *Anogeissus leiocarpa* wood could be related to the lowest percentage moisture content and low percentage shrinkage than the *Eucalyptus camaldulensis*. The heartwood axial portion of wood tissues are characterized by high density compared to the sapwood portions. The density values of the species could be classified as *heavy* and *medium-heavy* for *Anogeissus leiocarpa* and *Eucalyptus camaldulensis* respectively. By knowing the densities of these two species, it may in a way assist in predicting the wood strength density is closely related to end-use quality (Kaba & Desalegn 2020). Appiah-kubi et al. (2014) also contended that, density is a key factor that influences the wood strength.

The plantation grown *Anogeissus leiocarpa* and *Eucalyptus camaldulensis* timber species were classified as *heavy* and *medium-heavy* hardwood timber, which are comparable to many tropical hardwoods such as, odum (*Milicia excelsa*), danta (*Nesogordonia papaverifera*), edinam (*Entandrophragma angolense*), asanfen (*Aningeria spp*), ofram (*Terminalia superba*), and emire (*Terminalia ivorensis*) which are mostly used for furniture construction in Ghana (Ayarkwa 1998). Based on their density class, their potential usages may include furniture construction, cabinet making, as well as other general usage.

Table 2

### Variability of % moisture content and density of *Anogeissus leiocarpa* and *Eucalyptus camaldulensis*

Species	Rdial Portion	Physical properties	
		%Moisture Content	Density (kg/m <sup>3</sup> )
<i>Anogeissus leiocarpa</i>	Heartwood	41.39 ( $\pm 3.96$ )	818.51 ( $\pm 13.53$ )
	Sapwood	67.08 ( $\pm 1.55$ )	630.97 ( $\pm 20.79$ )
	Average	54.24 ( $\pm 2.76$ )	724.74 ( $\pm 17.16$ )
<i>Eucalyptus camaldulensis</i>	Heartwood	66.61 ( $\pm 4.66$ )	629.09 ( $\pm 14.04$ )
	Sapwood	82.01 ( $\pm 3.68$ )	550.76 ( $\pm 13.46$ )
	Average	74.31 ( $\pm 4.17$ )	589.93 ( $\pm 13.75$ )

