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ARTÍCULO

Experimental analysis of axial variation in physical and mechanical properties of *Detarium microcarpum* wood and its potential for sustainable utilization

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Abstract:
This study addresses the limited availability of scientific data on the physical and mechanical properties of *Detarium microcarpum* (sweet detar) wood, which constrains its evaluation as a potential timber resource. An experimental characterization was conducted using wood samples obtained from three mature trees in Walateng-Goziir, Nandom Municipality, Ghana. The stems were sectioned into bottom, middle, and top portions to assess axial variation. Physical properties (moisture content, oven-dry density, volumetric shrinkage, and swelling) and mechanical properties (modulus of elasticity, modulus of rupture, compression parallel to grain, and shear strength) were determined at 12 % moisture content using standardized methods. The results showed significant axial variation ($p < 0,05$) across all measured properties. Moisture content increased from 13,78 % at the base to 16,35 % at the top, while oven-dry density decreased from 775,84 kg/m³ to 670,28 kg/m³. Mechanical properties also declined along the stem height, with modulus of elasticity decreasing from 6453,78 MPa to 5996,44 MPa. These findings provide empirical data that contribute to the scientific understanding of *Detarium microcarpum* (sweet detar) wood and support its evaluation as a lesser-used species with potential for timber applications.

Keywords: Axial variation, *Detarium microcarpum*, mechanical properties, modulus of elasticity, modulus of rupture, volumetric shrinkage, tropical hardwood, wood properties.

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Introduction

Ghana's timber industry has historically been a cornerstone of the national economy, providing substantial employment, foreign exchange earnings, and infrastructural development. However, unsustainable practices, including illegal logging, agricultural expansion, and overharvesting of high-value species such as odum (*Milicia excelsa* (Welw.) C.C.Berg), mahogany (*Khaya ivorensis* A.Chev.) and wawa (*Triplochiton scleroxylon* K.Schum.), have significantly reduced both forest cover and the availability of these key timber resources (Chakurah *et al.* 2025). The Food and Agriculture Organization (2015) reports that Ghana lost about 2,5 million hectares of forest between 1990 and 2010, representing a 33 % decline in forest area.

This decline has severely impacted the availability of traditional timber species, resulting in increased prices and market scarcity (Adom *et al.* 2024). Forest depletion also poses significant challenges to the sustainability of Ghana's furniture and construction industries (Antwi-Boasiako and Boadu 2016), while contributing to broader ecological consequences such as biodiversity loss, soil degradation, and disruption of water cycles (Qu *et al.* 2024). These challenges highlight the urgent need to identify and promote alternative timber species capable of reducing pressure on overexploited forests while meeting industrial demand.

In response, increasing attention has been directed toward lesser-used species (LUS), which have historically remained underexploited due to limited knowledge of their properties, processing difficulties, and uncertain applications (Chakurah *et al.* 2024). Nevertheless, many LUS exhibit favorable characteristics, including adequate mechanical strength, durability, and aesthetic qualities, making them promising alternatives to conventional timber species (Antwi-Boasiako *et al.* 2022). The utilization of LUS can support sustainable forest management by diversifying the species base and reducing dependence on traditional timber resources (Kaba *et al.* 2022), while also creating economic opportunities for local communities.

Among the species gaining interest is sweet detar (*Detarium microcarpum* Guill. & Perr.), commonly known as sweet detar, a tree native to the savannah regions of West and Central Africa, including Ghana (Amegah *et al.* 2024). The species is well adapted to dry environmental conditions and poor soils, demonstrating resilience that makes it suitable for the climatic conditions of northern Ghana, particularly in the Walateng-Goziir area of the Nandom Municipality (Bernard *et al.* 2019). In addition to its traditional uses for edible fruits and medicinal purposes, its potential as a timber resource remains insufficiently explored.

