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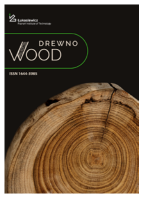

Assessment of Static and Dynamic Moduli of Elasticity of Antrocaryon Micraster Stemwood from Semi-Deciduous Ecological Zone in Ghana

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The paper investigates an assessment of mechanical strength in relation to the dynamic and static MOE of *Antrocaryon micraster* stemwood from the semi-deciduous ecological zone in Ghana. The objective was to assess the strength variation of *Antrocaryon micraster* stemwood along the axial direction, using destructive and non-destructive methods. *Antrocaryon micraster* stemwood that was divided into bottom, middle, and top positions was prepared for the study. The results reveal that the stemwood bottom position obtained maximum density (530.43 kg/m^3), representing 10% and 16.02% higher when compared to other corresponding positions (middle and top), respectively. For stemwood along the axial direction, the static MOE values were 18.54%, 22.82%, and 27.48% more than the dynamic MOE obtained in the bottom, middle, and top positions, respectively. At 1% and 5% levels of significance, the position of the stemwood along the tree height has a significant effect on dynamic MOE and static MOE. Statistical evaluation with regression and Pearson correlation also indicates a positive relationship with the variability of 50.4% and 71%, respectively. In a whole, the mechanical behaviour of the *Antrocaryon micraster* stemwood, especially the bottom position along the axial plane, is considered wealthy to be selected for furniture applications.

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Introduction

Wood is a natural material considered to be a renewable and sustainable resource. It has been utilized for centuries as a structural material due to its versatility, strength, and aesthetic appeal. It is known to be one of the oldest natural resources in the engineering, building construction, and furniture-making industries. The scientists, technologists, and researchers have taken a keen interest in the properties determination of wood, ranging from physical, anatomical, mechanical, and others (Bonfatti Júnior et al., 2023; Demol et al., 2021) due to their usefulness in predicting its utilization potential across engineering, building construction, and furniture making industries. One considerable wood species that is gaining attention within the construction industry in the West African sub-region, particularly in Ghana, is Antrocaryon micraster, due to its unique characteristics of a cylindrical shape and its straight height growth (Kumatia et al., 2021). *Antrocaryon micraster* is a lesser-known species (LKS) and is highly available in Ghana. It has been used for construction purposes, including housing, roofing, furniture, and others, as indicated by different studies (Dadzie & Amoah, 2015; Dumenu & Bandoh, 2014), due to the decline of commercially known timber species. Notwithstanding, Ghana possesses hundreds of different timber

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types capable of replacing some of the commercially known timber species either fully or partially upon evaluation of their mechanical properties.

One of the mechanical properties is the static bending, which has been widely used to predict various wood load-bearing capacities, ready to be used for industrial applications (Chen & Guo, 2017; Lahr et al., 2017). Additionally, Divós and Tanaka (2005) reported that the most important strength predictor factor is MOE, and this predictor has been determined by static and dynamic methods. The static method is seen to be destructive in nature, while the dynamic method is nondestructive. Studies have shown that static and dynamic MOE have become essential indicators to measure the response of timber within specified conditions (Brunetti et al., 2023; Villasante & Fernández-Serrano, 2022). As static MOE seeks to give an understanding of the timber behavior when subjected to a load. Similarly, dynamic MOE seeks to give the timber behavior relative to its internal structure (Nowak et al., 2021). Having the foreknowledge and understanding of the MOE values for the *Antrocaryon micraster* species, using these methods is helpful to provide complete information on this wood species for maximizing its strength potential in many applications across the construction sectors (Aramburu et al., 2023; Ettelaei et al., 2022).

In view of this, the study focuses on assessing modulus of elasticity (static and dynamic) in *Antrocaryon micraster* stemwood harvested from the semi-deciduous ecological zone in Ghana. Performing property evaluations in relation to the dynamic and static modulus along *Antrocaryon micraster* stemwood will provide comprehensive results useful for the analysis of the strength behavior. Additionally, the study will highlight the acoustic procedure of measurement in achieving an accurate determination of MOE. Using acoustic procedure for properties determination provides a non-destructive assessment for the species under study, leaving its structural integrity intact (Olaoye & Ojo, 2022; Pantelić et al., 2020).

