Wood Science — Non-Tree Plants

Emmanuel Ebanyenle* and Andrew Akwasi Oteng-Amoako

Anatomical and density properties of *Oxytenanthera abyssinica* culm

https://doi.org/10.1515/hf-2025-0003
Received January 9, 2025; accepted November 12, 2025;
published online November 27, 2025

Abstract: *Oxytenanthera abyssinica* (A. Rich.) Munro is the only indigenous bamboo species in Ghana but remains underutilized. Investigating the technological properties of *O. abyssinica* culms could facilitate it efficient processing and comprehensive utilization. In this study, the anatomical and density properties of matured culms of *O. abyssinica* growing in the savanna region of Ghana were examined. The anatomy of the intermodal culm wall of *O. abyssinica* showed a monocotyledonous stem structure. The wall structures showed distinct outer cortex, central cylinder comprising vascular bundles embedded in a ground parenchyma and an inner pith ring. *O. abyssinica* exhibited a combination of type III and IV vascular bundles. Furthermore, tissue proportions, fiber characteristics and other properties including, internode length and diameter, and culm wall thickness, varied significantly with culm positions but basic density was not impacted by axial positions. The anatomical and density properties could facilitate the efficient processing and utilization of this underutilized bamboo species.

Keywords: Africa; anatomy; fiber; poaceae; savanna bamboo; technological properties

1 Introduction

Oxytenanthera abyssinica (Savanna bamboo) is a member of the grass family Poaceae and native to Africa, distributed from Senegal to Mozambique (Inada and Hall 2008). It is typically a lowland bamboo which grows in areas up to 2,000 m above sea level and with mean annual rainfall greater than 800 mm. However, in Ghana, *O. abyssinica* is drought tolerant and grows on river banks, fire prone savanna areas and on shallow soils. It is known to grow on termite hills. In Ghana, *O. abyssinica* is confined to the savanna vegetation zone (Irvine 1961). The savanna zone covers about 60 % of Ghana's total land area of about 238,535 km^2 and receives an annual mean rainfall of 900 mm to 1,200 mm with a relief of up to 150 m above sea level.

Oxytenanthera abyssinica was not listed as one of the 20 global priority species of economically important bamboo (Maviton and Sankar 2022). However, the culms are used locally for charcoal, fencing, construction and number of household implements (Inada and Hall 2008; Obiri and Oteng-Amoako 2007). Recent investigations are exploring the strength properties and the potential utilization of *O. abyssinica*. The pulping characteristics of *O. abyssinia* was examined (Abdalla and Elzaki 2014). Abegaz et al. (2005) investigated the potential utilization of *O. abyssinica* as a reinforcement steel bar in concrete. Furthermore the anatomical and mechanical properties were recently studied to aid in the development of biomimetic materials (Yu et al. 2023).

The technological properties of bamboo culms differ within and between species and have implications on their processing and utilization (Chen et al. 2022, Jiang 2020, Liese 1998, Mulyaningsih et al. 2022). The physical and mechanical properties of bamboo culm correlate with its anatomical structures (Janssen 1981; Latif and Jusoh 1992; Latif and Liese 2002; Liese 1998; Widjaja and Risyad 1985). Proportion of fiber tissue; fiber diameter; and cell wall thickness impact density. As a result, density of bamboo culms vary considerably within and between species (Siam et al. 2019). The peripheral portion of the bamboo culm with higher proportion of fibers exhibit higher density values than the inner portion (Liese 1998). Similarly, density increases along the culm from the base to the top due to the thinner culm wall with higher proportion of vascular bundles. Shrinkage is influenced by the stage of fiber maturation and the density of vascular bundles (Liese and Weiner 1996). The radial and tangential shrinkage decreases with the height of the culm since the top portion has a higher number of vascular bundles (Liese 1998).

***Corresponding author: Emmanuel Ebanyenle**, CSIR – Forestry Research Institute of Ghana, UPO 63, Kumasi, Ghana,
E-mail: ebanyenle@csir-forig.org.gh. https://orcid.org/0009-0001-6730-029X
Andrew Akwasi Oteng-Amoako, CSIR – Forestry Research Institute of Ghana, UPO 63, Kumasi, Ghana, E-mail: oteng.amoako@gmail.com

Variation in bamboo culm morphology, anatomy and physical properties could be attributed to species, geographic sources, genotypic constitution and climate (Banik 1997, Prasad 1948). For example, *Gigantochloa pseudoarundinacea* growing on hill slopes, exhibited higher values of density, bending and tensile strength than those growing in lowlands (Soeprayitno et al. 1988). Likewise fiber characteristics of *O. abyssinica* were impacted by site in Sudan (Abdalla and Elzaki 2014). Despite abundant genetic diversity observed in *O. abyssinica* (Lian et al. 2016), virtually no studies have been conducted on the basic technological properties including anatomy and physical properties of *O. abyssinica* from Ghana. Therefore, the objective of this research was to examine the basic technological properties of *O. abyssinica* to aid in their efficient processing and utilization.