Previous studies on related species, such as ditax (*Detarium senegalense* J.F.Gmel.), have reported promising physical and mechanical properties for timber applications, although concerns regarding durability have been noted (Ogunwusi 2012). Furthermore, timber density and durability are critical parameters influencing the suitability of wood for construction and furniture applications (Palanti and Terziev 2022). However, empirical data on the physical and mechanical properties of sweet detar (*Detarium microcarpum* Guill. & Perr.) wood remain limited, particularly with respect to variation along the stem. There is currently a lack of systematic scientific data describing these properties, which restricts the ability to adequately evaluate its behavior and potential utilization. This variability along the stem has been widely reported and is associated with differences in anatomical structure, growth characteristics, and wood formation processes. The assessment of axial variation is therefore essential for understanding the performance and potential applications of a given wood species. Consequently, detailed characterization of these variations is necessary to provide a reliable scientific basis for evaluating the material properties of sweet detar (*Detarium microcarpum* Guill. & Perr.) wood.

This study therefore aims to evaluate the physico-mechanical properties of sweet detar (*Detarium microcarpum* Guill. & Perr.) wood, with emphasis on axial variation along the stem, in order to provide empirical data that contribute to the scientific characterization of the species and support a preliminary assessment of its potential as a lesser-used timber resource.

Materials and methods

This study is an experimental characterization of the physical and mechanical properties of sweet detar (*Detarium microcarpum* Guill. & Perr.) wood, with emphasis on axial variation along the stem.

Sample collection and preparation

Three mature sweet detar (*Detarium microcarpum* Guill. & Perr.) trees were purposively selected from the natural woodlands in Walateng-Goziir in the Nandom Municipality of the Upper West region of Ghana. The diameters of the trees were 39, 45 and 52 cm and the heights of their stems were 1190, 1250 and 1320 cm respectively. The boles were taken from breast height (1,5 m above the ground level) to the point where the first branch began for each tree. The bole of each tree was divided into three (3) billets Sections (Bottom, Middle and Top) to determine the axial tree variation as indicated in Figure 1. The billets from each axial section were further converted into lumber using the quarter sawing method. Marking and sawing were carefully done to ensure that the juvenile wood portion of each billet was excluded.

Wood samples were prepared at the Council for Scientific and Industrial Research's (CSIR) wood workshop in Kumasi. Three segmental discs, each of about 7,5 cm of each tree were cut from the ends of each tree's bottom, middle, and top sections in order to assess their physical characteristics at 12 % moisture content. In total, nine billets each approximately 100 cm in length, were selected for the study. Each board was clearly marked for identification and stored in polythene bags to prevent moisture variation prior to testing for moisture content, density, and dimensional stability.