The foremost objective of the study is to evaluate the strength variation of *Antrocaryon micraster* stemwood along the axial direction from the semi-deciduous ecological zone in Ghana, using destructive and non-destructive methods. The assessment objectives of this study will include: 1. to conduct dynamic and static modulus assessment for the Antrocaryon micraster stemwood along the axial direction; 2. to conduct assessment on density along the axial plane of the Antrocaryon micraster stemwood, and 3. to evaluate the relationship that exists among density, static, and dynamic modulus of elasticity.

Materials and methods

1. Materials

Antrocaryon micraster stemwood obtained from Bibiani forest zone within the moist-deciduous region of the Western North Region of Ghana, with latitude 3° and 6°N, and longitude 2° and 3°W. The area has an average rainfall of approximately 1200 – 1500 mm with two seasons (March-August, & September-October) while average relative humidity is approximately 75 – 95% (Awotwe-Mensah et al., 2023). One selected *Antrocaryon micraster* tree with a 51.3cm diameter was felled below breast-height. The tree was cross-cut into bottom, middle, and top positions of equal height of 8 feet. The three portions were marked with 'BP', 'MP', and 'TP' representing Bottom portion, Middle portion, and Top portion, respectively, before being transported to the Wood Science workshop of Akenten Appiah-Menka University. These portions were converted separately into beams and preserved under a shed for 12 weeks in order to dry to approximately 12% moisture content for the study.

2. Preparation of the sample

The samples totaling twenty (20) each for the tree height of bottom, middle, and top positions were prepared according to BS 373 (1957) established protocols for testing modulus of elasticity (MOEs). Additionally, twenty (20) samples were prepared from each tree position to aid determination of density for the samples studied. Both the sample mass and volume were established to enable calculation of the densities. All the tests were conducted at the Wood Laboratory of the Ghana Forestry Research Institute in Kumasi.

3. Acoustic dynamic test of *Antrocaryon micraster* stemwood

In all, twenty (20) samples, each measured 300 x 20 x 20 mm, were prepared from the bottom, middle, and top positions for the acoustic dynamic test. An acoustic dynamic test was achieved with the help of the Fakopp Acoustic machine. The device has two probes, a receiver and a transmitter, that were fixed to the *Antrocaryon micraster* stemwood samples from each tree height (bottom, middle, top) at a 45-degree angle with a rubber mallet. The signal was produced through the transmitter probe when it was hit with a metallic hammer to cause the receiver probe to pick it up. In all, four hits were made, and the average was used for the calculation. Figure 1 presents the Fakopp acoustic machine setup. Equation 1 was used to compute the dynamic MOE.

Fig.1. Fakopp Acoustic Machine Setup

Fig. 2. Static Modulus Setup

$$E_d = \rho . V^2 \quad (1)$$

Where: E_d = Dynamic modulus (MPa), ρ = Density of the sample (kg/m³), V = Velocity (m/s) of the wood.

4. Static test of *Antrocaryon micraster* stemwood

In all, twenty (20) samples of *Antrocaryon micraster* stemwood that measured 300 x 20 x 20 mm each were selected randomly within the bottom to top positions of the tree height and were tested for static modulus following BS 373 (1957) protocols. A universal testing machine (Inspekt 50-1) was used to perform the test under a 3-point loading procedure, as shown in Figure 2. Static MOE is then established through equation 2.

$$E_S = \frac{FL^3}{4bd^3} \quad (2)$$

Note: E_s = Static modulus of elasticity (MPa), F = Applied load in the center (N), L = length between the two supporting beams (mm), b = Width of test piece (mm), d = depth of test piece (mm).