Average means value and standard deviation in parentheses

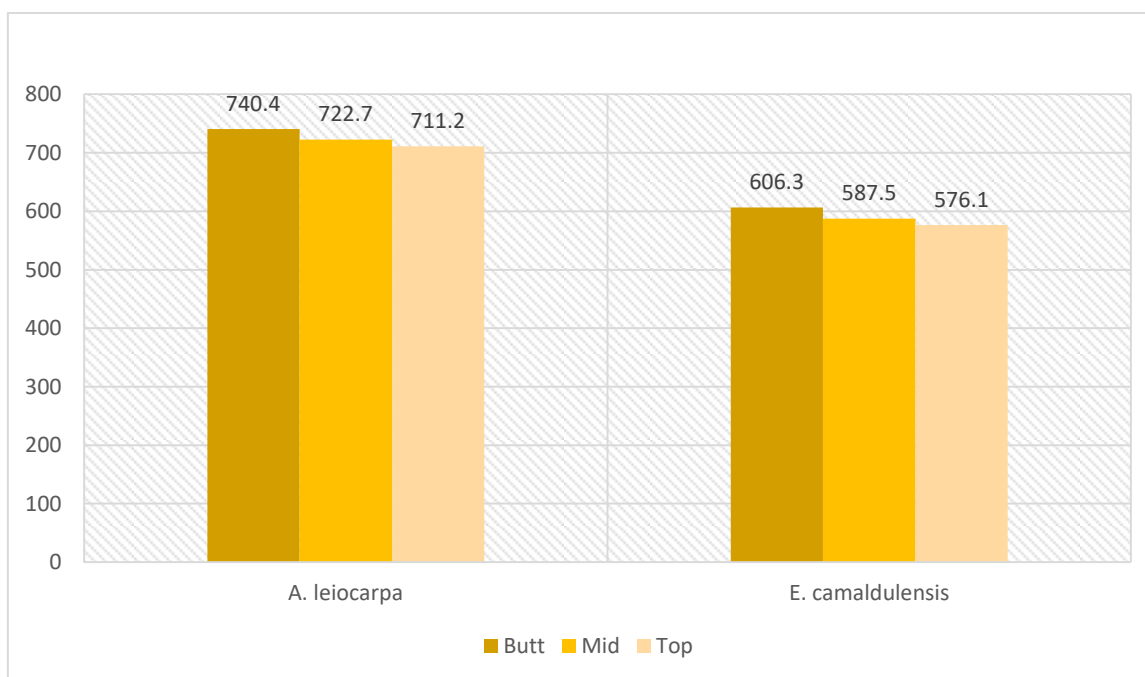


Fig. 3.

**Axial Density Variation of Plantation Grown *Anogeissus leiocarpa* and *Eucalyptus camaldulensis*.**

### Dimensional Stability

Wood is dimensionally unstable when moisture content is less than the fiber saturation point. At this point, wood changes dimension as it gains moisture (swells) or loses moisture (shrinks), because volume of the cell wall depends on the amount of bound water. This shrinking and swelling can result in warping, checking, and splitting of the wood, which in turn can lead to decreased utility of wood products. This property has important practical consequences for the use of wood because variations in ambient relative humidity and temperature during processing and in-service result in moisture content changes. It is therefore very important to understand and consider the dimensional stability of wood before it is used for artifacts that will be exposed to large moisture fluctuations in service.

It follows that, wood as an anisotropic material shrinks or swells in the direction of the annual growth rings (tangentially), about half as much across the rings (radially), and only slightly along the grain (longitudinally) Presented in Table 3 is the average longitudinal, radial, tangential percentage (%) volumetric shrinkage and swelling of the plantation grown *Anogeissus leiocarpa* and *Eucalyptus camaldulensis* species investigated. *Anogeissus leiocarpa* recorded 1.9%, 12.3% and 8.2% shrinkage values in the longitudinal, tangential and radial directions respectively. Whereas shrinkage values of *Eucalyptus camaldulensis* recorded 0.7%, 15.6% and 9.9% for longitudinal, tangential and radial respectively. The result showed that, volumetric shrinkage was high in the tangential direction, follows by the radial and the longitudinal directions marginally in both species. This is in conformity of the study by Taha et al. (2020) who stated that average values for shrinkage from green to oven-dry are between 0.1% and 0.2% for most species of wood in parallel to grain, thus lengthwise.

In terms of swelling, *Eucalyptus camaldulensis* had the significantly highest swelling (0.9%, 16.7%, 10.3%) as compared to *Anogeissus leiocarpa* (0.2%, 11.7%, 10.1%) for the longitudinal, tangential and radial directions respectively. This implies that, *Eucalyptus camaldulensis* possesses high ability to shrinkage than *Anogeissus leiocarpa* wood when used outdoor and in high temperature conditions. The percentage of shrinkage for *Eucalyptus camaldulensis* wood was rated as *high*, whilst the percentage of shrinkage for *Anogeissus leiocarpa* wood was rated as *average*. The shrinkage rating for these plantations grown timber species was based on the percentage shrinkage in the tangential direction from green to air dry. These dimensional stability values are favorable in terms of comparing them with most of the tropical hardwoods that are used in the furniture industries. Such characteristics were considered by Effah et al. (2014) as appropriate for furniture production.