2 Materials and methods

2.1 Sampling of materials

The total land area of Ghana is about 238,535 km^2. Nearly 60 % of the total land area is savanna and 40 % is tropical high forest (Hall and Swaine 1981). The Guinea savanna zone which hosts *O. abyssinica* receives annual rainfall of 900–1,200 mm. Culms of *O. abyssinica* were sampled from the Guinea savanna zone of Ghana. A total of seven matured culms 3–4 (5) years old of *O. abyssinica* were sampled from different growing sites in Bolgatanga, Sadema, Gabanga East Forest Reserve and Wa for investigations. Each bamboo culm was randomly sampled from different growing clumps separated by a minimum distance of about 2 km apart. This sampling procedure was followed in order to capture and describe the entire range of variation as accurately as possible.

2.2 Determination of morphological and density properties

Culm length was determined from ground level to the tip of the bamboo. Each culm was subdivided into basal, middle and top sections, each representing a third of the total bamboo culm length. The mid internodes of the basal, middle and top sections were collected for the determination of internode diameter and length, culm wall thickness and density. The determination of density followed the procedures of international standards for testing bamboo culms. A 2.5 cm disc test samples were prepared from the mid internodes of the basal, middle and top sections. The green volume of the test samples were determined by measuring the dimensions of the discs using a Vernier caliper with an accuracy of 0.05 mm. The tests samples where then dried in an oven at a temperature of 103 ± 2 °C for 24 h. The mass of the dried test samples were determined at intervals of 2 h after 24 h. The drying was deemed completed when the difference between successive mass did not exceed 0.001 g. The density for test samples were determined by the formula: density (kg m^{-3}) = (m/v) × 10^6, where m is the mass in g, v is the volume in mm^3 (Trujillo 2019).

2.3 Determination of anatomical properties

A 2 cm disc samples were prepared from the mid internodes of the basal, middle and top sections for anatomical investigations. The 2 cm disc samples were sub-divided into two diameter flanks. One flank was used for making thin sections and the other for maceration purposes. The sample for thin sections were softened by saturating it with water and later keeping it in a mixture of ethanol and glycerol (1:1) in labeled containers for an average period of about 20–30 days. Five transverse sections of thickness 15–25 μm across the periphery, middle and core regions of the discs (Figure 1) were cut using a sliding microtome. The sections were first washed in distilled water and then stained in 1 % safranin in 50 % ethanol solution for about 10–20 min. After staining, they were washed in water and dehydrated in increasing concentration of ethanol: 30, 50, 70, 85, 90 and 100 % and later mounted in Canada balsam. All prepared slides were dried at 60 °C overnight. The prepared transverse thin sections were then examined under light microscope. Fiber, conducting tissue and parenchyma proportions (Figure 2) were determined from the periphery, middle and core regions using a10× objective lens and 10× eyepiece with a dot grid scale of 20 points. The dot grid scale was randomly placed five times each at the periphery, middle and core transverse sections. At each placement the number of points covering any fiber, parenchyma and conducting tissue were counted and expressed as a proportion of the total number of points (Figure 3).

To determine the bamboo fiber characteristics, a split of matchstick size were taken from the periphery portions only of the anatomical test samples and macerated using mixtures of hydrogen peroxide and acetic acid (1:1). The specimens were then incubated at 60 °C for a day to obtain complete maceration. The macerated samples were rinsed with water and mounted temporarily in dilute glycerol for measurements of fiber dimensions (length, diameter, lumen, double fiber wall thickness). Measurements were made with

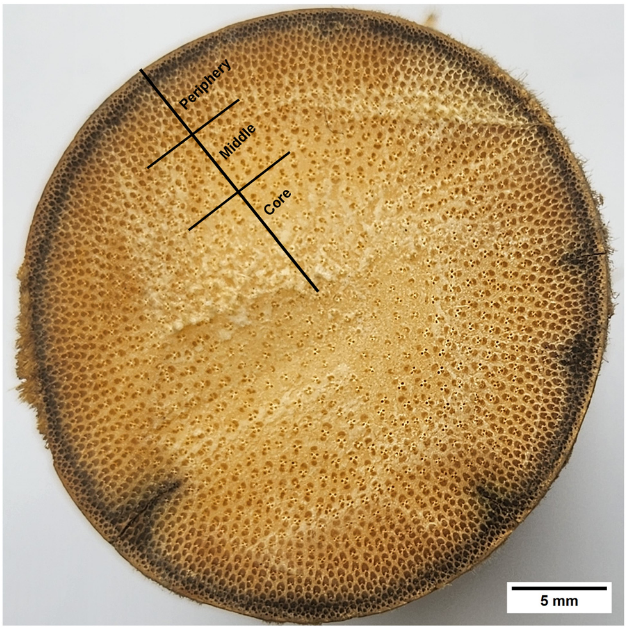

Figure 1: Picture of a transverse view of *Oxytenanthera abyssinica* culm showing a solid culm and the periphery, middle and core regions.

