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Wood physical and mechanical properties of rambai (*Baccaurea motleyana*), a tropical fruit tree species

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Abstract. *Dayadi I, Ridho MR. 2026. Wood physical and mechanical properties of rambai (*Baccaurea motleyana*), a tropical fruit tree species. Asian J For 10: r100103. https://doi.org/10.13057/asianjfor/r100103.* This study evaluated the physical and mechanical properties of rambai (*Baccaurea motleyana*) wood to assess its potential as a timber resource in multipurpose fruit-timber systems. Small clear specimens were prepared from the base, middle, and top section of three mature rambai trees (diameter at breast height 38-44 cm) grown in a private garden, and tested for physical and mechanical properties following the Deutsches Institut für Normung (DIN) standards. The results showed that rambai wood has Green Moisture Content (GMC) of 104.98±9.20%, decreasing significantly from the base toward the top of the stem. Apparent density at ~12% MC averaged 0.62±0.04 g/cm^3 and did not differ significantly among axial positions of the stem. Shrinkage behaviour was typical of hardwoods, with tangential and radial shrinkage of about 5.9% and 3.8%, respectively, and a tangential–radial ratio of 1.59±0.28, indicating satisfactory dimensional stability. Mean mechanical properties across the whole stem were 9.52±1.49 GPa for MOE, 85.16±11.28 MPa for MOR, 51.69±5.69 MPa for compression parallel to grain. Impact bending strength and shear strength averaged 7.26±1.65 J/cm^2 and 11.81±1.35 MPa, respectively. Overall, these values characterize *B. motleyana* as a medium grade hardwood with physical and mechanical properties compatible with potential usein furniture, interior joinery and light construction, while further studies on durability, workability and anatomical characteristics are needed to provide stronger support to its promotion as a lesser-known tropical wood resource from fruit-timber systems.

Keywords: Agroforestry, *Baccaurea motleyana*, lesser-known species, multipurpose plant, strength classes

INTRODUCTION

Tropical forests are known for their high biodiversity and provide various valuable sources, including timber and non timber forest products that support rural livelihoods (Meinhold and Darr 2019; Jansen et al. 2020; Krainovic et al. 2025). In many tropical regions, increasing demand for wood, combined with pressure on natural forests, highlights the need to diversify timber species and to make better use of underutilized resources, including lesser-known timber species (Báder et al. 2023; Goodman et al. 2024). Conventional timber production often relies on long-rotation species, meaning that trees must grow for several decades before their wood can be harvested, which can reduce the economic attractiveness of timber-oriented plantations (Chang et al. 2019). One way to address this challenge is through the cultivation of multipurpose tree species that provide marketable products, such as fruit, during the rotation period while ultimately yielding timber at the end of their life cycle, thereby enhancing land-use efficiency and providing more continuous economic benefits.

Fruit-bearing trees are particularly important in this context, as they contribute to food security while storing significant amounts of carbon (Yulizah et al. 2023). Beyond their fruit, the wood of these species represents a potential secondary product that can be mobilised to support timber supply if its characteristics are suitable. This makes quantitative characterization of their wood properties essential if they are considered as alternative timber sources. Previous studies have examined fruit trees as potential wood sources and quantified their important characteristics. Sahin and Onay (2020) reported that wood from several orchard species have medium to high density and hardness, make them suitable for playground elements and outdoor furniture. Marasigan et al. (2024) reported that several senile tropical fruit trees retain adequate density and strength for furniture and light construction. These findings indicate that edible-fruit trees can provide credible timber as their properties are properly characterized. However, most of this work has focused on temperate or senile orchard trees and does not address native fruit-tree species in tropical agroforestry systems. For many underutilized tropical fruit trees, basic information on wood characteristics is still lacking, and their potential uses remain unexplored.