Table 3

**Dimensional stability of *Anogeissus leiocarpa* and *Eucalyptus camaldulensis***

Species	Tree portion	Volumetric Shrinkage (%)			Volumetric Swelling (%)		
		L <sub>s</sub>	T <sub>s</sub>	R <sub>s</sub>	L <sub>sw</sub>	T <sub>sw</sub>	R <sub>sw</sub>
<i>Anogeissus leiocarpa</i>	h	2.4 (±0.014)	10.1 (±0.014)	6.7 (±0.008)	0.1 (±0.000)	9.7 (±0.007)	8.4 (±0.008)
	s	1.4 (±0.013)	14.5 (±0.016)	9.7 (±0.010)	0.3 (±0.002)	13.7 (±0.010)	11.8 (±0.009)
	Average	1.9 (±0.014)	12.3 (±0.015)	8.2 (±0.009)	0.2 (±0.001)	11.7 (±0.009)	10.1 (±0.009)
<i>Eucalyptus camaldulensis</i>	h	0.6 (±0.001)	14.4 (±0.010)	9.2 (±0.011)	0.8 (±0.001)	15.5 (±0.011)	9.5 (±0.011)
	s	0.8 (±0.002)	16.8 (±0.009)	10.6 (±0.009)	1.0 (±0.002)	17.9 (±0.010)	11.0 (±0.009)
	Average	0.7 (±0.002)	15.6 (±0.010)	9.9 (±0.010)	0.9 (±0.002)	16.7 (±0.011)	10.3 (±0.010)

h: heartwood, s: sapwood, L<sub>s</sub>: longitudinal shrinkage, T<sub>s</sub>: tangential shrinkage, R<sub>s</sub>: radial shrinkage, L<sub>sw</sub>: longitudinal swelling, T<sub>sw</sub>: tangential swelling, R<sub>sw</sub>: radial tangential  
Average means value and standard deviation in parentheses.

**NATURAL DURABILITY**

**Percentage Mass Loss**

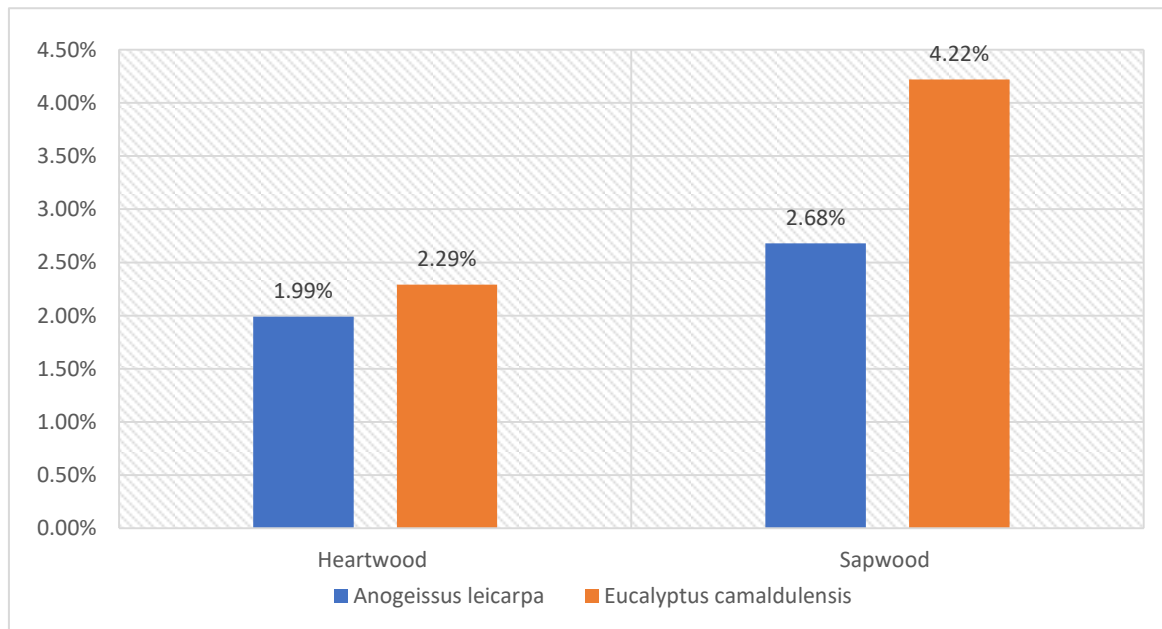
Decay initially affects the ability of wood to withstand impacts. This is generally reducing the strength values of wood. Strength loss during early stages of decay can be considerable, depending on the severity of the attack and to a lesser extent the type of wood undergoing decay. According to Kollmann and Cote Jr (1968), the natural durability and resistance of wood depends on many factors including the density as influenced by the moisture content. The extent of variations in decay resistance of plantation grown *Anogeissus leiocarpa* and *Eucalyptus camaldulensis* wood samples is reported in Fig. 4. *Anogeissus leiocarpa* wood recorded an overall mean percentage (%) mass loss of 1.99% and 2.68% for the heartwood and sapwood portions respectively. With regard to *Eucalyptus camaldulensis* wood, the sapwood also recorded higher mean percentage (%) mass loss (4.22%) than the heartwood portion (2.29%). In general, the percentage (%) mass loss is higher in the sapwood portions than the heartwood. Statistically there was a significant difference between the heartwood and the sapwood of *Anogeissus leiocarpa* and *Eucalyptus camaldulensis* wood (P < 0.001). The wood of the plantation exotic timber species demonstrated high decay resistant just like other commercial native species of wood.