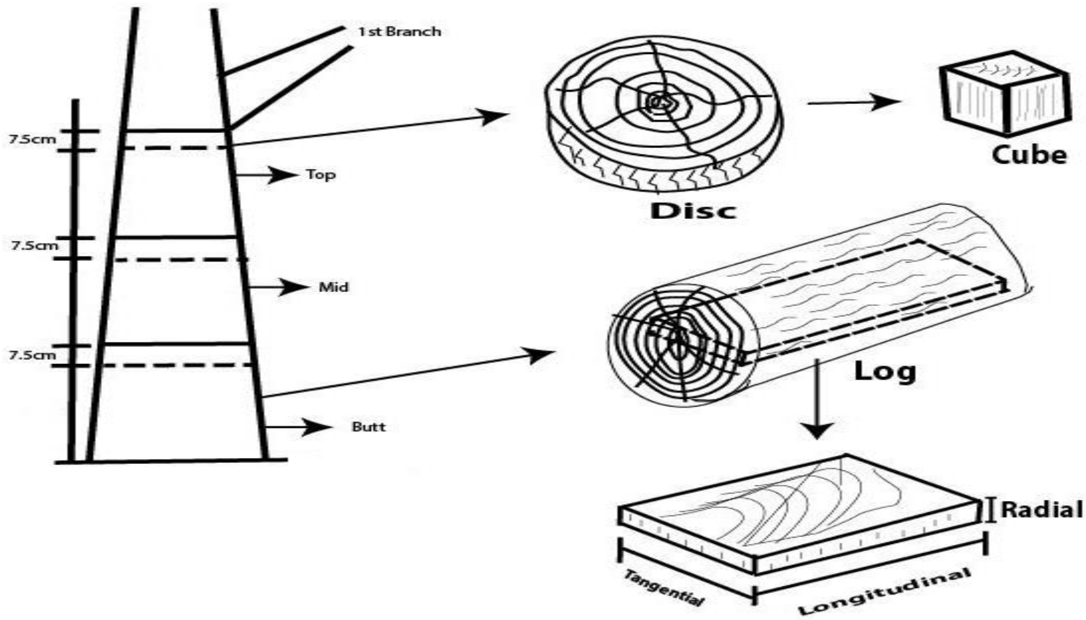

Figure 1: Schematic axial extraction of samples for the determination of the physical and mechanical properties of sweet detar (*Detarium microcarpum* Guill. & Perr.) wood (Tampori *et al.* 2024).

Determination of physical properties

Physical properties were determined in accordance with ASTM D4442-20 (2020), ASTM D2395-22 (2022), and ASTM D143-23 (2023). A total of 135 defect-free specimens were prepared from the three axial sections.

Moisture content, oven-dry density, volumetric shrinkage, and swelling were determined under standard conditions. Specimens were oven-dried at 103 °C until constant mass.

Determination of mechanical properties

Mechanical properties were determined after preparing test specimens and air-drying to 12 % moisture content at the timber mechanics and engineering laboratory at Forestry Research Institute of Ghana (FORIG). The mechanical properties determined include static bending (MOR and MOE), compression parallel to the grain, and shear parallel to the grain in accordance with (BS 373 (1957)).

Static bending (MOR and MOE)

A total of 135 specimens (20 × 20 × 600 mm) were tested under three-point bending with a span length of 280 mm. Load was applied at a constant rate until failure, and modulus of elasticity (MOE) and modulus of rupture (MOR) were calculated.

Figure 2: Image of universal testing machine during testing (UTM). (Author 2025)

Compression parallel to grain

Compression tests were conducted on 135 specimens (20 × 20 × 60 mm). Load was applied until failure, and maximum compressive strength parallel to grain was recorded.

Shear strength parallel to the grain

Shear strength was determined using 135 specimens (50 × 50 × 50 mm). Load was applied at a constant rate until failure, and maximum shear strength was calculated (Figure 3).