Among these underutilized tropical fruit trees, *Baccaurea motleyana*, commonly known as “rambai” in Indonesia, is an indigenous fruit tree of the family Phyllanthaceae that is naturally distributed across Southeast Asia. The species is often found in lowland forest and cultivated in orchards and home gardens (Matius et al. 2018; Suwardi et al. 2023). Its fruits are consumed either fresh or processed, and contain appreciable levels of sugars, organic acids, and phenolic compounds with antioxidant and functional-food potential (Debnath et al. 2022; Pardede et al. 2024). As a native fruit-tree frequently retained in multistrata gardens, *B. motleyana* has the potential to suplly both fruit and timber within the same land-use units. Although primarily valued for its edible fruit, *B. motleyana* also produces wood that is harvested locally but remains absent from timber properties databases. Its relatively wide distribution, frequent occurrence in traditional agroforestry systems, and current status as an underutilized species make *B. motleyana* a promising candidate for multipuspose management in which both fruits and timber are obtained from the same resource. Therefore, this study aims to characterize the physical and mechanical properties of *B. motleyana* wood to assess its potential as a timber resource within multipurpose fruit-timber systems.

To date, to the best of our knowledge, there is no published information that systematically quantifies the physical and mechanical properties of *B. motleyana* wood using standard testing procedures, nor any assessment of its potentital uses in comparison with established commercial timber. For lesser-known species, characterization of density, shrinkage, static bending, and compressive strength is essential to assign strength classes, compare performance with established commercial timbers and identify suitable uses (Belleville et al. 2020; Arriaga et al. 2023). Addressing this knowledge gap for *B. motleyana* is therefore necessary step if its wood is to be considered as a credible timber resources within multipurpose tree-based systems. Accordingly, this study investigates the physical and mechanical properties of *B. motleyana* wood to provide fundamental data supporting its potential use and diversification of lesser-known tropical wood resources.

MATERIALS AND METHODS

Samples preparation

A total of three rambai (*B. motleyana*) trees, with diameter at breast height of 38-44 cm and total height of 10-13 meter, were harvested from a private garden in Samarinda Seberang, Samarinda, East Kalimantan, Indonesia (Figure 1). The study site is located in a tropical rainforest climate, with an average air temperature of about 28-29°C and relative humidity around 78-82% (Karyati et al. 2025). The exact ages of the trees were unknown, but they were mature tree, fruit-bearing representative of home gardens in the area. From each harvested tree, approximately 4 m of clear bole height was obtained and then cut proportionally into three logs. Each log was subsequently sawn radially into quarter-sawn boards measuring ~6 cm in thickness and 1.0-1.3 m in length. The boards were then processed into small clear specimens for subsequent measurement, yielding a total of 30 specimens for each testing parameter. Specimens were collected continuously from the pith towards the bark on both sides. Prior to testing, all specimens were conditioned in a constant-temperature room with a temperature of ~20°C and relative humidity of ~67% for 72 hours to achieve equilibrium moisture content.

Determination of physical properties

The measurement of physical properties in this study was followed the standards of the Deutsches Institut für Normung (DIN): DIN 52183-77 for Green Moisture Content (GMC), DIN 52182-76 for apparent density (Aρ), and DIN 52184-79 for shrinkage (β) and swelling (α). The samples size are 20×20×20 mm for GMC and Aρ, and 100×20×20 mm for β and α. Prior to conditioning, GMC specimens were measured for their green weight using analytical balance with an accuracy of 0.01 g. Meanwhile, β specimens were measured for their longitudinal, radial, and tangential dimensions using digital caliper (InSize, China) with an accuracy of 0.01 mm. After air-dried, all specimens were then oven dried in a laboratory oven (Memmert UN55, Germany) at 103±2°C for 48 hours. The GMC, Aρ, β, and Tangential-to-Radial (T/R) ratio were then calculated using the following equations:

$$\text{GMC (\%)} = ((w_g - w_o) / w_o) \times 100 \qquad [1]$$

$$\text{A}\rho\ (\text{g/cm}^3) = w_\alpha / v_\alpha \qquad [2]$$

$$\beta\ (\%) = ((d_g - d_o) / d_o) \times 100 \qquad [3]$$

$$\text{T/R ratio} = \beta_T / \beta_R \qquad [4]$$

Where, the w_g is green weight (g), w_o is oven-dried weight (g), w_α is air-dried (~12% MC) weight (g), v_α is air-dried volume (cm^3), d_g is green dimension (mm), d_o is oven-dried dimension (mm), β is shrinkage (%).