5. Density determination of *Antrocaryon micraster* stemwood

The density of *Antrocaryon micraster* species used for both static and dynamic modulus of elasticity tests was determined based on EN 13183-1 (2002) established protocols. Sample masses were measured with an electronic scale balance with 0.001 precision. The volume of each of the samples was measured as Length by Width by Height, all in millimeters. The density of the sample was calculated using equation (3):

$$Density = \frac{Mass\ (kg)}{Volume\ (m^3)} \quad (3)$$

6. Data analysis

An analysis tool (SPSS version 16.0) was employed to analyze the data of the study. At a 95% confidence level, ANOVA was conducted to verify the significance among different variables. Tukey's multiple comparisons test was performed to establish whether mean value variations are significant at the positions along the axial direction of the stemwood. Interactions among density, dynamic, as well as static modulus were determined using a Pearson correlation matrix and simple linear regression.

Results and discussions

1. Difference in density, dynamic, and static MOEs of *Antrocaryon micraster* stemwood

Fig. 3 shows the density, dynamic, and static MOEs outcomes of *Antrocaryon micraster* stemwood at three different positions along the tree height. The density ranges from 445.44 kg/m³ - 530.43 kg/m³, where an average is 484.42 kg/m³ for stemwood along the axial plane. The stemwood bottom position obtained a maximum density of 530.43 kg/m³, representing 10% and 16.02% higher when comparing its differences to other positions (Middle and Top) as expressed in percentage. Variation of density between the positions (Bottom, Middle, Top) of the stemwood along the axial plane is significant (Table 2). This implies that density changes from one position to another along the axial direction, which leads to position consideration when selecting *Antrocaryon micraster* stemwood for structural application. The variation could be traced to different proportions of fibers, extractive content present, coupled with different thicknesses of cell walls along the axial plane (Custodio et al., 2019; Wassenberg et al., 2015). This result is comparable to the similar trends of results as stated by Appiah-Kubi et al. (2024), Seidu et al. (2024), Bonfatti Júnior et al. (2023), and Liepiņš et al. (2023).

The trends in variation of density for the tree positions clearly reflect the changing trend of both static and dynamic MOEs performance (Fig. 3). This indicates that density differs at different positions along the tree height, thereby contributing significantly to the strength properties (static and dynamic) behavior of the species, as the relationship is positively correlated (Table 3). Similar trends of results were observed by Appiah-Kubi et al. (2024), Bonfatti Júnior et al. (2023), Demol et al. (2021), Jaskowska-Lemanska and Przesmycka (2021), Dadzie and Amoah (2015), and Shmulsky and Jones (2011). Again, as the position of the stemwood changes from the bottom through to the top, the density value decreases from 10% to 6.69% when expressing its comparing differences in percentage, respectively (Fig. 3). The results of ANOVA (Table 2) and Tukey multiple test (Table 1) reveal that there are significant variations between the stemwood positions at 1% level of significance. This explains and defines the position effect on the load-bearing capacity of *Antrocaryon micraster* stemwood, such that each position (Bottom, Middle, Top) should be considered differently when the species is being used for structural applications.

The dynamic MOE ranges from 4337 MPa – 5584 MPa, while 5980 MPa – 6855 MPa is for the static MOE, respectively (Fig. 3). The stemwood bottom obtained 6855 MPa, which is 733 MPa and 1247 MPa higher than the middle and top positions when compared to dynamic MOE differences, whereas 570 MPa and 875 MPa were similarly observed for static MOE when compared bottom stemwood differences to the middle and top, respectively. From Table 2, significant variations occur in the positions of the stemwood along the tree height for both dynamic and static MOEs, respectively. This variation could be traced to density variations occurring along the tree height of the species. Variations in the density of species axially (Wassenberg et al., 2015) truly influenced the modulus of elasticity (Appiah-Kubi et al., 2024; Bonfatti Júnior et al., 2023; Demol et al., 2021). This implies that different load-bearing capacity is required at different positions (Bottom, Middle, Top) along the tree height. This trend of results is comparable to similar results found in other studies (Seidu et al., 2024; Jaskowska-Lemanska & Przesmycka, 2021; Nowak et al., 2021).

