Nexus of short rotation plantation tree acceptance, investor attraction, and environmental sustainability: the case of physical and mechanical properties of plantation teak for structural application.

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Abstract

Trees play important roles in ensuring sustainable environmental quality for living things, including man. However, continuous overexploitation of the forest for timber, minerals among others is depleting tree stock and threatening the sustainability of environmental quality. Plantation forestry is being used to replenish degraded forest using teak as one preferred timber species. However, there is apparent inadequate information on short rotation plantation teak to aid user acceptance. The aim of this study is to provide information on physical and strength properties of plantation teak towards acceptance and utilization. Ten-year-old teak was evaluated in terms of its MC (using EN 13183-1:2004) and density -using ISO 3131:1973), bending MoE and MoR, compression, hardness, and shear strengths - using BS 373 protocols. Six trees were selected from a plantation in Kakum in the Central Region and processed for the study. Results indicated average values of 27.33%, 614kg/m3, 80 N/mm2, 12,914 N/mm2, 36N/mm2, 6.0 N/mm2, 14N/mm2 respectively for MC, density, MoE, MoR, compression, hardness, and shear strength. All but MoR were better than same properties for 50- to 70-year-old teak. The MoR, therefore, limits using the 10-year-old teak for relatively light structures such as furniture and not high load-bearing construction members like trusses or beams.

Key words: *Environmental quality, Teak wood, Density, Plantation forestry, Forest depletion, Millennium Development Goal (MDG) 7.*

1.0 Introduction

Trees, as part of their environmental roles sequester carbon dioxide to purify atmospheric air, ensure water purity, prevent air pollution and erosion, and reduce noise levels to provide quality environment for all living things, including human beings (European Environmental Agency 2004; Sphera 2023; TreePeople 2023). Economically, trees also provide timber and other associated materials for both local and international markets in various forms for the housing and construction, pharmaceutical, pulp and paper sectors, and which generate income for individuals and nations (Dadzie et. al. 2015; Shmulsky and Jones, 2011). Thus, it is an undisputable fact that trees are very important towards environmental sustainability and that their extinction could have dire consequential effects on sustainable life of all living things. However, there appears to be perpetuation of overexploitation of forest trees to meet the economic demand for wood to the detriment of the environmental benefits (Sphera 2023; Tree People 2023; Dadzie et al 2018) and thereby continuously threatening environmental quality and sustainability. Current reports indicate that Ghana lost 114Kha equivalent to 8% of total tree cover loss of its natural forest translating into 62.9Mt of CO2 emission in 2021 alone (Global Forest Watch nd.; Sasu 2022 In Statistica 2023). This has triggered global congressional concerns, discussions, and actions on the need for reforestation of depleted and degraded forests, as well as afforestation of fallow lands to forestall environmental quality globally (Gorte and Sheik 2010), and Tectona grandis (Teak) is reported to be one of the most preferred timber species for this course of action (Brown et al. 2016).

It is reported that for every hectare of teak planted, half hectare of nature reserve is created and therefore, tree planting has been identified as one major way of replenishing the continuously depleting natural forests and creating additional ones towards conserving biodiversity and ensuring environmental quality in line with Millennium Development Goal 7 (Arbofino 2023; FAO Committee on Forestry 2005; Gorte and Sheik 2010). The 7th of the MDGs was 'ensure environmental sustainability'-which as part of actions to achieving it was to intensify efforts for the management of all types of forest which was seen as an international commitment towards sustainable forest management (FAO Committee on Forestry 2005). However, compared to timber from long rotation trees, the timber from short rotation trees appears to be suffering some acceptance challenges by wood merchants and users due to some technical property shortfalls (Thulasidas & Baillères In Kollert and Kleine 2017). This situation is apparently not making investments in tree farming attractive business and making people reluctant to engage in it as many perceive the venture as one that holds capital for far too long. This situation, if not checked, could have consequential effects on the sustenance of environmental quality and apparently threatening the achievement of the MDG 7. Thus, efforts should be made to reverse the perception by researching and bringing out the qualities of timber from short plantation trees to make it acceptable for use which will in turn make more timber available for use, increase patronage in tree farming business, and also contribute positively towards environmental sustainability and quality.

Teak (Tectona grandis) is reported to be one top-ranked tree species considered as national priority species of more than 20 countries in the world for plantation forestry towards the conservation and management of forest genetic resources (Brown et al. 2016). Ghana, on her part, has also taken tree plantation seriously and pursuing it vigorously with teak as the dominant species to provide both economic and environmental benefits of trees to the nation and beyond. It is reported that the project proponent (pp) of Form Ghana (one of the companies engaged in reforestation and afforestation programmes in Ghana) is 90% teak and 10% native tree species (Form Ghana, 2017). However, the goal of the tree planting efforts can be achieved only when both local and international wood merchants, and users/buyers have quality information about both short (10 to 20 years old) and long rotation (beyond 25 years) teak wood. Such information will enable acceptance for structural applications which will in turn create expanded and sustainable market, and subsequently attract many more investors into the tree farming business.