Thereafter, the β specimens were soaken in the distilled water for 72 hours to achieve maximum dimension. The volumetric swelling (α_V) then calculated using the following equation:

$$\alpha_V\ (\%) = ((v_m - v_o) / v_o) \times 100 \qquad [5]$$

Where, the v_m is maximum volume (mm^3), and v_o is oven-dried volume (mm^3).

Figure 1. *Baccaurea motleyana* growing in a private garden in Samarinda, East Kalimantan, Indonesia

Determination of mechanical properties

Some of wood mechanical properties were assessed in this study to obtain important information, including static bending strength, compressive strength parallel to grain, impact bending, and shear strength parallel to grain. The measurement was conducted using Universal Testing Machine (UTM) (Wolpert, Germany), according to the standards of Deutsches Institut für Normung (DIN). The static bending strength, including Modulus of Elasticity (MOE) and Modulus of Rupture (MOR), was determined using specimens measuring 20×20×360 mm and a span length of 300 mm, giving a span-to-depth rasio of 15:1, as specified in DIN 52186-78. The compressive strength parallel to grain (σ_C) was evaluated on specimens measuring 20×20×60 mm following DIN 52185-76. The impact bending test (E_i) was carried out using 20×20×300 specimens according to DIN 52189–48. The shear strength parallel to grain (τ) was measured on 50×50×50 mm specimens in accordance with DIN 52187-79. In each test, loading was applied under displacement control following the loading rate of the corresponding DIN standards. Thereafter, the MOE, MOR, σ_C, E_i, and τ were calculated using this following equations:

$$\text{MOE (GPa)} = (P \times L^3) / (4 \times \Delta y \times b \times h^3) \quad [6]$$

$$\text{MOR (MPa)} = (3 \times P_{max}) / (2 \times b \times h^2) \quad [7]$$

$$\sigma_C \text{ (MPa)} = P_{max} / A \quad [8]$$

$$E_i \text{ (J/cm}^2\text{)} = E / A \quad [9]$$

$$\tau \text{ (MPa)} = P_{max} / A_s \quad [10]$$

Where, the P is load at proportional limit (N), L is span length (mm), Δy is deflection (mm), P_{max} is maximum load (N), b is specimen width (mm); h is specimen thickness (mm), A is contact area under loading head (cm^2), E is adsorbed energy (J), and A_s is the shearing area (mm^2).

Statistical analysis

Data obtained were statistically analyzed using a One-Way Analysis of Variance (ANOVA) at 95% confidence level (α=0.05) to evaluate the variation in wood physical and mechanical properties along the longitudinal axis of the stem. Prior to ANOVA, the data were checked for normality of variances using Shapiro-Wilk test and no strong deviations were detected. When significant differences were detected, Tukey's Honest Significant Differences (HSD) test was applied to identify pairwise differences among means.