According to Mensah et al. (2022) sapwoods of timber species are usually regarded as having low natural durability because they mostly contain very little extractives and are laden with starches normally intended for the growth of the tree. As such, the sapwood portions become more attractive for the growth of fungi and other wood bio-degraders. Ibrahim et al. (2020) therefore argued that the amounts of extractives found in some sapwoods greatly influence their natural durability. It follows that, in decay prone environments heartwood of species in the resistant category generally gives satisfactory service for wood used above-ground, while those in the very resistant category generally give satisfactory performance in contact with the ground. Generally, both plantations grown timber species recorded less moisture content and greater densities in the heartwood portions than the sapwood. This suggest that, the heartwood portion of the studied species more resistant to decay and termite attack than the sapwood portions. The natural durability of heartwood is usually due to the presence of accessory substances in the wood (Anastasia Pournoustems 2020; Taha et al. 2020). According to Amoah and Inyong (2019) and Kwaku et al. (2022), denser impermeable timbers tend to be more resistant than light porous species.

This observation is similar to earlier research work by Jamala et al. (2013), Kollmann and Cote (1968) and Osman and Tarig (2013) who reported that, the durability of individual wood species depend on the density, moisture content and the amount of extractives. The implication of this result is that, the heartwood portions of both *Anogeissus leiocarpa* and *Eucalyptus camaldulensis* wood in application will be more resistant to decay and termite attack than their sapwood portions (Table 7, 8). This is evident when the heartwood of the butt portions of all the samples investigated recorded higher densities (Table 2) and marginal percentage mass loss (Fig. 4), follows by the mid and then the top portions. This supports earlier research works by Brémaud et al. (2011), Horbelt et al. (2021) and Oyediran et al. (2023) who reported that the most durable wood is often present at the heartwood of the base of the stem, since it has the highest concentrations of extractives.

Kollmann and Cote (1968) also explained that, the relative amount of extractives decrease with increasing height above the ground. As such, Hounlonon et al. (2022) and Younis and Nemeth (2023) claims

that, older tissues have more extractives than younger ones. This could explain why the heart and butt portions of the plantation grown exotic timber species wood was more durable than the sapwood portions. Based on CEN (2005) / TS, 15083-1 standard, the plantation grown exotic *Anogeissus leiocarpa* and *Eucalyptus camaldulensis* is highly resistant to decay and termite attack and can be employed for interior joinery, light carpentry work, cabinet work as well as could be used for outdoor structural applications.



**Fig. 4.**

**Percentage (%) mass loss of *Anogeissus leiocarpa* and *Eucalyptus camaldulensis* woods after 12 months of field exposure.**

**Visual Durability Ratings**

The visual durability rating shows that, the heartwood portions of *Anogeissus leiocarpa* and *Eucalyptus camaldulensis* experienced slight attack by termites after the 12 months of field exposure. Whereas the sapwood test specimens were moderately attacked (Fig. 5). *Eucalyptus camaldulensis* species tissue however demonstrated greater termite attack than the tissue portions *Anogeissus leiocarpa* (Table 5). The deterioration increases along the species stem from the butt to the top portions. The *Eucalyptus camaldulensis* sapwood portion recorded the greatest termite attack. But, *Anogeissus leiocarpa* sapwood were moderately attacked by termites. It is worthy to note that, conditions of use of timber depends greatly on its resistance to fungal decay, insect attack, mechanical wear and chemical attack. Based on performance in ground contact, the plantation grown *Anogeissus leiocarpa* and *Eucalyptus camaldulensis* can be expected to have longer life in hazardous conditions.