Structural application of teak covers both light and heavy structural applications, especially in electricity transmission poles, boat deck building, flooring, tongue and grooved ceiling panels, joinery, and carpentry, even sometimes without preservative due to its numerous positive characteristics (Pleydell 1994). The author posits that the species is both weather, termite and pest resistant due to the presence of some natural oils in its fibre. These attributes, among others, make teak wood very durable and extremely suitable for outdoor and indoor applications (Form Ghana, 2013; Pleydell 1994). In fact, its attributes have made it one of the tropical hardwoods mostly demanded for luxury markets for both construction and the furniture industry, and farmers in Ghana for instance, achieve averages of more than 19% return on investment- Internal Rate of Return (IRR), besides income from carbon offset schemes (Brown et al., 2016a; Brown et al. 2016b).

Teak grows faster, is more suited for small holder farmers, does well in intercropping systems, does not suffer much from disease which in turn reduces the risks of plantation failure and impact of sustainable teak production on the environment since no or very little chemical treatment may be required (Form Ghana 2017; Brown et al., 2016). This makes teak farming easier and less demanding, and which have all subsequently contributed to attracting people into teak plantations both at homes and in farms. However, the generally known maturity age of beyond 30 years for most trees for timber/wood production (Tsoumis 1991; Shmulsky & Jones 2011) is apparently not making a lot of potential investors interested as they are unwilling to lock up their monies for such long periods of maturity time.

Timber productivity/yield of trees and the qualities of wood produced from them in terms of mechanical /strength properties are dependent on age of trees for which reason tree felling cycles and or rotations are usually >30 years, especially for natural forest trees. However, due to return on investment issues in the tree plantation business, growers find it unattractive to wait till such a long period. Hence, it is important to determine some properties of short rotation trees such as 10-year-old teak (one of the lowest age for plantation trees to produce some useable wood – Arbofino 2023) to contribute to making the business attractive to many people. This could contribute towards reducing the rate of deforestation and provide sustainable environmental quality. But data on 10-year teak in terms of some physical and strength properties is either limited or unavailable (Midgley et al 2007). The most current study in Ghana on teak (Amoah & Inyong 2019) unfortunately omitted and failed to publish data on moisture content (MC), density, and the mechanical properties of 10-year-old teak. Meanwhile, assessment of some properties of young plantation teak from Laos indicated that the physical and mechanical properties of 10-, 15-, 20-, and 25-years old teak from plantation were not significantly different (Wanneng et al 2014). Also, reports indicate that teak can have appreciable quality wood from 7 to 10 years and therefore it is harvested within those ages (short rotation) in some countries (Rizanti et al 2018; Arbofino 2023). It is also scientifically proven that aside age, wood properties can sometimes be affected by tree axial positions (Tsoumis 1991; Amponsah & Meyer 2000; Shmulsky & Jones 2011).

It is in this light that the current study was undertaken on 10-year-old Ghanaian plantation teak to ascertain whether or not its physical (moisture content -MC, and density) and mechanical properties (static bending MoE and MoR, compression parallel to the grain, Janka hardness, shear strengths) from the base of the tree to the top are comparable or not to those of teak of same or older ages. The findings will be significant for timber users and marketers to have adequate information on short rotation plantation teak to encourage maximum acceptance for utilization which will subsequently lead to expansion of the market for such timber and thereby attracting more investors into engaging in tree plantations. These plantations through their environmental roles in sequestering carbon among others, will have general positive effect on environmental quality conservation and sustainability.

2.0 Materials and methods

2.1 Sample collection and preparation

Six teak trees of 10 years old were felled from a private teak plantation farm in Kakum in the Hemang Lower Denkyira District of the Central Region of Ghana. According to Pandey and Brown (200), the district lies within the semi-equatorial zone between latitudes 5’50˚N and 5’51˚N and longitudes 1’50W and 1’10˚W. The general altitude is between 60 – 200 metres above sea level marked by double maximal rainfall which peaks in June and October, and with a mean of 1,750mm. Temperature ranges from 26˚C (in August) and 30˚C (in March) with relatively high relative humidity throughout the year, ranging between 70 – 80 percent in the dry season and 75 – 80 percent in the wet season.

Six teak trees of Diameter at Breast Height (DBH) ranging from 18-22 cm, and useable heights range of 14-20 m were felled from the plantation farm. Samples for testing were taken from three main sections along the boles of the trees (i.e., butt section-310cm from ground, middle section- 320 to 630 cm; and top section - 650 to 970 cm). These sections were initially divided into quadrants to aid easy conveyance. To prevent moisture losses, the quadrants were wrapped with black polyethene before they were transported for further processing and preparation to the standard sizes prescribed by the various protocols. Only defect free heartwood were selected and labelled for easy identification. These final test specimens were prepared in accordance with the dictates of the respective specific protocol used for the various tests.