RESULTS AND DISCUSSION

Physical properties

The wood physical properties of rambai (*B. motleyana*), including Green Moisture Content (GMC), apparent density (Aρ), shrinkage (β), T/R ratio, and volumetric swelling (α_v), are summarized in Table 1. The mean GMC was 104.98±9.20% (Figure 2) and showed a significant difference among stem positions ($p<0.001$), with a decreasing trend from the base toward the top of the stem. Such axial variation of GMC is commonly observed in hardwood species and is associated with changes in tissue composition and proportion of juvenile wood along the stem, although the anatomical characteristics of *B. motleyana* wood were not examined in this study. The GMC values observed here are comparable to those reported by Listyanto (2018) for *Paraserianthes falcataria* (111-146%) and Seta et al. (2023) for clonal teak (104-109%), but lower than those of *Peronema canescens* (145-161%) reported by Khan et al. (2022). Recent studies on tropical and temperate hardwoods similarly show that species with high initial moisture contents tend to exhibit greater drying stress and higher risks of checking and distortion during drying (Tari et al. 2015; do Nascimento et al. 2019). As stated by Shmulsky and Jones (2019), differences in wood moisture content can significantly influence physical and mechanical characteristics, biological resistance, and dimensional stability. Yamasaki et al. (2017) further demonstrated that moisture content strongly affects stress-wave propagation velocity and that Young's modulus in the air-dry state can be reliably estimated from measurements taken under high-moisture conditions when MC effects are properly accounted. Taken together, these findings emphasise the central role of moisture content in both drying behaviour and stiffness evaluation, and support the interpretation that the moderate GMC of *B. motleyana* wood may contribute to more favourable behaviour during processing and subsequent use, although species-specific drying studies would be needed to confirm this inference.

The mean value of apparent density of *B. motleyana* wood (~12% MC) was 0.62±0.04 g/cm^3, with no statistically difference within stem along axial direction (p=0.069; Table 1). This relatively uniform density along the stem is advantageous for processing and utilization because it reduces variability in drying behaviour and mechanical performance between boards sawn from different heights. This value of apparent density is noticeably higher than some tropical fast-growing or plantation wood species reported in previous studies. Duong and Matsumura (2018a) found a basic density of 0.51 g/cm^3 for *Melia azedarach* wood, while *P. canescens* showed values around 0.48 g/cm^3 (Ishiguri et al. 2021). Twenty-year-old clonal teakwood (*Tectona grandis*) examined by Nugroho et al. (2024) had a mean density of 525.67 kg/m^3 (~0.53 g/cm^3), and 15-year-old clonal teak studied by Seta et al. (2023) were even lighter, with density of 0.485–0.488 g/cm^3. Likewise, *Gmelina arborea* wood has been reported to have basic density of 0.46-0.49 g/cm^3 (Hidayati et al. 2017). These comparisons indicate that rambai wood is consistently denser than several tropical merchantable wood species commonly used for furniture, interior components and light construction. This also suggesting that *B. motleyana* may offer comparatively higher mechanical performance while still remaining within a workable medium-density range.

At the whole stem level, *B. motleyana* wood exhibited the typical anisotropic shrinkage pattern of hardwoods, with tangential shrinkage (β_T) greater than radial shrinkage (β_R). The mean value of longitudinal shrinkage (β_L) was 0.26±0.07% and showed a significant decrease from the base towards the top of the stem (p=0.009; Figure 3), whereas β_T and β_R did not differ significantly among stem positions. This indicates that β_L is minimal but slightly more pronounced in the basal wood, while transverse shrinkage remains relatively uniform along the merchantable stem. Furthermore, the resulting T/R ratio was averaged 1.59±0.28, indicating that β_T is roughly 1.6 times higher than β_R. This falls within the general range reported for hardwoods, where β_T is typically 1.5-3 times greater than β_R (Shmulsky and Jones 2019) and suggests that *B. motleyana* wood shows a well-behaved anisotropic and relatively good dimensional stability. Compared with other tropical wood, the T/R ratio of *B. motleyana* is considerably lower than *Schizolobium parahyba* wood (~2.74) reported by Athanázio-Heliodoro et al. (2018) and clonal teak studied by Seta et al. (2023) and Nugroho et al. (2024) (2.30 and 2.32, respectively). Comparable results were reported by Duong and Matsumura (2018a) in *M. azedarach* wood, with T/R ratio of 1.64.