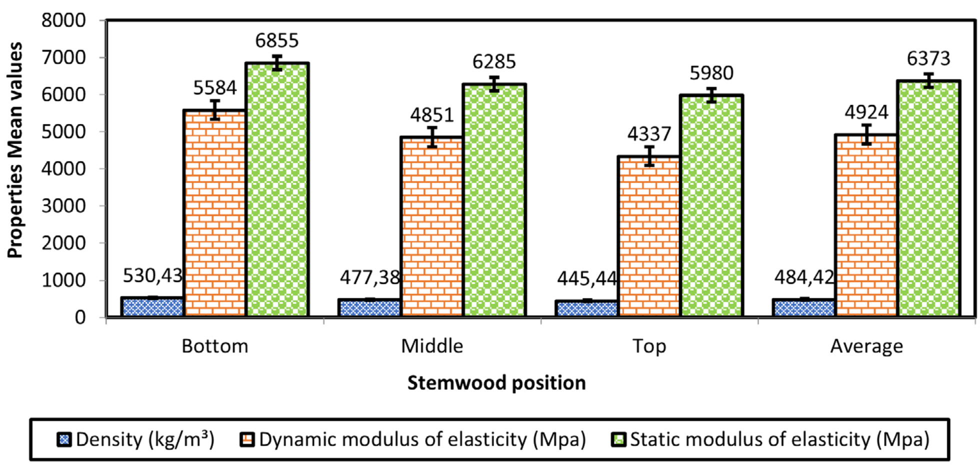

Fig. 3. Density, static and dynamic MOEs of *Antrocaryon micraster* stemwood; Error bars = standard deviation

Comparatively, for stemwood along the axial direction, the static MOE values were 18.54%, 22.82%, and 27.48% more than the dynamic MOE values obtained in the bottom, middle, and top positions when comparing differences are expressed in percentage, respectively. At 1% level of significance, Table 2 reveals that the position of the stemwood has a greater effect on both dynamic and static MOEs, and their difference is significant. Similarly, results for post-hoc indicate variations within and across dynamic and static MOEs of stemwood positions are significant (Table 1). This implies that along the tree height strength behavior differs. This result is comparable to similar trends of results recorded in studies by Seidu et al. (2024), Jaskowska-Lemanska and Przesmycka (2021), and Nowak et al. (2021). The variation within the dynamic modulus of elasticity could be traced to the grain direction of the *Antrocaryon micraster* species. Studies have shown that dynamic and sound velocity values tend to be higher when the grain direction of the species is parallel than perpendicular (Nowak et al., 2021; Kasal et al., 2010; Lourenço et al., 2007; Wang et al., 2004). This is a result of obstructions to the speed of sound waves that travel across the grain of the wood and thereby require more time to complete their passage. The important factors include high presence of extractive content and thickness of cell-walls (Nowak et al., 2021; Zhang et al., 2021) within the wood internal structure. This implies that the uniformity of the properties of the species studied along the tree height is position specific (Tables 1 & 2), which then impacts its strength behavior for industrial applications within the building and furniture industry.

2. Relationship between density and modulus of elasticity for *Antrocaryon micraster* stemwood

Correlation matrix results (Table 3) show that density, dynamic, and static elastic modulus of *Antrocaryon micraster* stemwood at three different positions along the tree height have a good relationship. Results indicate a significant positive correlation relationship among the dynamic modulus of elasticity (E_{dm}) and density. This could be explained by how the density greatly influenced the variations of tree height along stemwood positions for the dynamic modulus of elasticity, with variability of 91.5% (Table 3). As dynamic MOE changes in value along the axial plane from the bottom to top, density also changes in the same direction, respectively. This implies that these properties are directly proportional. A similar trend of results was