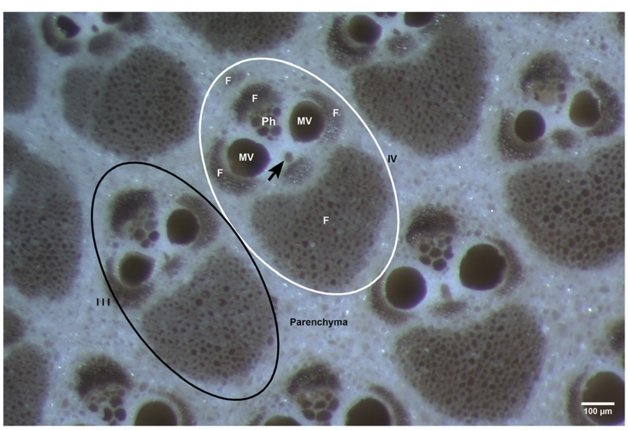

Figure 2: Macrograph of transverse section of *Oxytenanthera abyssinica* culm showing the fibers (F) and the conducting tissue consisting of metaxylem vessels (MV), phloem (Ph) and the protoxylem (black arrow). The black elliptical selection is vascular bundle type III and white elliptical selection is vascular bundle type IV.

an eyepiece scale of 100 divisions after the micrometer value has been determined for all the objective lenses. Fiber length, width, lumen and double wall thickness were measured on 50 complete and straight fibers per macerated sample. Terminology for anatomical descriptions followed Liese (1998).

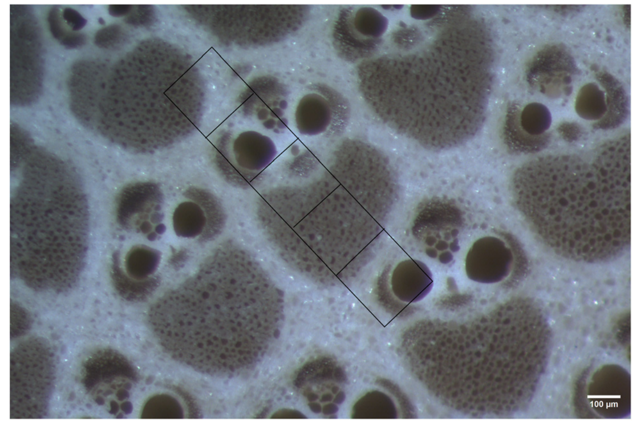

Figure 3: Macrograph of transverse section of *Oxytenanthera abyssinica* culm showing a portion of a 20 dots grid. Here only 12 dots (intersections) are shown. The number of dots that cover fiber, or parenchyma or conducting tissues (phloem, metaxylem and protoxylem vessels) were divided by 20 expressed in percentage as a fiber, parenchyma or conducting tissue proportion.

2.4 Analysis of data

Qualitative anatomical traits were presented in descriptive form with photomicrographs. R, version 4.4.2 (R CoreTeam 2024) was used to perform analysis of variance (ANOVA) to evaluate the variation in quantitative anatomical, morphological and physical properties along the length of bamboo culm from basal, middle and top (axial position effect) and across the bamboo culm from periphery, middle and core (radial position effect). Position effects were considered significant when the P – value of ANOVA F – test was less than 0.05. Descriptive mean values were presented with standard errors.

3 Results

3.1 Physical properties of bamboo culms

The mean culm length and internode number were 6 ± 0.5 m and 26 ± 2 cm, respectively. Additional culm characteristics of *O. abyssinica* are presented in Table 1. Mean intermodal length (26.0 ± 1.4 cm) and diameter (17.0 ± 1.8 mm) and culm wall thickness (7.0 ± 1.3 mm) varied significantly with axial position (Table 1). The middle internode was longer than the basal and top internodes whilst internode diameter and culm wall showed greater mean values at the base than the middle and top positions. The mean density irrespective of

Table 1: Mean bamboo culm diameter, internode length, wall thickness and density in relation to position along the culm (basal, middle and top) of *Oxytenanthera abyssinica*.