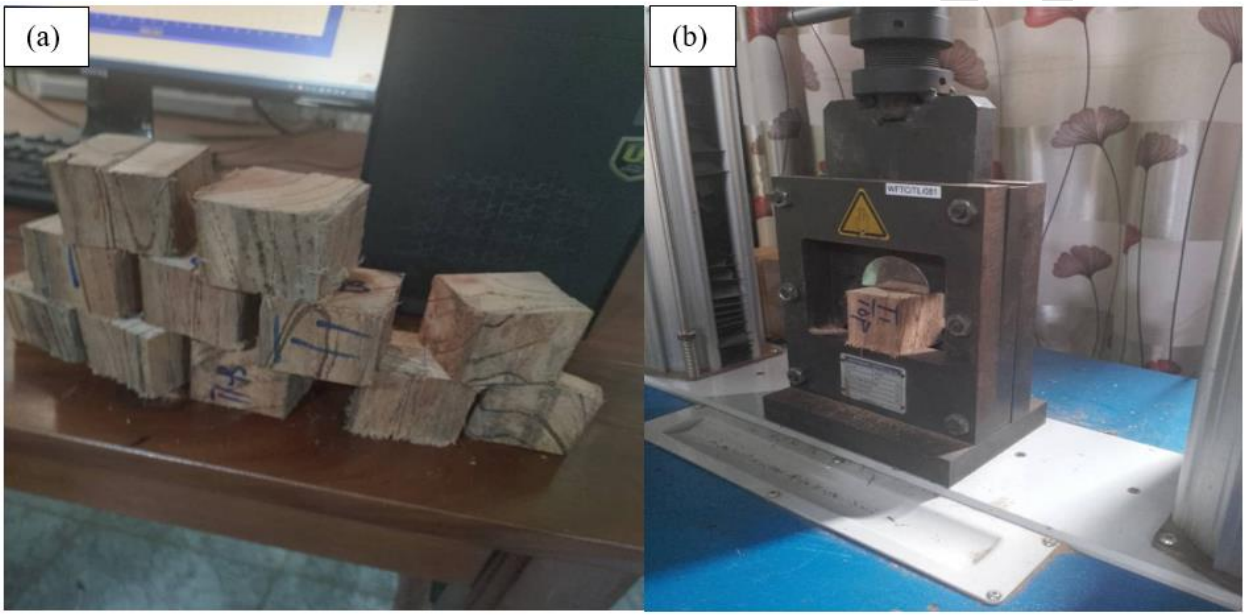

Figure 3: Shear strength test setup: (a) prepared specimens; (b) specimen under loading in the UTM.

Data analysis techniques

Mean values of physical and mechanical properties were computed. One-way ANOVA was performed using IBM SPSS Statistics 23 to evaluate the effect of axial position (bottom, middle, top). Statistical significance was assessed at $p < 0,05$ and effect size (η^2) was reported.

Results and discussion

The results of this study show that the mechanical properties of sweet detar (*Detarium microcarpum* Guill. & Perr.) wood vary significantly along the stem, with higher values observed in the basal sections.

Moisture content (MC %)

The results of this study showed that Moisture content increased progressively from the bottom to the top sections of the stem (Table 1). One-way ANOVA indicated significant differences among axial sections ($p < 0,05$), with axial position explaining 96 % of the observed variation ($\eta^2 = 0,96$). The increase in moisture content toward the upper stem sections observed in this study may be associated with differences between stem sections, and similar trends have been reported in previous studies, where higher moisture content is observed toward the upper parts of the stem (Thybring and Fredriksson 2023).

Conversely, lower moisture content in the basal sections may be linked to the presence of mature wood, which is typically characterized by higher density and reduced moisture uptake. This observation is consistent with findings by Arisandi *et al.* (2023) and Bengono *et al.* (2024), who reported lower moisture content in basal regions due to heartwood formation and reduced parenchyma content.

Table 1: Mean values with Variance components for Physical properties of sweet detar (*Detarium microcarpum* Guill. & Perr.).

Tree Section	Moisture content (%)		Oven-dry density (kg/m^3)		Volumetric shrinkage (%)		Volumetric swelling (%)	
	Mean	Var. (%)	Mean	Var. (%)	Mean	Var. (%)	Mean	Var. (%)
Bottom	13,78 (±0,97)	0,94	775,84 (±36,24)	22,54	23,49 (± 1,66)	2,75	29,36 (± 2,03)	0,79
Middle	14,41 (±1,21)	1,46	708,91 (±51,73)	51,73	26,42 (± 2,33)	5,43	31,9 (± 2,53)	1,43
Top	16,35 (±1,35)	1,81	670,28 (±91,62)	68,11	28,89 (± 2,49)	6,18	33,87 (± 1,92)	1,87

Mean values and standard deviation in parentheses with Variance.

Table 2: One-way ANOVA of physical properties between axial sections of sweet detar (*Detarium microcarpum* Guill. & Perr.).

Physical Properties	Sum of Squares	df	Mean Squares	F-value	p	η^2
Moisture content	10,77	2	5,38	47,9	0,002**	0,96
Oven-dry density	17115,07	2	8557,53	50,74	0,001**	0,96
Volumetric shrinkage	43,83	2	21,92	100,8	<0,001**	0,98
Volumetric swelling	30,57	2	15,29	53,59	0,001**	0,96

** = significant at p<0,05 ns = not significant.

Wood density

Wood density decreased progressively from the bottom to the top sections of the stem (Table 1), with mean values of 775,84 kg/m³, 708,91 kg/m³, and 670,28 kg/m³, respectively. One-way ANOVA indicated a highly significant effect of axial position ($F = 50{,}74$; $p = 0{,}001$; $\eta^2 = 0{,}96$), showing that stem position accounted for 96 % of the observed variation.