2.2. Test samples preparation and properties determination

2.2.1 Physical Properties

In all, 48 samples were tested for density and MC of each tree axial position (i.e., 4 sapwood + 4 heartwood x 6 trees = 48), hence for the three axial positions, a total of 144 samples were used for each of the physical property test (i.e., 48 x 3 = 144). Moisture contents (MCs) were determined by the oven dry method with sample in the form of square prisms with sides of 20 mm square for the butt, middle and top sections in accordance with European standard -EN 13183-1(2004) protocol. The specimens were weighed immediately after cutting to ascertain their initial masses (M1) using an electronic digital balance with 0.01g accuracy. The samples were oven-dried at temperature of 103 ± 2°C, removed at intervals of 2 hours and reweighed till constant mass. The final mass (i.e., oven-dry mass-Mo) was taken immediately after removing from the oven, according to the dictates of the protocol used. The average MCs were estimated as a percentage by mass using the relation expressed in equation (1).

$$MC\ (\%) = \frac{Initial\ Mass\ (M1) - Oven{-}dry\ Mass(Mo)}{Oven{-}dry\ Mass\ (Mo)}\ x\ 10 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(1)$$

{EN 13183-1 (2004); Shmulsky and Jones (2011)}

Oven-dry density (Do) of *Tectona grandis* was estimated in accordance with the International Standard Organization -ISO 3131 (1975). Samples in the form of right prisms with square cross-section of sides of 20 mm and length of 25 ±5mm along the grain were measured with digital veneer calliper of length 150mm having resolution of 0.01mm and accuracy of ± 0.02mm. Afterwards, the oven-dry volumes (Vo) of the samples were estimated as Lo x Bo x Wo. Where Lo = oven-dry length, Bo = oven-dry breadth, and Wo = oven-dry width. After obtaining the masses and the volumes, the oven-dry density was calculated using the relation expressed in equation (2).

$$\text{Oven-dry Density (Do)} = \frac{Oven{-}dry\ Mass\ (Mo)}{Volume\ of\ wood\ (Vo)}\ x\ 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(2)$$

{ISO 3131 (1975); Shmulsky and Jones (2011)}

2.2.2 Mechanical properties

The standards, test methods and test parameters used are summarized in Table 1.

Table 1. Mechanical properties, test method, test standards and other parameters

	Property	Standard	Specimens' dimensions (mm)	N	Direction of loading	Loading rate/speed (mm/min)
1	MoE in bending	BS 373	20 x 20 x 300	144	Perpendicular to the grain	6.604
2	MoR in bending	BS 373	20 x 20 x 300	144	Perpendicular to the grain	6.604
3	Compression	BS 373	20 x 20 x 60	144	Parallel to the grain	0.632
5	Shear	BS 373	50 x 50 x 50	144	Parallel to the grain	0.632

5	Janka Hardness	BS 373	50 x 50 x 150	144	Side and end grain	6.250

In all, 48 samples were tested for each mechanical property of each tree axial position (i.e., 4 sapwood + 4 heartwood x 6 trees = 48), hence for the three axial positions, a total of 144 samples were used for each of the mechanical property tests. This resulted in an overall total of 576 samples (i.e., 48 x 3axial positions x 4 mechanical tests = 576) of varied dimensions according to the employed protocol for the mechanical studies.

All mechanical tests were carried out in accordance with British Standard BS 373: 1957(1986) protocols on a Universal Testing Machine (model, UTN-110) which is fitted with automatic computerized system that captures all results.

In estimating static bending properties (MoE and MoR), the samples were prepared to dimension of 20 x 20 x 300mm.

Compression strength samples were also of dimensions 20mm x 20mm x 60mm, whereas shear test samples were of dimensions 50 mm x 50 mm x 50 mm. The Janka hardness test samples were also of dimensions of 50mm x 50mm x 150mm.

All test results were adjusted to 12% mc using Equation 3 as recommended by BS 373: 1957(1986).

$$l_{12} = l_w [1 + x (w-12)] \quad \text{--------------------------------} \quad (3)$$

where l_{12} is the strength property at 12% mc, l_w is the calculated strength property from experiment, w is the mc of the test specimen, and x is a constant (0.04).

2.3 Data Analysis

Data obtained from the experiment were summarized in Microsoft Excel and imported onto SPSS (17.0 version) for analysis. Excel graphs were also used to pictorially present some of the results. Significant differences were tested at 95% confidence levels. Multiple comparison tests were also used to determine the significance of the differences in the values of one tree section to the other.

Also, correlation analysis was conducted to determine the relationships among density and various mechanical properties of the ten-year-old Tectona grandis wood.

3.0. Results and discussion

3.1. Physical properties

The initial moisture content- MC (%) for the 10-year plantation teak averaged 36.33% and was found to be higher at the treetops compared to the other two sections. The MCs and density are presented in Figure 1. At 95% significant level, the MC of the middle sectional samples were averagely 7.41% insignificantly higher than the base samples whereas the top rather had 37.30% significantly higher MC than the middle samples.