	Culm axial position			
Culm parameter	**Basal**	**Middle**	**Top**	***P*-value**
Diameter (mm)	26 ± 3.2	19 ± 1.8	9 ± 0.9	0.00
Internode length (cm)	28.4 ± 1.4	30.2 ± 0.7	19.4 ± 1.4	0.00
Wall thickness (mm)	14.0 ± 3.8	4.6 ± 0.2	2.2 ± 0.2	0.00
Basic density (kg m^{-3})	683 ± 34	679 ± 29	641 ± 8	0.48

Values are means ± SE; $n = 7$. Axial position effect is significant when $p < 0.05$.

axial position was 668 ± 11 kg m^{-3}. Although differences existed in the mean density in relation to culm axial position, it was not statistically significant (Table 1).

3.2 Anatomical properties

The anatomy of the intermodal culm wall of *O. abyssinica* showed a monocotyledonous stem structure (Tomlinson 1961). The wall structure showed distinctly an outer cortex, a central cylinder comprising vascular bundles embedded in a

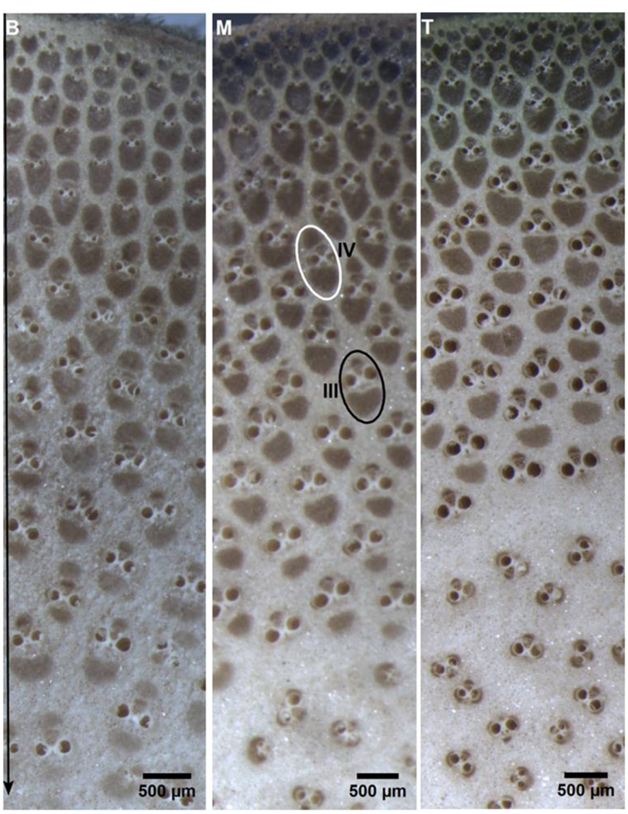

Figure 4: Macrographs of transverse sections of *Oxytenanthera abyssinica* culm at the base (B), middle (M) and top (T) illustrating distribution of vascular bundles from peripheral zone to the inner zone (black arrow). The peripheral portions exhibit more densely arranged vascular bundles with larger fiber strands compared to the core vascular bundles.

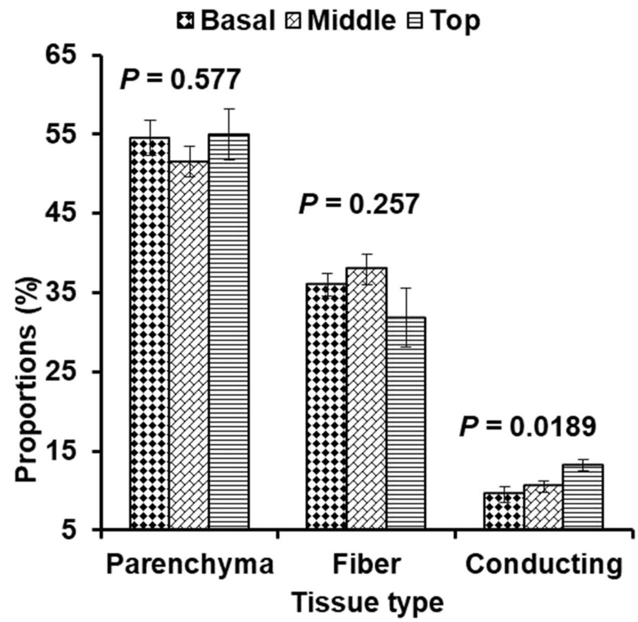

Figure 5: Proportions of parenchyma, fiber and conducting tissues in relation to the axial positions (basal, middle and top) along the bamboo culms. Bars are means ± SE, $n = 7$. Axial position effect is significant when $p < 0.05$.