The higher density observed in the bottom section in this study may be associated with differences between basal and upper stem sections, and this axial trend is consistent with previous findings in tropical hardwoods, where density decreases from the base toward the crown. (Wiemann 2022, Yonkeu *et al.* 2021).

Similarly, Purusatama *et al.* (2025) reported higher density in basal regions due to increased heartwood formation, while José *et al.* (2022) and González *et al.* (2020) linked lower density in upper stem sections to differences in anatomical composition associated with juvenile wood.

The development of relatively denser wood in the lower stem observed in this study may also be associated with greater mechanical and physiological demands in this region, as reported by Baer *et al.* (2021), Huo *et al.* (2021), and Dória *et al.* (2022).

These results confirm a clear axial variation in density, with higher values observed in the lower stem sections.

Volumetric shrinkage

The volumetric shrinkage of sweet detar (*Detarium microcarpum* Guill. & Perr.) wood increased progressively from the bottom (23,49 %) to the middle (26,42 %) and top sections (28,89 %) (Table 1), indicating a clear axial variation. This trend was statistically significant, as confirmed by one-way ANOVA ($F = 100{,}8$; $p < 0{,}001$; $\eta^2 = 0{,}98$; Table 2), showing that axial position explained 98 % of the observed variation. The higher standard deviation in the top section further suggests greater variability in shrinkage in this region.

The increase in volumetric shrinkage toward the upper stem sections observed in this study is consistent with previous findings (Areghan and Ogutuga 2019, Bengono *et al.* 2024, Adegoke *et al.* 2021). This pattern may be associated with differences between basal and upper stem sections. Similar trends have been reported in previous studies, where higher shrinkage values are observed toward the upper parts of the stem (Rahayu *et al.* 2021, Purba *et al.* 2021, Horbelt *et al.* 2021, Fos *et al.* 2023).

Similar axial trends have been reported in tropical hardwoods, where higher shrinkage values in upper stem sections have been associated with variations in wood structure and moisture-related behavior (Ojo *et al.* 2022, Bengono *et al.* 2024).

The relatively higher shrinkage values observed in this study suggest a greater susceptibility to dimensional changes, particularly in the upper stem sections. In contrast, the lower shrinkage recorded in the bottom section indicates comparatively better dimensional stability.

These results confirm that axial position significantly influences dimensional stability in sweet detar (*Detarium microcarpum* Guill. & Perr.) wood. The lower and middle stem sections may offer comparatively better dimensional stability, while the upper sections indicate greater susceptibility to dimensional variation in the upper stem sections. Such variation highlighting the influence of axial position on dimensional stability, as also reported in previous studies (Bonduelle *et al.* 2015, Taube *et al.* 2020).

Volumetric swelling

The volumetric swelling of sweet detar (*Detarium microcarpum* Guill. & Perr.) wood increased progressively from the bottom to the top sections of the stem (Table 1), with the lowest mean value recorded in the bottom section and the highest in the top section, indicating a clear axial variation. This trend was statistically supported by one-way ANOVA (Table 2), which showed a significant effect of axial position ($p = 0,001$; $\eta^2 = 0,96$), with the most pronounced difference observed between the bottom and top sections ($p = 0,015$).

The increase in volumetric swelling toward the upper stem sections observed in this study is consistent with previous findings (Ilek *et al.* 2024, Zambonini *et al.* 2024, Arzola-Villegas *et al.* 2019), where swelling tends to increase along the stem height, and similar patterns of variability in moisture-related properties have also been reported (Muñoz and Lorenzo 2022).

The relatively higher swelling values observed in the upper sections in this study indicate greater dimensional variability, while the lower values in the bottom section suggest comparatively better dimensional stability.

These results indicate greater variability in dimensional response in the upper stem sections compared to the basal regions.