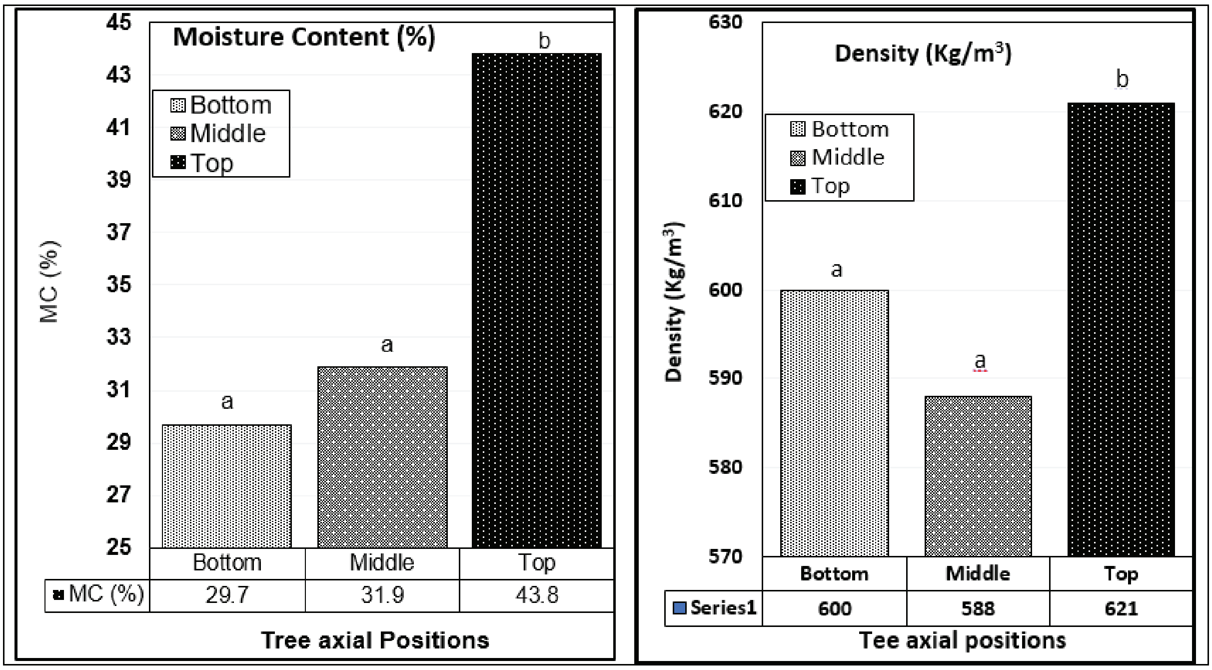

Figure 1. Physical properties (%Moisture content and density -Kg/m³) of the three axial sections of plantation teak. N = 48. ***Mean values with different letters indicate significant difference at $P < 0.05$.***

The 10-year old teak also exhibited an average oven-dry density of 614 ± 57 and was significantly ($P < 0.05$) highest at the top of the tree and smallest at the middle. Comparatively, tree top wood samples averaged 33Kg/m³ significantly ($P < 0.05$) higher in density than the wood at the middle and representing 5.6% higher; 21 Kg/m³ significantly ($P < 0.05$) higher in density than the wood at the base and representing 3.5% higher (Figure 1).

3.2. Mechanical properties

Generally, wood from different axial positions of the 10-year-old teak exhibited some differences in mechanical properties from the bottom to the top with Janka hardness and shear strength being the only exceptions (Figure 2). Some of these differences in values were marginal whereas others were significant at 95% confidence level. Static bending properties (MoE) and MoR respectively averaged 12,914N/mm² and 80N/mm², whereas mean maximum crushing strength, mean hardness, and mean shear strengths averaged 36 N/mm², 6 N/mm², and 14 N/mm² respectively.

MoE exhibited bottom to middle significant ($P < 0.05$) increase of 1135 N/mm² (9.31%), bottom to top significant increase of 1496 N/mm² (12.27%), and middle to top nonsignificant increase of 361 N/mm² (2.71%) (Figure 2).