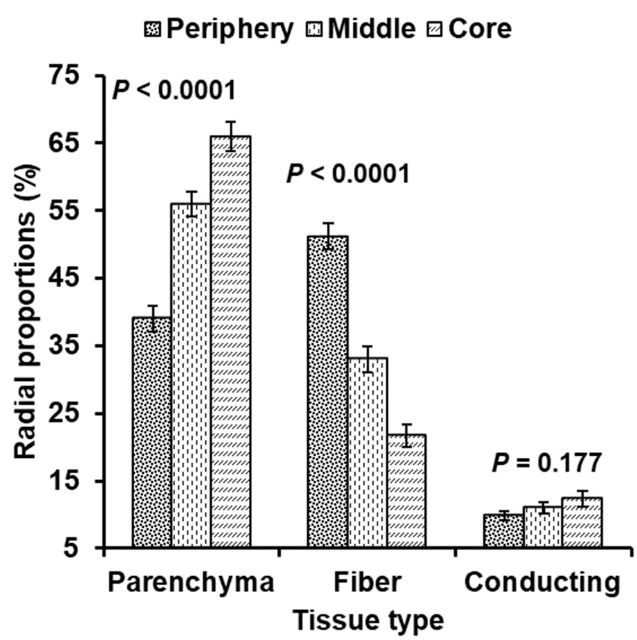

Figure 6: Proportions of parenchyma, fiber and conducting tissues in relation to the radial positions (periphery, middle and core) across the bamboo culms. Bars are means ± SE. Means were determined, across all axial positions (basal, middle and top). Radial position effect is significant when $p < 0.05$, and $n = 21$.

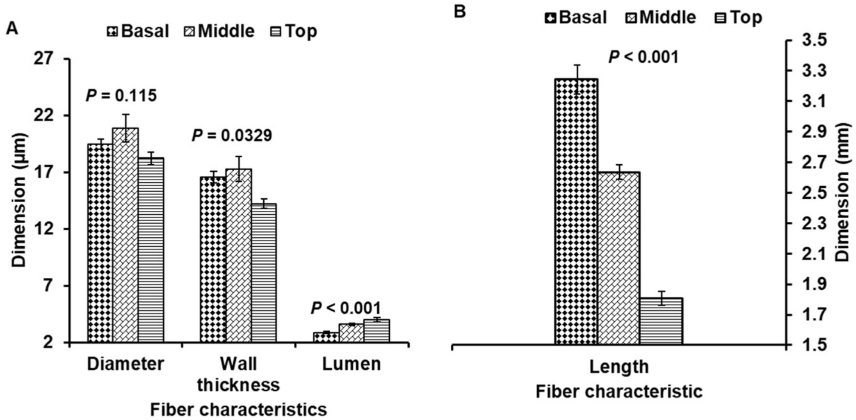

Figure 7: Fiber diameter, fiber wall thickness, and fiber lumen diameter (A) and fiber length (B) in relation to the axial positions (basal, middle and top) along the bamboo culms. Bars are means ± SE. Means were determined from the peripheral portion of the culms. Axial position effect is significant when $p < 0.05$ and, $n = 7$.

ground parenchyma. The vascular bundle consists of metaxylem vessels, protoxylem vessels, phloem and fibers (Figure 4). Vascular bundles appeared densely arranged at the peripheral and middle zones but fewer in the inner zone (Figure 4). *O. abyssinica* exhibited a combination of type III and IV vascular bundles (Liese and Grosser 2000). The type III vascular bundles were predominant but few type IV were observed, also (Figure 4). Irrespective of positions, percentage proportion of parenchyma, fiber and conducting tissues, were 54 ± 1, 35 ± 1 and 11 ± 1, respectively. Proportion of parenchyma and fiber did not exhibit significant variation along the axial direction of the bamboo culms. However, the proportion of conducting tissue increased significantly from basal to the top portions of the culms (Figure 5). Likewise, proportions of fiber and parenchyma tissues varied significantly with radial position (Figure 6). Mean fiber diameter, lumen diameter, fiber wall thickness and fiber length were 19.5 ± 0.4 µm, 3.5 ± 0.1 µm, 16 ± 0.4 µm, 2.6 ± 0.05 mm respectively, irrespective of culm positions. However, there were significant statistical variations along the bamboo culms with respect to fiber lumen, fiber wall thickness and fiber length (Figure 7).

4 Discussion

Measurements of the culm characteristics showed that the culm length compares well with culm length of *O. abyssinica* from Ethiopia (Anjulo et al. 2022; Bahru and Ding 2021) and other Africa countries (Bahru and Ding 2021; Inada and Hall 2008). Bamboo culm length, internode length, diameter, wall thickness and density are important traits in many bamboo applications. These traits vary significantly between and within species (Ebanyenle and Oteng-Amoako 2007; McClure 1966) due to genetics and site conditions. Bamboo species with thick to solid culm wall (more than 10 mm), large size diameter (8–25 cm), shorter internodes (less than 30 cm) and high density (greater than 500 kg m^{-3}) are generally suitable for structural purposes. Whereas bamboo species with thin culm wall (less than 10 mm), small to medium diameter (3–10 cm), internodes longer than 30 cm, are appropriate for handicrafts and roofing purposes (Banik 1997). Based on the observed culm traits, *O. abyssinica* will be suitable for the handicrafts purposes. Several uses of *O. abyssinica* including weaving, household utensils and handicrafts were reported by Bahru and Ding (2021).