Mechanical properties of *Detarium microcarpum*

Table 3: Mean values with Variance components for mechanical properties of sweet detar (*Detarium microcarpum* Guill. & Perr.).

Tree Section	Modulus of Elasticity (MPa)		Modulus of Rupture (MPa)		Compression parallel to grain (MPa)		Shear parallel to grain (MPa)	
	Mean	Var. (%)	Mean	Var. (%)	Mean	Var. (%)	Mean	Var. (%)
Bottom	6453,78 (±146,35)	21418,11	53,68 (± 3,57)	12,76	40,44 (± 3,32)	11,03	17,24 (± 0,9)	0,81
Middle	6218,47 (± 178,75)	31952,08	50,94 (± 2,67)	7,13	36,62 (± 2,15)	4,61	16,2 (± ,89)	0,79
Top	5996,44 (± 191,54)	36686	48,65 (± 2,69)	7,22	33,33 (± 0,82)	0,67	14,7 (± 0,1)	0,01

Mean values and standard deviation in parentheses with Variance.

Table 4: One-way ANOVA of mechanical properties between axial sections of sweet detar (*Detarium microcarpum* Guill. & Perr.).

Mechanical Properties	Sum of Squares	df	Mean Squares	F-value	p	η^2
Modulus of elasticity	313816,38	2	156908,19	30,54	0,004**	0,94
Modulus of rupture	38,06	2	19,03	64,44	0,001**	0,97
Compressive strength	76,12	2	38,06	13,25	0,017**	0,87
Shear strength	9,79	2	4,89	15,93	0,012**	0,89

** = significant at p<0,05 ns = not significant.

Modulus of elasticity (MOE)

The results in Table 3 show that the values of Elasticity Modulus (MOE) for sweet detar (*Detarium microcarpum* Guill. & Perr.) reduce from the base section to the top. The one-way ANOVA revealed a significant variation between axial stem sections ($F = 30{,}54$; $p = 0{,}004$; $\eta^2 = 0{,}94$), indicating that 94 % of the variation in MOE is attributed to stem position (Table 4).

The variation in axial Modulus of Elasticity (MOE) observed in this study reflects the differences between stem sections, with higher values recorded in the basal region. This trend is consistent with previous findings in tropical hardwoods, where MOE decreases from the base toward the top of the stem (Luo *et al.* 2021).

These differences may be associated with variations in wood characteristics between basal and upper stem sections (Zhang *et al.* 2022). The results of this study align with previous findings, as Rahayu *et al.* (2021) and Jarrett *et al.* (2020) reported that mature wood in the lower stem exhibits higher MOE. Similar axial variation has been reported in tropical hardwoods (Tumenjargal *et al.* 2020 and González *et al.* 2020).

Modulus of rupture (MOR)

The modulus of rupture (MOR) of sweet detar (*Detarium microcarpum* Guill. & Perr.) wood decreased progressively from the bottom to the top sections of the stem (Table 3), indicating a clear axial variation. This trend was statistically confirmed by one-way ANOVA ($F = 64{,}44$; $p = 0{,}001$; $\eta^2 = 0{,}97$), showing that 97 % of the variation in MOR is explained by stem position (Table 4).

The progressive decline in MOR from the base to the top of the stem observed in this study is consistent with axial variation reported in tropical hardwoods (Hone *et al.* 2021, Dessie *et al.* 2022, Stubbs *et al.* 2022). Similar trends have been associated with differences between basal and upper stem wood, which influence mechanical performance (Tian *et al.* 2023, Bektaş *et al.* 2020).

The higher MOR values observed in the bottom section in this study may be associated with the presence of more developed wood in the basal region, while the lower values in the upper sections may reflect differences in wood characteristics along the stem. Comparable observations have been reported in previous studies (Wang *et al.* 2021, Piponiot *et al.* 2022, Yang *et al.* 2024, Eng Kuan *et al.* 2021).