**a**



**b**



**Fig. 5.**

**Appearance of attack on heartwood (B, D) and sapwood (A, C) of *Anogeissus leiocarpa* and *Eucalyptus camaldulensis* after 12 months of field exposure.**

*Table 4*

**Visual durability ratings of *Anogeissus leiocarpa* and *Eucalyptus camaldulensis* after 12 months of field exposure**

Species	Species Tissues	Durability Ratings	
		Visual Durability	% Mass Loss
<i>Anogeissus leiocarpa</i>	Heartwood	Slight attack	Very durable
	Sapwood	Moderate	Durable
<i>Eucalyptus camaldulensis</i>	Heartwood	Slight attack	Very durable
	Sapwood	Moderate	Durable

*Table 5*

**ANOVA for comparison of density between heartwood and sapwood portions of plantation grown *Anogeissus leiocarpa* and *Eucalyptus camaldulensis***

Wood section	N	Missing	Mean	Std Dev	SEM	Source of Variation	DF	SS	MS	F	P
Bh	5	0	834.4	14.952	6.687	Between Sections	4	4454.552	1113.638	357.3	<0.001
Mh	5	0	817	12.126	5.423	Between Species	5	268074.6	53614.93		
Th	5	0	804.2	13.51	6.042	Residual	20	3001.505	150.075		
Bs	5	0	646.4	23.172	10.363	Total	29	275530.7	9501.058		
Ms	5	0	628.3	21.302	9.526						
Ts	5	0	618.3	17.893	8.002						

Bh- Butt heartwood, Mid – heartwood, Top - heartwood, Butt – sapwood, Mid – sapwood, Top - sapwood

*Table 6*

**All pairwise multiple comparison between heartwood and sapwood density (This is used to compare all possible pair of means between tree sections to determine if there are significant differences between them as shown in the Table)**

Comparison	Diff of Means	t	P	P<0.050
Butt H vs. Top S	216.059	27.886	<0.001	Yes
Butt H vs. Mid S	206.068	26.597	<0.001	Yes
Mid H vs. Top S	198.71	25.647	<0.001	Yes
Mid H vs. Mid S	188.719	24.357	<0.001	Yes

Butt H vs. Butt S	188.003	24.265	<0.001	Yes
Top H vs. Top S	185.869	23.99	<0.001	Yes
Top H vs. Mid S	175.878	22.7	<0.001	Yes
Mid H vs. Butt S	170.654	22.026	<0.001	Yes
Top H vs. Butt S	157.812	20.368	<0.001	Yes
Butt H vs. Top H	30.19	3.897	0.005	Yes
Butt S vs. Top S	28.057	3.621	0.008	Yes
Butt S vs. Mid S	18.065	2.332	0.116	No
Butt H vs. Mid H	17.349	2.239	0.106	No
Mid H vs. Top H	12.841	1.657	0.213	No
Mid S vs. Top S	9.992	1.29	0.212	No

### Correlation Factors Influencing Percentage Mass Loss and Visual Ratings

Percentage mass loss may be used to explain the variation of the degree of resistance in the stem positions within the *Anogeissus leiocarpa* and *Eucalyptus camaldulensis* wood. Table 7 and 8 presents the correlation of the stem height positions of the plantation grown exotic timber species. Except for the heartwood of the middle and top portions, as well as the sapwood portions of the middle and top portions in both species, all the other stem heights correlated significantly and positively with percentage mass loss. Relatively, the non-significant positive relationship between the trees stem could be explained by the spontaneous increase of percentage mass loss from each of the bottom portions of each tree to the top portions.