The mean intermodal length and diameter and culm wall thickness varied significantly with axial position (basal, middle and top) in *O. abyssinica*. Culm diameter and wall thickness were significantly higher in the basal portions than the middle and top portions whilst internode length was longer in the middle portion than the basal and top. Similar trends have been reported for several bamboo species (Latif and Jusoh 1992; Latif and Liese 2002; Liese 1998; Mensah et al. 2021; Wahab et al. 2010). This observation implies that bamboo culm axial position is important factor for consideration during bamboo processing. Regarding density, axial position did not have significant effect. Similar observation was observed for *Bambusa vulgaris* (Portal-Cahuana et al. 2023). However, density has been observed to increase from the basal to the top portions due to increase in fibro-vascular bundles at the top of bamboo culms (Latif and Liese 2002; Liese 1998; Siam et al. 2019). Variations in the physical and technological properties of different bamboo species is not uncommon (Siam et al. 2019). Hence bamboo species type may be an important factor for consideration in bamboo products development and utilization (Bahru and Ding 2021; Chen et al. 2022; Espiloy 1992; Latif and Liese 1995; Maviton and Sankar 2022).

The anatomy of the intermodal culm wall of *O. abyssinica* showed a monocotyledonous stem structure (Tomlinson 1961) and comparable to bamboo anatomical structure (Liese 1998). The wall structures of showed distinctly an outer cortex, a central cylinder comprising vascular bundles embedded in a ground parenchyma and inner pith ring. *O. abyssinica* exhibited a combination of type III and IV vascular bundles (Liese and Grosser 2000). In contrast, a combination of type III and IV have also been observed in other bamboo species (Siam et al. 2019). This suggests that the use of vascular bundle as diagnostic taxonomic feature in identification of processed culms of *O. abyssinica* from Ghana should be done with extreme caution. Consistent with observations by Yu et al. (2023) for the same species from Ethiopia, vascular bundles appeared smaller and densely arranged at the peripheral zone but larger and fewer in the core zone. Proportion of parenchyma tissue increased from the peripheral zone towards to the core but proportion of fiber decreased from periphery towards the core zone. Similar trends have been reported for different bamboo species (Liese 1998, Siam et al. 2019) and *O. abyssinica* (Yu et al. 2023) This explains why bamboo is stronger at the peripheral zone and weaker in the core zone.

Fiber characteristics are good indicators of bamboo culm strength and important criteria for bamboo pulp quality (Xiang et al. 2020; Zhan et al. 2016). The observed means for fiber diameter, lumen diameter, fiber wall thickness and fiber length is comparable to reported values for *O. abyssinica* from Ethiopia, Sudan and other Africa countries (Abdalla and Elzaki 2014; Inada and Hall 2008; Yu et al. 2023). For example, fiber length of 1.7–2.8 mm were reported by Yu et al. (2023) and Inada and Hall (2008) whilst 1.92–1.94 mm were reported by Abdalla and Elzaki (2014) for the same bamboo species under investigation. These earlier observations are comparable to the current investigation with an overall mean fiber length of 2.6 ± 0.05 mm irrespective of axial position. The observed fiber values are considered to be within the suitable range for pulping purposes (Abdalla and Elzaki 2014; Yu et al. 2023).

Furthermore, there were significant statistical variations along the axial positions of bamboo culms of *O. abyssinica* with respect to fiber lumen, fiber wall thickness, and fiber length. Fiber length was significantly higher in basal zones than the middle and top positions. This study examined fiber dimensions in the peripheral zones of the basal, middle and top portions. Fiber length has been observed to be longer in the peripheral zone than the middle and the inner regions of *O. abyssinica* (Yu et al. 2023). In addition, fiber dimensions in *O. abyssinica* are influenced by site differences (Abdalla and Elzaki 2014) and radial positions (Abdalla and Elzaki 2014; Yu et al. 2023). This trends were also observed in *O. abyssinica* from Sudan (Abdalla and Elzaki 2014) and 13 bamboo species from Malaysia (Siam et al. 2019). Fiber characteristics impact on strength properties of bamboo culms (Chen et al. 2022; Janssen 1981; Portal-Cahuana et al. 2023; Siam et al. 2019), hence variations within the culm is important factor for consideration during bamboo processing and utilization (Chen et al. 2022).