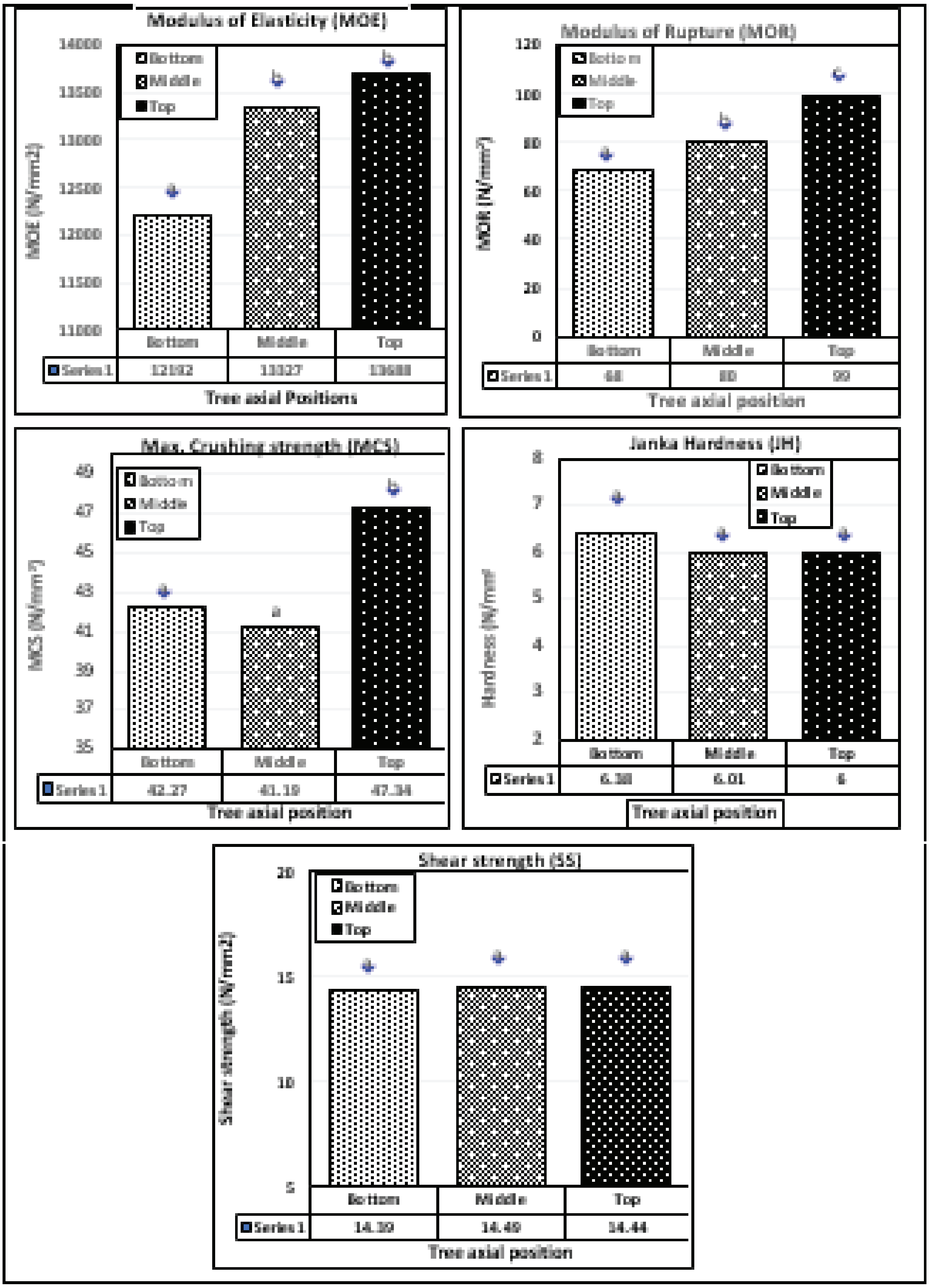

Figure 2. Mean mechanical properties (MoE, MoR, MCS, Hardness, and Shear) of 10-year-old teak wood from different axial positions. N = 48; *Mean values with different letters indicate significant difference at P < 0.05*.

The static Modulus of Rupture (MoR), which is the breaking strength of the material, as in the case of MoE, also exhibited a trend of significant (P<0.05) increasing values from bottom to middle of 12 N/mm^2 (17.65%), from bottom to top of 31 N/mm^2 (45.59%), and from middle to top of 19 N/mm^2 (27.94%). Maximum crushing strength (MCS) registered non-significant decrease from bottom to middle of 1.08N/mm^2 (2.55%), bottom to top significant increase of 5.07N/mm^2 (11.99%), and middle to top significant increase of 6.15N/mm^2 (14.93%). Janka hardness averaged 6N/mm^2 whereas shear strength averaged 14N/mm^2 but both did not exhibit any significant axial variation.

3.3. Relationship among density and mechanical properties

Density could be used to explain the mechanical properties of wood. Density of the 10-year-old teak correlated significantly and positively with all the mechanical properties studied, except for MoE ($r = 0.375$; $p > 0.05$) Table 2. These are indicative of strong connections among density and the mechanical properties. MoR had significant positive relationship with MoE ($r = 0.820$; $p < 0.01$), and shear strength ($r = 0.638$; $P < 0.01$). Janka hardness also had relatively high positive significant relationship with maximum crushing strength (MCs $r = 0.603$; $P < 0.01$) and shear strength ($r = 0.737$; $P < 0.01$).

Table 2 Pearson's correlation matrix of density and mechanical properties of 10-year old teak

	Density	MoE	MoR	Hardness	MCS	SS
Density	1					
MoE	0.375^{ns}	1				
MoR	0.719**	0.820**	1			
Hardness	0.667*	0.299^{ns}	0.537*	1		
CS	0.734*	0.221^{ns}	0.592*	0.603**	1	
SS	0.985**	0.249^{ns}	0.638**	0.737**	0.692**	1

Note: MoE=Modulus of Elasticity; MoR = Modulus of Rupture; MCS = Maximum Crushing Strength; SS = Shear Strength

ns = non-significant; *p < 0.05; **p< 0.01

4.0. Discussions

4.1 Physical properties

The initial moisture content (MC) was determined and compared to the green MCs along the axis of the 10-year-old teak. However, it is worth acknowledging that the values may not be actuals due to time lapse from felling to processing of the timber though all were wrapped with polythene, as it took about 3 weeks before test began. The finding of high and significant moisture of the tree top wood compared to the middle and the bottom sections appear to be consistent with wood science fundamentals. It is established that generally, the top of trees is not as mature as the middle and base, and therefore contains a lot of sapwood and transitional wood, all of which contain relatively more moisture and therefore, such moisture content differences are expected (Shmulsky & Jones 2011). The mean initial MC of 36.33% is lower than the 41.59% as reported by Wanneng et al. (2014) on 10-year-old old teak grown in Laos in India. The difference could be attributable to location/climatic factors differentials (Thulasidas & Baillères In Kollert and Kleine 2017). Wannang et al. (2014) took samples from an area of altitude 300m to 5000m above sea level and having annual precipitation of 1,809mm and annual temperature range of 20.36°C to 28.65°C, as against 60 to 200m above sea level altitude and 1,750mm annual precipitation and annual temperature range of 26°C to 300°C.