Meanwhile, volumetric swelling (α_v) averaged 10.54±1.44% accross the stem, with no significant differences among base, middle, and top positions (p = 0.665). This moderate level of α_v, together with the relatively low T/R rasio of shrinkage, indicates that rambai wood exhibits a balanced dimensional response to moisture changes. As stated by Shmulsky and Jones (2019), volumetric swelling and T/R rasio of shrinkage are key indicators of dimensional stability and often considered for the timber products where dimensional stability is crucial, such as furniture and joinery. Studies on tropical timber wood species similarly emphasize volumetric swelling as an important criterion when assessing suitability for interior applications and value-added uses (Belleville et al. 2020; Marasigan et al. 2024). In this context, the α_v values of *B. motleyana* wood, together with its T/R rasio of shrinkage, indicates a satisfactory dimensional stability for utilization such as furniture components and interior joinery.

Mechanical properties

The examined mechanical properties of *B. motleyana* wood, including Modulus of Elasticity (MOE), Modulus of Rupture (MOR), compressive strength parallel to grain (σ_C), impact bending strength (E_i), and shear strength (τ) are summarized in Table 2. The ANOVA showed that all the mechanical properties were significantly different among stem positions (base, middle, and top) (p<0.05; Table 2). Generally, all mechanical properties exhibited a similar pattern, with values decreasing from the base towards the top of the stem, despite no significant differences in apparent density. This suggests that factors other than density, such as proportion of juvenile wood or variation in anatomical structures, may be responsible for the observed reduction in mechanical strength along the stem. However, the underlying anatomical or microstructural causes were not investigated in this study and would be valuable to address in future studies.

Table 1. The mean values of physical properties of *B. motleyana* wood

Parameters	**Stem positions**			***p*-value**
	Base (n=30)	**Middle (n=30)**	**Top (n = 30)**	
GMC (%)	110.33±9.55	104.45±8.36	100.16±9.68	<0.001**
Aρ (g/cm^3)	0.63±0.05	0.63±0.03	0.61±0.03	0.069^{ns}
β (%)				
Longitudinal	0.29±0.08	0.24±0.06	0.23±0.08	0.009**
Tangential	6.14±0.77	5.85±0.81	5.81±0.83	0.905^{ns}
Radial	3.86±0.67	3.81±0.84	3.78±0.70	0.222^{ns}
T/R ratio	1.62±0.28	1.59±0.31	1.57±0.26	0.243^{ns}
α_v (%)	10.86±1.26	10.43±1.58	10.34±1.47	0.665^{ns}

Note: Values are presented as mean ± standard deviation, **: Significant at 1% level, ^{ns}: Non significant

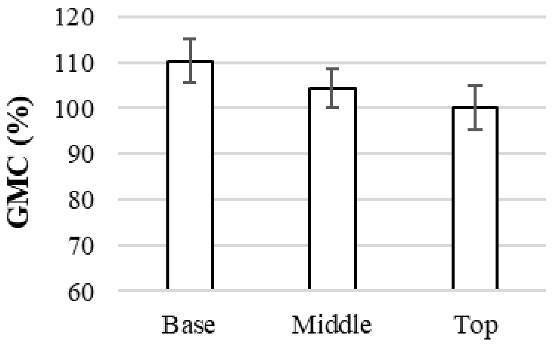

Figure 2. Green Moisture Content (GMC) of *B. motleyana* wood (HSD = 5.70). Error bars represent standard deviation