Table 1. Tukey multiple test results for density, dynamic, and static MOE

Tree Height	Density (kg/m^3)	E_d (MPa)	E_s (MPa)
Bottom	530.43 ± 7.09a	5584 ± 293.64m	6855 ± 188.87x
Middle	477.38 ± 13.61b	4851 ± 254.67n	6285 ± 103.46y
Top	445.44 ± 15.36c	4337 ± 200.28t	5980 ± 129.70z

Equal letters for rows and columns values read insignificant @ 95% confidence level

Table 2. ANOVA for density and modulus of elasticity of stemwood

Properties	df	F - value	P - value
Density (kg/m^3)	2	234.389	0.001**
Dynamic modulus of elasticity (MPa)	2	123.269	0.001**
Static modulus of elasticity (MPa)	2	39.721	0.001**

Note: ** = values are significant @ 95% confidence level

Table 3. Correlation matrix for density, dynamic, and static MOE of Antrocaryon micraster stemwood

Properties	1	2	3
1. Density (kg/m^3)	1		
2. Dynamic modulus of elasticity (MPa)	0.915**	1	
3. Static modulus of elasticity (MPa)	0.743**	0.710**	1

Note: ** = values are significant @ 95% confidence level

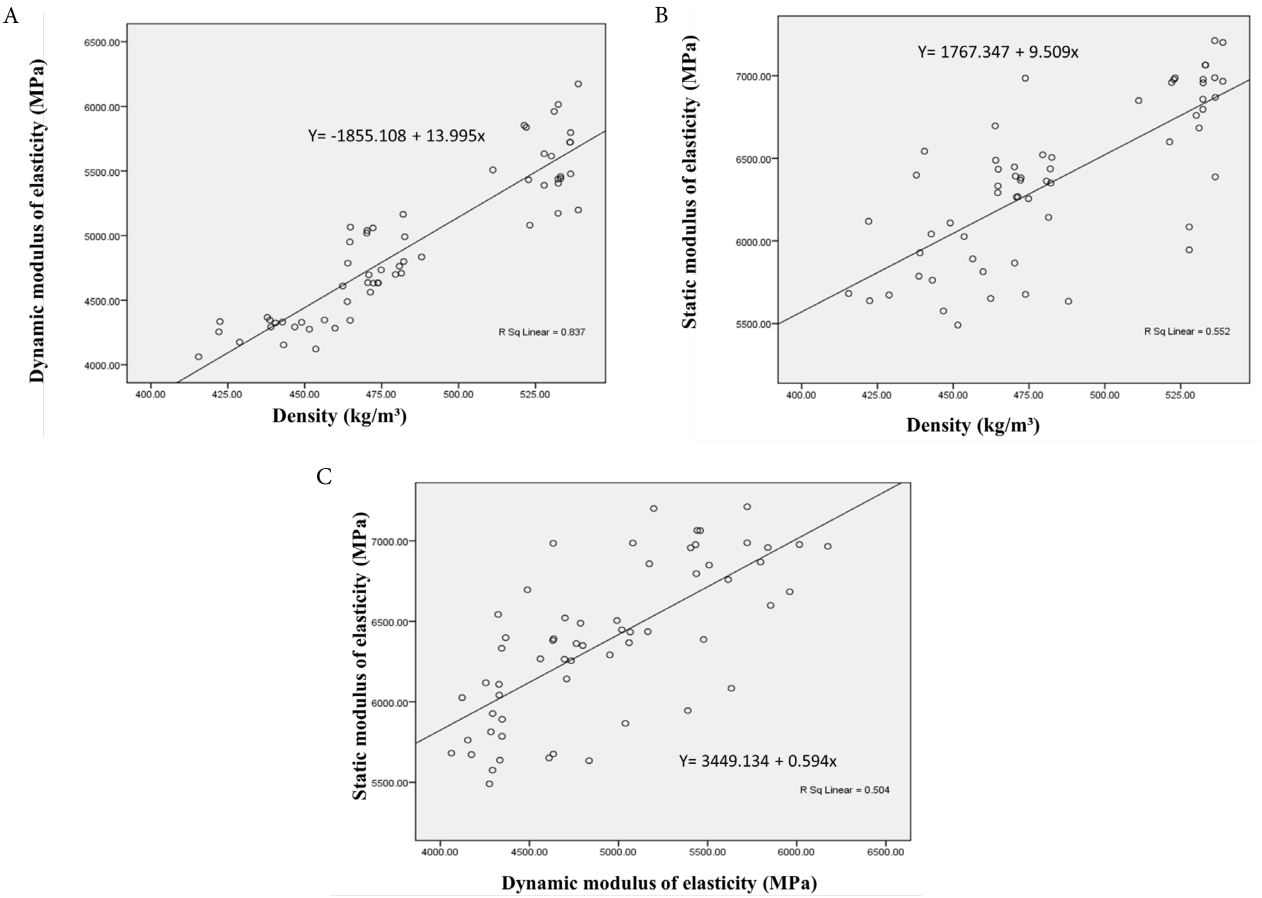

Fig. 4. Relationship between density, dynamic and static MOEs

reported by Divós and Tanaka (2005). Simple linear regression analysis indicates that at a variability of 83.7%, the density contributes significantly towards the increase in dynamic MOE (Fig. 4A). The same results trend was observed for density and static MOE (Table 3, Fig. 4B). This suggests that for both dynamic MOE and static MOE, density significantly influenced their variation of elasticities along the positions of the stemwood. This finding is comparable to what was recorded by Mvolo et al. (2022). From Fig. 4C and Table 3, dynamic MOE positively correlates to static MOE with the variability of 50.4% and 71%, respectively, for the statistical evaluation with regression and Pearson correlation. This outcome could be comparable with similar conclusions as stated in Nowak et al. (2015); Madhoushi and Boskabadi (2019).

Conclusions

This study assesses dynamic and static MOEs of *Antrocaryon micraster* stemwood along the positions of the axial plane and thereby evaluates the level of influence on the strength properties. From the study, the following conclusions are made:

1. Density had correlated significantly, positively with both modulus of elasticity (dynamic and static), with a variability of 91.5% and 74.3% respectively. This affirms the density influence on the variation of stiffness along the positions of the stemwood. Therefore, higher density stemwood is the most suitable for any industrial applications due to its quality mechanical properties.
2. Statistically, dynamic MOE correlated significantly, as positive ($R^2 = 0.504$; $R = 0.710$) with static MOE after linear regression and Pearson correlation analysis.
3. Positions along the axial plane of the *Antrocaryon micraster* stemwood significantly influence the variation of the strength properties. Therefore, the mechanical behavior of the *Antrocaryon micraster* stemwood, especially the bottom position along the axial plane is considered a wealthy and most preferred position to be selected for furniture applications.

In a whole, the *Antrocaryon micraster* stemwood exhibited different strength behavior along the axial direction. Therefore, position consideration along the tree height is key when selecting *Antrocaryon micraster* stemwood for industrial applications.

Conflict of interest

The author(s) declare(s) that there is no conflict of interest concerning the publication of this article.

References

Appiah-Kubi, E., Dadzie, P.K., Yinye, J., & Awotwe-Mensah, M. (2024). "Basic density and static bending properties of coppiced African rosewood (*Pterocarpus erinaceus Poir*) grown in the Savannah Zone of Ghana", *Wood Material Science & Engineering*, 1–9. 10.1080/17480272.2024.2372819

Aramburu, A. B., Gatto, D. A., Beltrame, R., & Delucis, R. A. (2023). "Sampling sufficiency for mechanical properties of wood". *Maderas: Ciencia y Tecnologia*, 11(25): 1–12. 10.4067/s0718-221x2023000100411

Awotwe-Mensah, M., Mitchual, S.J., Appiah-Kubi, E., Dadzie, P.K., Mensah, P., & Donkoh, M.B. (2023). "Assessment of the drying behaviour of young and mature *Bambusa vulgaris* from Ghana". *Advances in Bamboo Science*, 5(2023), 100044. 10.1016/j.bamboo.2023.100044

Bonfatti Júnior, E.A., Lengowski, E.C., Cabral, B.M., Gonçalves de Oliveira, T.W., Rodrigues de Barros, J.M., Oliveira, R.S., Sulato de Andrade, A., Klock, U., & Agostinho da Silva, D. (2023). "Basic wood density, fiber dimensions, and wood chemical composition of four eucalyptus species planted in southern Brazil". *Revista Árvore*, 47, e4704. 10.1590/1806-908820230000004.