The average oven-dry density of 614 kg/m3 finding in this study was higher than 604 kg/m3 obtained by Sekhar and Rawat (1966) for mature teak, and lower than 675kg/m3 reported by Wanneng et al. (2014) for 10-year-old teak. The finding that the treetops of teak were denser than the base could be attributable to maturity and moisture content differentials, and it appears to be in conformity with normal trend that characterizes axial variations in wood density and as also reported by Amoah and Inyong (2019) on teak wood. The oven dry (OD) density in the current studies also compares very well with even air dry (AD) density of teak reported in literature. Shukla and Viswanath (2014) found specific gravity values of 0.559, 0.606, and 0.572 for 12-year plantation teak from Panama. Also, Ghat and Priya (2004) found density of 21- to 65-year-old plantation teak to range from 619 to 682kg/m3. Some of the disagreements in values could also be due to the fact that this current study estimated oven-dry density (i.e., density at 0% MC) while others were on air-dry density (density at 12%MC). So, the mass of wood at 12% moisture content could create some differences. But all notwithstanding, these are indicative that the 10-year-old plantation teak, in terms of density, is comparable to 12 to 21+ year-old teak elsewhere which are well for some structural application such as furniture, and for other wood products such as veneer, plywood and sawlog (Thulasidas & Baillères In Kollert & Kleine 2017). Thus, the relatively short rotation (10-year-old) teak wood in Ghana could similarly be applied. Such application of short rotation teak could take off the associated fear of lock-up of capital due to longer gestation periods for return on investment characterized by longer rotation and instead guarantee relatively quick returns to investors as is being practiced in many tropical countries of the world. Should this happen, investors will be attracted to investing in tree plantations which will go a long way to ensure environmental quality preservation and sustenance for both flora and fauna.

4.2. Mechanical properties

The finding in this study that except for Janka hardness and shear strength, treetop wood of 10-year-old teak had highest mechanical properties than the middle and bottom sections with some differences being significant ($p < 0.05$) appears to agree with Amoah and Inyong (2019). However, the pattern is also partly at variance with some findings of these authors who rather found Janka hardness to be significantly influenced by tree axial positions. The average values of the mechanical properties viz; MoE = 12,914N/mm2 are higher than 11,730 N/mm3 reported by Sekhar and Rawat (1966) for mature teak and 9920 N/mm2 found by Amoah & Inyong (2019) for relatively older teak. Thulasidas and Baillères In Kollert and Kleine (2017) also found MoE of 65-year-old plantation teak to be 12,335N/mm2 and that of 65-year-old natural forest teak to be 12,530N/mm2. These also suggest superiority of the MoE of 10-year-old plantation teak in Ghana over 65-year-old plantation and natural forest teak from Nilambur in India. The bending Modulus of Rupture (MoR) or breaking strength average of 80 N/mm2 which also showed increasing trend in value from the bottom to the top is lower than 94.08 N/mm2 reported by Sekhar and Rawat (1966) for mature teak. However, this MoR of 80N/mm2 is higher than 75N/mm2 reported by Amoah and Inyong (2019) for relatively older than 10-year-old teak, and also higher than the 74.48N/mm2 to 84.34N/mm2 reported by Shulkla and Viswanath (2014) for 12-year-old plantation teak from different agroforestry management systems. Again, the MoR found in the current study falls below the 108N/mm2 and 100N/mm2 recorded for Indian plantation teak of 13 and 65 years old respectively (Thulasidas & Baillères In Kollert & kleine 2017). The decreasing trend also appears to be similar to some insignificant decreasing trend found by Amoah and Inyong (2019). Thus, in terms of bending, the stiffness strength (MoE) of the 10-year- old teak compares favourably with even 60-year-old plantation and natural teak and the breaking strength is also comparable to some 12- to 15-year-old plantation teak. It is also reported that juvenile wood content in short rotation timber could also be responsible for the low breaking strength of wood (Thulasidas & Baillères In Kollert & kleine 2017; Desch & Dinwoodie 1996; Tsoumis 1991). The bending property qualities (MoE and MoR) are needed for applications in structures such as beam-like members, tabletops, shelves, chair seats, some parts of door and window frames among others. and therefore, the findings in this study could be described as very positive as the 10-year-old teak is as better as >10years to 60years teak in stiffness, and the breaking strength is also good enough for such light structures, except possibly for beams in buildings.