Similarly, lower MOR values in upper stem sections have been reported in relation to axial variation in wood properties (Valdovinos-Ayala *et al.* 2022, Alqrinawi *et al.* 2024, França *et al.* 2022, Petrova *et al.* 2024), supporting the pattern observed in this study.

Compressive strength parallel to the grain

The compressive strength parallel to the grain of sweet detar (*Detarium microcarpum* Guill. & Perr.) wood decreased progressively from the base to the top of the stem, with mean values of 40,44 MPa, 36,62 MPa, and 33,33 MPa for the bottom, middle, and top sections, respectively (Table 3), indicating a clear axial variation. This trend was statistically confirmed by one-way ANOVA ($F = 13,25$; $p = 0,017$; $\eta^2 = 0,87$; Table 4), showing that 87 % of the variation in compressive strength is explained by stem position.

The progressive decline in compressive strength from the base to the top observed in this study is consistent with previous findings in wood mechanics, where similar axial trends have been reported (Niez *et al.* 2020, Zhang *et al.* 2023).

The higher compressive strength observed in the bottom section in this study may be associated with the presence of more developed wood in the basal region, while the lower values in the upper sections may reflect differences in wood characteristics along the stem (Chambers-Ostler *et al.* 2022, Osazuwa-Peters *et al.* 2017, Wang *et al.* 2024, Plavcová *et al.* 2024).

Overall, the results indicate a clear axial variation in compressive strength, with lower stem sections exhibiting comparatively higher values than the upper sections.

Shear strength parallel to the grain

The shear strength parallel to the grain of sweet detar (*Detarium microcarpum* Guill. & Perr.) wood decreased progressively from the base to the top of the stem (Table 3), indicating a clear axial variation. This trend was statistically confirmed by one-way ANOVA ($F = 15,93$; $p = 0,012$; $\eta^2 = 0,89$; Table 4), showing that 89 % of the variation in shear strength is explained by stem position.

The axial decline in shear strength observed in this study is consistent with previous findings in tropical hardwoods (Khaeso and Laloon 2019, Vilkovský *et al.* 2022). Similar trends have also been reported by Li *et al.* (2021), where variations in shear strength were associated with differences between basal and upper stem wood.

The higher shear strength observed in the bottom section in this study may be associated with the presence of more developed wood in the basal region, while the lower values in the upper sections may reflect differences in wood characteristics along the stem (Higham *et al.* 2022, Miller *et al.* 2019, Eloy *et al.* 2023).

These results indicate relatively high shear strength values across all stem sections, with higher performance observed in the basal region.

Conclusions

This study evaluated the physical and mechanical properties of sweet detar (*Detarium microcarpum* Guill. & Perr.) wood, with particular emphasis on axial variation along the stem. The results demonstrated a clear and consistent pattern, with most properties varying significantly from the base to the top of the stem. In general, the basal sections exhibited comparatively higher density and mechanical strength, while the upper sections showed increased moisture-related responses and reduced strength properties.

These findings confirm the presence of pronounced axial variation in both physical and mechanical properties of sweet detar (*Detarium microcarpum* Guill. & Perr.), highlighting the importance of stem position in determining wood performance.

The results of this study provide baseline data on the physical and mechanical properties of sweet detar (*Detarium microcarpum* Guill. & Perr.), contributing to the limited scientific information available for this species. The observed mechanical performance, particularly in the basal sections, suggests potential for applications where higher strength is required. However, considering that the results are based on small clear specimens, these implications should be regarded as preliminary and would require further validation under practical conditions.

Overall, this study contributes to a better understanding of the material properties of sweet detar (*Detarium microcarpum* Guill. & Perr.) and supports its consideration as a potential alternative timber resource. Future studies should focus on processing characteristics, durability, and long-term performance to further support its utilization.

Authorship contributions

Z. A.S: Conceptualization, resources, methodology, writing – original draft. I. C: Investigation, validation, formal analysis, writing-review & editing. M. B. D: Supervision, proofreading, visualization. F.K.B: Software, data curation, visualization. S.J.M: Investigation, resources, supervision.

Conflicts of interest

Authors declare no conflicts of interest.

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