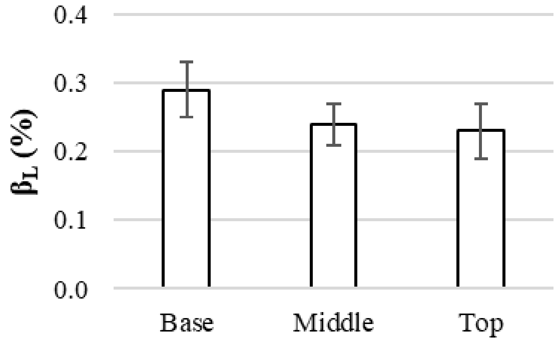

Figure 3. Longitudinal shrinkage (β_L) of *B. motleyana* wood (HSD = 0.05). Error bars represent standard deviation

For MOE and MOR, the mean values across the whole stem were 9.52±1.49 GPa and 85.16±MPa, respectively (Figures 4-5). Meanwhile, the mean value of compressive strength parallel to grain (σ_C) was 51.69±5.69 MPa (Figure 6). These values indicate that rambai wood is moderately stiff and strong hardwood. Compared with other tropical timber, rambai performs competitively or even favourably relative to species such as *M. azedarach* (Duong and Matsumura 2018b), *P. canescens* (Ishiguri et al. 2021) clonal and plantation teak (Seta et al. 2023; Nugroho et al. 2024; Samamba et al. 2025). According to Seng (1990), the MOE, MOR, and σ_C values obtained in this study places *B. motleyana* wood in Strength Classes II-III (Table 3). In addition, when evaluated using the grading standard for mechanical properties issued by Forestry and Forest Products Research Institute (FFPRI 1975), *B. motleyana* wood falls into Grade II-III (Table 4). Both classifications indicate that rambai wood can be regarded as medium-strength timber, suggesting that the wood is suitable for structural elements subjected to moderate loads and for non-structural components such as furniture and light construction.

In terms of impact bending strength (E_i), *B. motleyana* wood showed a mean value of 7.26±1.65 J/cm^2 (Figure 7), indicating a moderate capacity to absorb energy under sudden loading. When expressed as total energy absorbed per specimen, the E_i of *B. motleyana* (~28 J for 20×20×300 mm specimens) is comparable with other tropical fruit-tree woods that have been investigated for timber use. For example, Marasigan et al. (2024) reported impact energies of 28.18 J for *Mangifera altissima* wood and 26.88 J for *Artocarpus heterophyllus*, both of which are locally utilized and have been proposed as suitable for furniture and interior components. The close agreement between these values indicates that rambai wood provides a similar capacity to absorb energy under sudden loading and is consistent with its classification as a medium-strength timber. Recent work on hardwoods further shows that impact performance is controlled not only by density but also by microstructural features such as Microfibril Angle (MFA) and other anatomical traits. Nenning et al. (2025) found higher toughness in beech wood associated with higher density and lower MFA, but also concluded that the relationship between MFA and impact bending strength is complex and likely species-specific. Similarly, Miyoshi et al. (2018) showed that mechanical properties are strongly influenced by structural characteristics such as cell deformation, ray and vessel arrangement and the degree of transition from earlywood to latewood, in addition to density. Taken together, this underlines that, although the present study did not quantify anatomical features, the observed E_i is within the range of other fruit-tree timbers and that a more detailed anatomical-mechanical analysis would be valuable in future work.

Table 2. The mean values of mechanical properties of *B. motleyana* wood

Parameters	Stem positions			*p*-value
	Base (n=30)	**Middle (n=30)**	**Top (n=30)**	
MOE (GPa)	10.07±1.86	9.34±1.19	9.14±1.41	0.0473*
MOR (MPa)	89.00±12.59	85.19±10.83	81.28±10.43	0.0352*
σ_C (MPa)	53.79±6.06	51.89±5.27	49.38±4.35	0.0007**
E_i (J/cm^2)	7.90±1.82	7.07±1.75	6.81±1.38	0.0001**
τ (MPa)	12.45±1.23	11.70±1.46	11.29±1.36	0.0048**

Note: Values are presented as mean ± standard deviation, *: Significant at 5% level, **: Significant at 1% level