In conclusion, this study examined the density and anatomical properties of *O. abyssinica* from the savanna zone of Ghana. Although, measurements of the density and anatomical properties revealed values comparable to existing reports, there were some differences which could be attributed to differences in methodological approach, genetics and site differences. Diameter of culms, culm wall thickness and internode length varied significantly along the axial direction but the basic density was not affected by axial position. Similarly, axial and radial positions had significant effects on tissue portions (parenchyma, conducting and fiber) and fiber characteristics. The anatomical and density properties could facilitate the utilization of this underutilized species in Ghana and Africa.

Acknowledgments: We are grateful to Mr. F. A Awuku and Mrs. Ruth Esi Amuzu for assisting in the data collection.
Research ethics: Not applicable.
Informed consent: Not applicable.
Author contributions: All authors have accepted responsibility for the entire content of this manuscript and approved its submission.
Use of Large Language Models, AI and Machine Learning Tools: None declared.
Conflict of interest: The authors state no conflict of interest.
Research funding: This research was funded by CSIR – Forestry Research Institute of Ghana (CSIR – FORIG) and the African Forest Research Network Programme of African Academy of Sciences (AAS); Grant no. 4 of December 2003.
Data availability: The authors confirm that the data supporting the findings of this study are available within the article.

References

Abdalla, A.M.A. and Elzaki, A.F.A.E. (2014). Properties and pulping potentialities of (*Oxytenanthera abyssinica*) grown at two locations in Sudan. In: *Proceedings of the 5th annual conference of post graduate studies and scientific research*, Khartoum, Sudan.

Abegaz, M., Jiru, N., and Oluma, B. (2005). *Oxytenantheria Abyssinica* bamboo stems as reinforcement steel bar in concrete. *Ethiop. J Nat. Resour.* 7: 95–109.

Anjulo, A., Mulatu, Y., Kidane, B., Reza, S., Getahun, A., Mulat, S., Abere, M., and Teshome, U. (2022). *Oxytenanthera abyssinica* A. Rich. Munro species-site suitability matching in Ethiopia. *Adv. Bamboo Sci.* 1: 100001.

Bahru, T. and Ding, Y. (2021). A review on bamboo resource in the African region: a call for special focus and action. *Int. J. For. Res.* 2021: 8835673.