This indicated that the percentage mass loss of *Anogeissus leiocarpa* and *Eucalyptus camaldulensis* woods corresponds to the moisture in the woods. This observation was in agreement with the findings of earlier studies that high percentage of moisture content in wood increase their vulnerability of the wood to termites and other organisms that causes decay and damage (Kollmann & Cote Jr 1968). This present study clearly shows that, the physical properties significantly influence wood resistance to decay and de-grade agents.

Table 7

**Correlation of axial positions for % mass loss of *Anogeissus leiocarpa* woods after 12 months of field exposure**

		1	2	3	4	5	6
1	Butt heartwood	1					
2	Mid heartwood	-0.747	1				
3	Top heartwood	-0.776	0.116	1			
4	Butt sapwood	0.418	0.182	0.864	1		
5	Mid sapwood	-0.863	0.356	0.324	0.162	1	
6	Top sapwood	-0.803	0.649	-0.992	0.764	0.080	1

\*. Correlation is significant at the 0.05 level, \*\*. Correlation is significant at the 0.01 level

Table 8

**Correlation of axial positions for % mass loss and visual ratings of *Eucalyptus camaldulensis* woods after 12 months of field exposure**

		1	2	3	4	5	6
1	Butt heartwood	1					
2	Mid heartwood	-0.959	1				
3	Top heartwood	-0.918	-0.296	1			
4	Butt sapwood	0.142	-0.128	0.903	1		
5	Mid sapwood	0.431	-0.960	-0.771	0.865	1	
6	Top sapwood	-0.419	-0.843	-0.766	-0.129	-0.028	1

\*. Correlation is significant at the 0.05 level

### CONCLUSIONS

Plantation grown exotic timber species offers a great opportunity to provide a very stable and consistent source of timber supply for the timber industry, locally and export markets. This study has unearthed and provided useful information in terms of the technological utilization potentials of plantation

grown exotic timber species *Anogeissus leiocarpa* and *Eucalyptus camaldulensis* wood as a good possible substitute for the limited known tropical hardwoods that are in extinction. This will aid in global quest to alleviate pressure on the natural forest timbers species that are in extinction, hence limited in supply.

Based on the findings of this study, the following conclusions were made. Oven-dry density obtained by the heartwood and sapwood proportions of the species varied considerably and statistically significant with heartwood recording higher values than the sapwood portions. Density also decreased with height along the axial stem of each tree. The plantation grown exotic timber species has the potentials required by furniture and construction industries to substitute the scarlet timber species.

It was also observed that, the percentage volumetric shrinkage and swelling of *Anogeissus leiocarpa* and *Eucalyptus camaldulensis* varied significantly among all the three-dimensional sections of the samples. The tangential portions recorded the highest value, follow by the radial section with the longitudinal recording negligible values, suggesting stability and good strength for furniture and structural utilizations. This showed that the wood has high oven-dry density at 12% MC characterized with low shrinkage, swelling and mass loss indices which greatly validated their suitability for medium to heavy construction works. It was therefore concluded that, the plantation grown exotic timber species could be used for quality furniture products and other interior fittings. Since wood product manufacturers and consumers place a high premium on density and dimensional stability of wood use for the construction of wooden artifacts. The use of *Anogeissus leiocarpa* and *Eucalyptus camaldulensis* woods has the potential of increasing hardwood resource base which can withstand termites attacks as well as the weather conditions.

The heartwood portions of the *Anogeissus leiocarpa* and *Eucalyptus camaldulensis* was more resistant to attack by bio-degraders than the sapwood. As such, the heartwood portions of *Anogeissus leiocarpa* species was rated very durable while its sapwood portions rated durable. However, the *Eucalyptus camaldulensis* wood was rated moderately durable. Beside their high resistance to termite attack, both species have attractive natural colour and can be used for can be used for the manufacture of decorative furniture products and other wooden artifacts. Their use in outdoor environment in ground contact would cause any hazard when adequate protection is provided.

#### ACKNOWLEDGEMENT

The authors are grateful to the management and Staff, of the Tamale Forestry Commission for approving and granting permit for the samples to be harvested and carried to Kumasi for the study. We are also grateful to all the staff of the Forestry Research Institute of Ghana - Fumesua, Kumasi for making their furniture test laboratory available for the study.

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