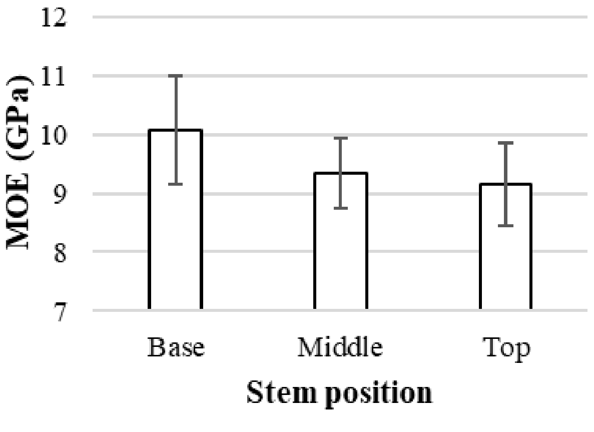

Figure 4. Modulus of Elasticity (MOE) of *B. motleyana* wood (HSD=0.78). Error bars represent standard deviation

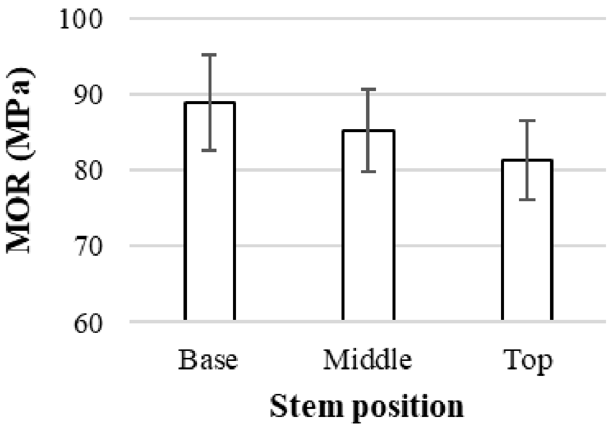

Figure 5. Modulus of Rupture (MOR) of *B. motleyana* wood (HSD=5.81). Error bars represent standard deviation

Table 3. Classification of strength classes for Indonesian timber according to Seng (1990). The data presented were converted from the original N/mm^2 units

Strength classes	MOE (GPa)	MOR (MPa)	σ_C (MPa)
I	> 15.0	> 110	> 65.0
II	11.2–15.0	72.5–110	42.5–65.0
III	9.0–11.2	50.0–72.5	30.0–42.5
IV	7.0–9.0	30.0–50.0	21.5–30.0
V	< 7.0	< 30.0	< 21.5

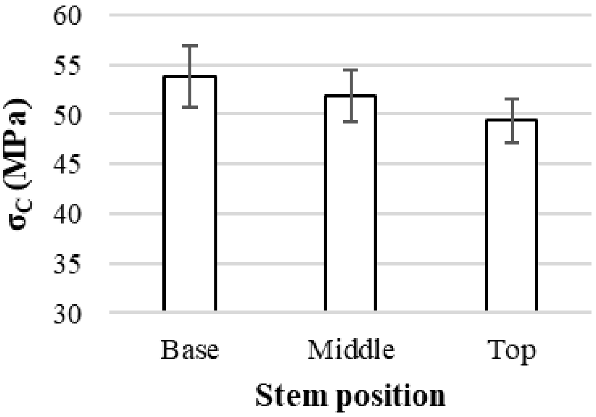

Figure 6. Compressive strength parallel to grain (σ_C) of *B. motleyana* wood (HSD=2.71). Error bars represent standard deviation