Banik, R. (1997). Domestication and improvement of bamboos. In: *UNDP/FAO forest and tree improvement project*. IDRC/INBAR Working Paper No.10. International Network for Bamboo and Rattan, New Delhi, p. 53.
Chen, C., Li, H., Dauletbek, A., Shen, F., Hui, D., Gaff, M., Lorenzo, R., Corbi, I., Corbi, O., and Ashraf, M. (2022). Properties and applications of bamboo fiber: a current-state-of-the art. *J. Renew. Mater.* 10: 605–624.
Ebanyenle, E. and Oteng-Amoako, A. (2007). Site differences in morphological and physical properties of *Bambusa vulgaris* grown in Ghana. *Discov. Innovat.* 19: 222–225.
Espiloy, Z. (1992). Properties affecting bamboo utilization. In: Zhu, S., Li, W., Zhang, X., and Wong, Z. (Eds.). *Bamboo and its use. Proceedings of the international symposium on industrial use of Bamboo, Beijing, China, 7–11 December 1992*. International Tropical Timber Organisation; Chinese Academy of Forestry, Beijing, China, pp. 139–142.
Hall, J.B. and Swaine, M.D. (1981). *Distribution and ecology of vascular plants in a tropical rain forest. distribution and ecology of vascular plants in a tropical rain forest. Forest vegetation in Ghana*, Vol. xv +. Springer, Dordrecht, pp. 383.
Inada, T. and Hall, J.B. (2008). *Oxytenanthera abyssinica* (A. Rich.) Munro. [Internet] record from PROTA4U records. In: Louppe, D., Oteng-Amoako, A.A., and Brink, M. (Eds.). *PROTA – (plant resources of tropical Africa/resources vegetales l'afrique tropicale), wageningen, Netherlands*, Wageningen, Netherlands, http://www.prota4u.org/search.asp (Accessed 22 October 2024).
Irvine, F. (1961). *Woody plants of Ghana. with special reference to their uses*, Vol. 9. Oxford University Press, London, p. 886.
Janssen, J.J. (1981). The relationship between mechanical properties and the biological and chemical composition of bamboo. Bamboo production and utilization. *Proc. XVII IUFRO World Congr.* 1981: 6–17.
Jiang, Z.H. (2020). Research advances in bamboo anatomy. *World For. Res.* 33: 1–6.
Latif, M. and Jusoh, M. (1992). Culm characteristics of *Bambusa blumeana* and *Gigantochloa Scortechnii* and its effect on physical and mechanical properties. *Int. Symp. Ind. Use Bamboo* 1992: 7–11.
Latif, A.M. and Liese, W. (1995). *Utilization of bamboo. planting and utilization of bamboo in peninsula Malaysia*. FRIM research pamphlet, Kuala Lumpur, Malaysia, pp. 50–102.
Latif, A.M. and Liese, W. (2002). *Culm characteristics of two bamboos in relation to age, height and site. Bamboo for sustainable development*. VSP BV, Zeist, The Netherlands, pp. 223–233.
Lian, C., Zhang, G., Feng, Y., Ran, H., Zhang, Y., and Guo, Q. (2016). Seed characters and genetic variation of *Oxytenanthera abyssinica*. *Guangxi Zhiwu/Guihaia* 36: 943–948.
Liese, W. and Grosser, D. (2000). An expanded typology for the vascular bundles of bamboo culms. In: *Proceedings of the bamboo 2000 international symposium*, Thailand, 2000: 121–134.
Liese, W. and Weiner, G. (1996). Ageing of bamboo culms. a review. *Wood Sci. Technol.* 30: 77–89.
Liese, W. (1998). *The anatomy of bamboo culms*. INBAR technical report. International Network for Bamboo and Rattan, Beijing.
Maviton, M.E. and Sankar, V.R. (2022). *Global priority species of economically important bamboo*. INBAR Technical Report 44, Beijing, China, pp. 1–216.
Mcclure, F.A. (1966). *The bamboos: a fresh perspective*. Harvard University Press, Cambridge, MA.
Mensah, M.A., Mitchual, S., Appiah-Kubi, E., and Donkoh, M. (2021). Comparative study of the morphological and physical properties of juvenile and matured *Bambusa vulgaris* shrad. ex. JC Wendl culms from Ghana. *J. Bamboo Rattan Kerala For. Res. Inst.* 20.
Mulyaningsih, T., Karnika, D.A., and Muspiah, A. (2022). Comparison of stem anatomy of *Bambusa vulgaris* schrad and *Schizostachyum brachycladum* (Kurz) Kurz (Poaceae) in Lombok. *Adv. Bamboo Sci.* 1: 100010.
Obiri, B.D. and Oteng-Amoako, A. (2007). Towards a sustainable development of the bamboo industry in Ghana. *Ghana J. For.* 21: 14–27.
Portal-Cahuana, L.A., Cáceres Velarde, A., and Pires De Moura Palermo, G. (2023). Anatomical and variation of physical properties in the axial direction of three bamboo species in the eastern Amazon of Peru. *Sci. Agropecu.* 14: 39–48.
Prasad, J. (1948). Silviculture of ten species of bamboo suitable for paper manufacture. *Indian For.* 74: 122–130.
R Core Team. (2024). *R: a language and environment for statistical computing*. R Foundation for Statistical Computing, Vienna, Austria, https://www.R-project.org/>.4.4.2.
Siam, N.A., Uyup, M.K.A., Husain, H., Mohmod, A.L., and Awalludin, M.F. (2019). Anatomical, physical, and mechanical properties of thirteen Malaysian bamboo species. *BioResources* 14: 3925–3943.
Soeprayitno, T., Tobing, L., and Widjaja, E.A. (1988). Why the Sundanese of West java prefer slope-inhabiting *Gigantochloa Pseudoarundinacea* to those growing in the valley. *Int. Workshop Bamboo Cochin* 1988: 14–15.
Tomlinson, P.B. (1961). *Anatomy of the monocotyledons. II. Palmae*. Oxford University Press, Oxford.
Trujillo, D. (2019). ISO 22157: 2019: Bamboo structures—Determination of physical and mechanical properties of bamboo culms—Test methods.
Wahab, R., Mustapa, M.T., Sulaiman, O., Mohamed, A., Hassan, A., and Khalid, I. (2010). Anatomical and physical properties of cultivated two- and four-year-old Bambusa vulgaris. *Sains Malays.* 39: 571–579.
Widjaja, E.A. and Risyad, Z. (1985). Anatomical properties of some bamboo utilized in Indonesia. Recent research on bamboos. In: *Proceedings of the International Bamboo Workshop 1985*. Chinese Academy of Forestry. International Development Research Centre., Singapore, Indonesia, pp. 244–246.
Xiang, E., Guo, Y., Yang, S., Liu, X., Tian, G., Ma, J., and Shang, L. (2020). Variations in the anatomical characteristics of *Bambusa pervariabilis* culms with age and height. *For. Prod. J.* 70: 72–78.
Yu, L., Dai, F., Zhang, K., Jiang, Z., Xia, M., Wang, Y., and Tian, G. (2023). Fiber characteristics and mechanical properties of *Oxytenanthera abyssinica*. *Plants* 12: 2987.
Zhan, H., Zhang, L.Y., Niu, Z.H., Wang, C.M., and Wang, S.G. (2016). Chemical properties and fiber morphology of *Dendrocalamus hamiltonii* as potential pulp material. *Eur. J. Wood Wood Prod.* 74: 273–276.