Brunetti, M., Aminti, G., Vicario, M., Nocetti, M. (2023). "Density Estimation by Drilling Resistance Technique to Determine the Dynamic Modulus of Elasticity of Wooden Members in Historic Structures". *Forests*, 14, 1107. 10.3390/f14061107.

BS 373 (1957). Methods of testing small, clear specimens of timber. British Standards Institution, London.

Chen, Y., & Guo, W. (2017). "Nondestructive evaluation and reliability analysis for determining the mechanical properties of old wood of ancient timber structure". *BioResources,* 12(2): 2310-2325. 10.15376/biores.12.2.2310-2325.

Custodio, M.C., Tomazello-Filho, M., Carneiro, M.E.B. Nisagoski, S. (2019). "Axial and radial evaluation of basic density and fiber dimensions of Guazuma crinite Martius wood". *FLORESTA*, Curitiba PR, 50 (2), 1143–1150.

Dadzie, P.K., & Amoah, M. (2015). "Density, some anatomical properties and natural durability of stem and branch wood of two tropical hardwood species for ground applications". *European Journal of Wood and Wood Products*, 73, 759–773.

Demol, M., Calders, K., Moorthy, S.M.K., Gielen, B. (2021). "Consequences of vertical basic wood density variation on the estimation of aboveground biomass with terrestrial laser scanning". *Trees*, 35 (2), 671–684. 10.1007/s00468-020-02067-7

Divós, F., & Tanaka, T. (2005). "Relation Between Static and Dynamic Modulus of Elasticity of Wood". *Acta Silv. Lign. Hung.*, 1: 105-110. 10.37045/aslh-2005-0009

Dumenu, W.K., & Bandoh, W.N., 2014. "Exploitation of African rosewood (Pterocarpus erinaceus) in Ghana: a situation analysis", *Ghana Journal of Forestry*, 32, 1–15.

EN 13183 (2002). Moisture Content of a Piece of Sawn Timber-Part 1. Determination by Oven Dry Method. Comité Européen de Normalisation, Brussels, Belgium.

Ettelaei, A., Taoum, A., & Nolan, G. (2022). "Assessment of different measurement methods/techniques in predicting modulus of elasticity of plantation Eucalyptus nitens timber for structural purposes". *Forests*, *13*(4), 607. 10.3390/f13040607.

Jaskowska-Lemanska, J. & Przesmycka, E. (2021). "Semi-Destructive and Non-Destructive Tests of Timber Structure of Various Moisture Contents". *Materials*, 14, 96. 10.3390/ma14010096.

Kasal, B.; Lear, G.; Tannert, T. (2010). *Stress waves. In Situ Assessment of Structural Timber.* Springer, 5–24.

Kumatia, E.K., Ayertey, F., Appiah-Oppong, R., Bolah, P., Ehun, E., & Dabo, J. (2021). "*Antocaryon micraster* (A. Chev. and Guillaumin) stem bark extract demonstrated anti-malaria action and normalized hematological indices in Plasmodium berghei-infested mice in the Rane's test". *Journal Ethnopharmacol,* 266,113427. 10.1016/j.jep.2020.113427.

Lahr, F.A.R., Christoforo, A.L., Varanda, L.D., Araujo, V.A., Chahud, E., & Branco, L.A.M.N. (2017). "Shear and longitudinal modulus of elasticity in wood. relations based on static bending tests". *Acta Sci-Tech,* 39: 433-437.10.4025/actascitechnol.v39i4.30512.