The mean maximum crushing strength (36N/mm2) found in this study was a little close to 38.20N/mm2-42.13N/mm3 as found by Shulkla and Viswanath (2014). This quality is required for applications such as columns in buildings, table and chair legs and parts of other interior products. With such closeness of the values of the 10-year-old teak to that found in Shulka and Viswanath (2014), it is a positive development for such structural applications. Surface hardness (6N/mm2) found in this study is also comparable to 3.74-5.08N/mm2 found by Shulkla and Viswanath (2014). Amoah and Inyong (2019) have also confirmed significant influence ($p < 0.01$ and $P < 0.05$) of axial variation on MoE, MoR, MCS and shear strength but not for Janka hardness. Surface hardness is also an important wood quality for flooring/floor tiles and stair construction. Thus, with the values found in this study, the 10-year-old plantation teak could be used for parquet flooring/floor tiles production provided the right method of conversion (quarter sawing) is used appropriately.

From the foregoing, it is apparently clear that in terms of stiffness in bending, the 10-year-old teak appears superior to even 65-year-old plantation and natural forest teak, the bending breaking strength appears not too bad though falls below the threshold (>135N/mm2) requirement for heavy structural applications. However, it could be used to manufacture light structural wood products (non-heavy load carrying structural members) such as furniture, slice veneer, and other interior furnishing products such as ceiling panels, tables, chairs and others as has been reportedly done in Laos (Thulasidas & Baillères In Kollert & Kleine 2017). Should this be extensively achieved in Ghana too, it is expected that expanded market will be created for the short rotation teak which will provide some motivation to the investor community that their capital will not be locked up for too long a time as in long rotation, and this will in turn probably entice many more investors into the venture of plantation forestry using teak. Moreover, such application of short rotation teak like 10-year old, could take off the associated fear of capital lock-up due to longer gestation periods for return on investment characterized by longer rotation tree felling and utilization. Instead, it will guarantee relatively quick returns to investors as is being practiced in many tropical countries of the world (Thulasidas & Baillères In Kollert & Kleine 2017). Timber merchants and wood users could also consider purchasing the short rotation plantation teak from farmers to enable them to recoup some returns relatively early enough from the investment to make the tree farming venture enticing to existing farmers and attract others into business. Should this happen, tree plantations will be expanded, and which will go a long way to protect biodiversity in general and ensure environmental quality and sustenance for both plants and animals, including human beings.

4.3. Relationship among the density and mechanical properties.

The strong significant correlation ($p < 0.01$ and $P < 0.05$) finding for density and all the mechanical properties with MOE being the only exception appears to corroborate the findings of Amoah and Inyong (2019). Thus, density can be used to explain and possibly predict the mechanical properties studied in this research.

5.0 CONCLUSIONS AND RECOMMENDATIONS

1. The physical properties (i.e., moisture content -averaged 36.33%, and density – averaged 614Kg/m3) of 10-year-old teak exhibited either higher or lower values than those of matured mature teak elsewhere and is dependent on the position of the wood from bottom to top of the tree.
2. Mechanical properties increased either significantly or non-significantly at 95% confidence level from the wood of the tree bottom to those of treetops. And with the exception of MoR values of the 10-year-old plantation teak that could not guarantee its safe application for beams and columns in heavy structures like buildings constructions, almost all other mechanical properties were comparable to those that can be used for light structures such as furniture, door and window frames, parquet flooring, other interior finishing products and the like.
3. Density had very strong positive correlation ($p < 0.05$ and $p < 0.01$) with all mechanical properties except for MoE.
4. Based on the conclusions drawn, the 10-year-old teak is not so inferior to those beyond 30 years and deemed as mature thus if nothing at all, the wood can be used for light structural applications such as furniture, door and window frames, partitions, ceiling, parquet flooring, and slice veneer.
5. It is recommended that dealers in the timber and wood supply chain such as timber merchants, wood processors and furniture producers, and other wood users should consider patronizing short rotation plantation teak from farmers in Ghana. This can create sustainable market and enhance investor confidence in terms of guaranteed early return on investment to make the tree farming an enticing and attractive venture to contribute towards achieving sustainable environmental quality and MDG 7.
6. Further studies on other wood qualities such as natural durability in terms of termite resistivity and other biodeterioration parameters, and reaction to finishings, sorption characteristics, among others should also be conducted to enhance confidence in

utilization of 10-year-old plantation teak from Ghana.

Author Contributions

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REFERENCES

Arbofino (2023) Nature conservation, sustainable forestry, and organic agriculture- Teak ImpactInvestment, https://arbofino.ch/en/ (Accessed, 10th January 2023).

Amoah M and Inyong S (2019). Comparison of some physical, mechanical, and anatomical properties of smallholder plantation teak (Tectona grandis Linn. F.) from dry and wet localities of Ghana, Journal of the Indian Academy of Wood Science 16 (2): 125-138.

Amponsah I, Meyer W (2000) Soil characteristics in teak plantations and natural forests in Ashanti Region, Ghana, Communications in Soil Science and Plants Analysis, 31 (3-4); 355 – 373.

Bhat K M and Priya P B (2004) Influence of provenance variation on wood properties of teak from the western Ghat region in India. IAWA Journal 25: 273-282.

Brown H, Glauner R, Goh D, Grausal L, Jerez M, Khaing N, Kleine M, Killert W, Minn Y, Monteuuis O, Roshetko J, Thulasidas P.K, Walotek P. J (2016a) -Experts; The future of Teak – What policy makers and managers need to consider, Summary report of the expert group meeting on Teak, Vienna, December 5th to 7th 2016; IUFRO and TEAKNET.