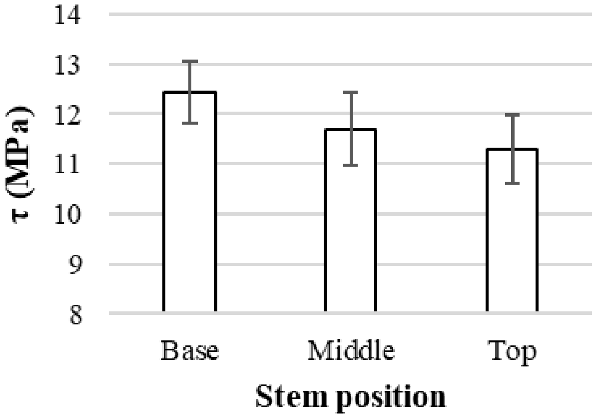

Figure 8. Shear strength (τ) of *B. motleyana* wood (HSD = 0.69). Error bars represent standard deviation

For shear strength (τ), the mean value at the whole-stem was 11.81±1.35 MPa (Figure 8), with values decreasing from the base to the top of the stem. This value places rambai wood toward the upper part of the range reported for comparable plantation and fast-growing wood species. For example, *S. parahyba* shows shear strength of ~8 MPa (de Almeida et al. 2013), which similar with *Eucalyptus grandis* reported by Hamdan et al. (2020). Belleville et al. (2020) reported shear strengths of 10.7 MPa for *Eucalyptus deglupta* and 11.3 MPa for *Anthocephalus chinensis*, and Samamba et al. (2025) found values of roughly 9 MPa for 24-year-old *T. grandis*. This indicates that rambai wood offers a level of shear resistance that is fully consistent with, or superior to, many established tropical plantation timbers and supports its suitability for applications where shear stress are critical, such as glued lamination and interior joinery.

Table 4. Grading standards for mechanical properties according to Forestry and Forest Products Research Institute (FFPRI 1975). The data presented were converted from the original kg/cm^2 units

Grade	MOE (GPa)	MOR (MPa)
I	≤ 7.4	≤ 58.8
II	7.5–10.3	58.9–82.4
III	10.4–13.2	82.5–106.9
IV	13.3–16.2	107.0–130.4
V	≥ 16.3	≥ 130.5

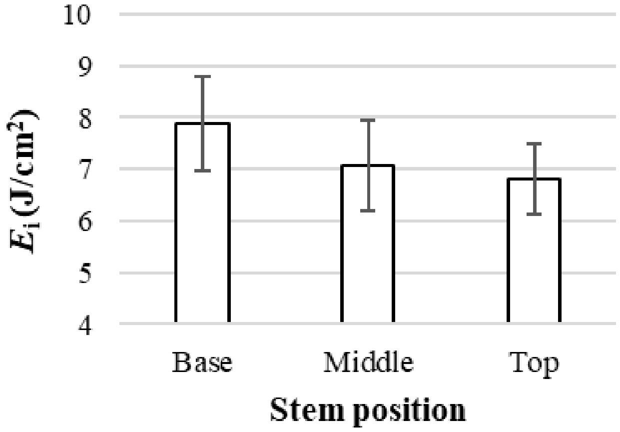

Figure 7. Impact bending strength (Ei) of *B. motleyana* wood (HSD=0.60). Error bars represent standard deviation

This study provides the first quantitative data on the physical and mechanical properties of rambai (*B. motleyana*) wood. The apparent density averaged 0.62±0.04 g/cm^3, with no significant axial variation along the stem, placing rambai in the medium-density wood and comparable to several plantation timbers. Shrinkage values yielded a T/R ratio of about 1.59, indicating a normal anisotropic behavior and good dimensional stability. For mechanical properties, based on existing classification system, *B. motleyana* wood characterized as a medium-strength timber (Strength Classes II-III and FFPRI Grade II-III), comparable to several commercial timber species. Taken together, based on physical and mechanical properties tested on small-clear specimens, these findings suggest that rambai wood has properties compatible with use for furniture, light construction, and provide a basic information for considering this species as a potential timber resource within multipurpose plantation systems where both fruit and wood are utilized. Other key considerations, including silvicultural performance and economic suitability were not evaluated in this study and should be addressed in future research.

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