Liepinš, K., Liepinš, J., Ivanovs, J.; Bardule, A., Jansone, L., Jansons, A. (2023). "Variation in the Basic Density of the Tree Components of Gray Alder and Common Alder". *Forests*, 14, 135. 10.3390/f14010135

Lourenço, P.B., Feio, A.O., & Machado, J.S. (2007). "Chestnut wood in compression perpendicular to the grain: Non-destructive correlations for test results in new and old wood". *Construction and Building Materials*, 21: 1617–1627. 10.1016/j.conbuildmat.2006.07.011.

Madhoushi, M., & Boskabadi, Z. (2019). "Relationship between the dynamic and static modulus of elasticity in standing trees and sawn lumbers of Paulownia fortune planted in Iran". *Maders. Ciencia y technologia.* 21(1). https://doi.org/10.4067/S0718-221X2019005000104.

Mvolo, C.S., Stewarta, J.D., & Koubaa, A. (2022). "Comparison between static modulus of elasticity, non-destructive testing moduli of elasticity and stresswave speed in white spruce and lodgepole pine wood", *Wood Material Science & Engineering*, 17(5): 345-355 doi.org/10.1080/17480272.2021.1871949.

Nowak, T., Hamrol-Bielecka, K., & Jasienko, J. (2015). „Experimental testing of glued laminated timber members using ultrasonic and stress wave techniques". *In Proceedings of the International Conference on Structural Health Assessment of Timber Structures*, SHATIS'15, Wroclaw, Poland, 9–11 September 2015; 523–533.

Nowak, T.; Patalas, F.; Karolak, A. (2021). "Estimating Mechanical Properties of Wood in Existing Structures—Selected Aspects". *Materials*, 14, 1941. 10.3390/ma14081941.

Olaoye, K. O., & Ojo, M. O. (2022). "Non-destructive acoustic assessment of wood quality in trees and logs and the effects of silvicultural treatments: a review". *International Wood Products Journal*, 13(3). 10.1080/20426445.2022.2061255.

Pantelić, F., Mijić, M., Šumarac Pavlović, D., Ridley-Ellis, D., & Dudeš, D. (2020). "Analysis of a wooden specimen's mechanical properties through acoustic measurements in the very near field". *The Journal of the Acoustical Society of America*, 147(4), 320–325. 10.1121/10.0001030.

Seidu, H.; Brougui, M.; Rahim, N.R.A.; Németh, R. (2024). "Evaluation of Dynamic and Static Moduli of Elasticity of Hybrid Eucalyptus Wood from Different Locations in Ghana". *Wood Research*, 69(1): 132–142. 10.37763/wr.1336-4561/69.1.132142.

Shmulsky, R., & Jones, P.D. (2011). *Forest products and wood science – an introduction*, 6th ed. John Wiley, West Sussex, U.K., 3–363.

Villasante, A., & Fernández-Serrano, Á. (2022). "Dynamic modulus of elasticity in flexural vibration tests of Pinus sylvestris sawn timber obtained with fundamental resonant frequency and overtones". *Holzforschung*, 76(6). 10.1515/hf-2021-0190.

Wang, X., Divos, F., Pilon, C., Brashaw, B.K., Ross, R.J., & Pellerin, R.F. (2004). "Assessment of Decay in Standing Timber Using Stress Wave Timing Nondestructive Evaluation Tools: A Guide for Use and Interpretation"; Gen. Tech. Rep. FPL-GTR-147; US Department of Agriculture, Forest Service, Forest Products Laboratory: Madison, WI, USA, 2004.

Wassenberg, M., Chiu, HS., Guo, W., & Spiecker, H. (2015). "Analysis of wood density profiles of tree stems: incorporating vertical variations to optimize wood sampling strategies for density and biomass estimations". *Trees*, 29, 551–561. 10.1007/s00468-014-1134-7.

Zhang, M., Zhang, Q., Li, J., Xu, J., & Zheng, J. (2021). "Classification of acoustic emission signals in wood damage and fracture process based on empirical mode decomposition, discrete wavelet transform methods, and selected features". *Journal of Wood Science*, 67(1).