Brown H.C.A, Pentsil M.Y, Torgbor B. A, Appah J, Bosompem K.P, Frimpong Y, and Gyambrah T (2016b) (Ed), Ghana Forest Plantation Strategy:2016-2040, Forestry Commission (FC), and Ministry of Lands and Natural Resources (MLNR), Ghana. PP.15.

BS (British Standard) 373 (1957) Strength Properties of Timbers, in Metric Unit: In Lavers, G. M., (1974). Strength properties of timber, The Princes Risburough Laboratory of the Building Research Establishment, ST. Leonard's House, Lancaster, England, MTP construction Medical and Technical publishing co. Ltd. pp. 1 – 24.

Dadzie P. K, Amoah M., Inkum P. B., Boampong E (2018) Branchwood utilization towards mitigating deforestation and climate change: A comparison of some characteristics of stemwood and branchwood across ecological zones, Presented at the 5th International Conference on Applied Science and Technology (ICAST), Kumasi Technical University, Anita Hotel, Kumasi, 27th -28th September 2018.

Dadzie P. K, Agyapong, A. K. & Inkum P. B (2015) Some Market Trends of Wood Products Exports in Ghana and Their Implications for Stakeholders: The Case of Furniture and Kiln-Dried Lumber. *International Journal of Business and Economics Research. 4(6): 307-314.*

Desch H E, Dinwodie J M (1996) Timber structure, properties, conversion and use. 7th ed. London. U. K., Macmillan Press. 306pp.

EN (European Standard)13183-1 (2004) Moisture content of a piece of sawn timber, Part 1: Determination by oven dry method, Österreichisches Normungsinstitut, 1020 Wien.pp.5

European Environmental Agency (2004), Environmental quality, https://www.eea.europa.eu/ (Accessed, February 2023).

Form Ghana (2017) Forest management plan: Asubima and Fresu Brohuma forest reserves, Ashanti Region, Ghana. Form Ghana, pp.36.

FAO (Food and Agricultural Organization) Committee on Forestry (2005), Report of the high-level panel of external experts on forestry to the Director-General of the Food and Agricultural Organization of the United Nations, Seventeenth Sesssion, Rome, Italy, 15th – 19th March, 2005, pp.8.

Gorte and Sheik (2010) Deforestation and climate change, CRS report for congress, Congressional Research Services, pp. 1-41.

Global Forest Watch (*nd*) https://www.globalforestwatch.org/dashboards/country/GHA?category=forest-change#:~:text=From%202001%20to%202021%2C%20Ghana,and%20740Mt%20of%20CO%E2%82%82e%20emissions.

ISO (International Standard Organization) (1975-1986) Wood- Determination of density for physical and mechanical tests, first edition, International Organization for standardization, Switzerland. pp. 4.

Midgley S J, Blyth M, Mounlamai K, Midley D, and Brown A (2007) Towards improving profitability of Teak in integrated smallholder farming systems in Northern Laos. ACIAR Technology Reports No. 64, Australian Centre for International Agricultural Research, Canberra.

Pandey D, and Brown C (2000) Teak: a global overview. Unasylva 201 (51): 3-13.

Pleydell G (1994) Tropical Timbers of Ghana, Timber Exports Development Board, Takoradi. Ghana. 86pp

Rizanti D. E, Darmawan W, George B, Merlin A, Dumarcay S, Chapuis H, Gerardin C, Gehaye E, Taharivelomanana P, Sari R.K, Syafii W, Mohamed R, and Gerardin P (2018), Comparison of teak wood properties according to forest management short versus long rotation, Annals of forest science, 75 (39); 1-12.

Sasu D. D (2022) *In* Statistica (2023) Primary Forest loss in Ghana from 2001 to 2021. https:/www.statista.com/ . (Accessed, February, 2023).

Sekhar A.C., and Rawat B.S (1996) Physical and mechanical properties of tak from different locations in India and neighbouring areas. Indian Forestry Rec. Timber Mech. 1(13): 197-212.

Shukla S. R, Viswanath S (2014) Comparative study on growth, wood quality and financial returns of teak (*Tectona grandis L. f.),* managed under three different agroforestry practices, Agroforest systems 88:331-341.

Shmulsky R and Jones P.D (2011) Forest Products and Wood Science-An Introduction, 6th ed. John Wiley & Sons Ltd., West Sussex, U.K. pp. 3-363

Sphera (2023) What is environmental sustainability, https://sphera.com/ (Accessed, February 2023).

Thulasidas P.K, and Baillères H. *In:* Kollert W, and Kleine M (eds) (2017) The global Teak study: Analysis, Evaluation and Future Potential of Teak Resources

TreePeople (2023) 22 benefits of trees, https://www.treepeople.org/ (Accessed, February, 2023).

Tsoumis G (1991) Science and Technology of Wood; Structure, properties, and utilization. The salonika, Greece: Verlag Kessel. pp 480.

Wanneng P. X, Ozarska B., and Daian M.S (2014) Physical Properties of Tectona Grandis grown in Laos, Journal of Tropical Forest Science, 26 3 389-396).