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Assessment of Wood Properties of *Hevea brasiliensis* Clones Grown in Zamboanga Sibugay Philippines for their Potential Applications

Oliver S. Marasigan* and Marina A. Alipon

Physics and Mechanics Section, Material Science Division, Forest Products Research and Development Institute (FPRDI), Department of Science and Technology (DOST), College, Los Baños, Laguna 4031 Philippines

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*** Corresponding author:**
E-mail:
oliver.marasigan@fprdi.dost.gov.ph

ABSTRACT

The potential utilization of 25 year old rubber tree (*Hevea brasiliensis* [Wild. ex A.Juss.] Müll. Arg.) clones (PB 260 and RRIM 600) were assessed based on their anatomical, physical, and mechanical properties. Anatomical features were evaluated using IAWA standards, while physical and mechanical properties were determined following ASTM D143-2019. Five trees per clone were collected from Naga, Zamboanga Sibugay. Results showed that PB 260 exhibited fiber dimensions significantly greater than RRIM 600, with 6.42% longer fibers, 9.42% larger fiber diameters, and 22.47% wider lumens. However, PB 260 had thinner cell walls by 13.33%. Vessel dimensions of PB 260 were also significantly higher, with 14.05% longer and 11.83% wider vessels. For physical properties, RRIM 600 showed higher basic relative density (0.53), tangential shrinkage (4.91%), and volumetric shrinkage (7.58%) compared to PB 260 (0.48, 4.52, and 7.21%, respectively). However, PB 260 had higher green moisture content (126.14%) than RRIM 600 (102.15%). Mechanical testing revealed RRIM 600 had higher strength, attributed to its higher basic relative density and thicker cell wall thickness. RRIM 600 is recommended for construction, flooring, and cabinetry, while PB 260 is suitable for medium grade furniture, carving, and pallets. The study highlights the potential of *H. brasiliensis* clones as alternative raw materials for the Philippine wood industry.

HIGHLIGHTS

- Full wood property test of PB 260 and RRIM 600 clones in the Philippines.
- *Hevea brasiliensis* clones show strong potential for local timber use.
- Significant variation observed in wood properties between the two clones.

1. INTRODUCTION

The rubber tree [*Hevea brasiliensis* (Wild. ex A.Juss.) Müll. Arg.] is native to regions in South America including Bolivia, northern, southern, and west-central Brazil, Colombia, French Guiana, Peru, and Venezuela. It has also been introduced to various Asian countries such as India, Bangladesh, Cambodia, Malaysia, Taiwan, and the Philippines (POWO, 2024). In the Philippines, *H. brasiliensis* is a vital agro-industrial crop, predominantly grown on Mindanao Island, with smaller cultivation areas in Luzon and Visayas. The top-producing regions in Mindanao include the Zamboanga Peninsula, SOCCSKSARGEN (South Cotabato, Cotabato, Sultan Kudarat, Sarangani, and General Santos), ARMM (Autonomous Region in Muslim Mindanao), the Davao Region, and the Caraga Region (PSA, 2021).

As of 2021, approximately 229,431 ha were planted with *H. brasiliensis*, with Zamboanga Peninsula, SOCCSKSARGEN, and ARMM contributing 85% of the country's production (PSA, 2021). The Zamboanga Peninsula is the largest producer, accounting for 41.7% of the total yield. Of the 111,845 ha of mature plantation, 43,592 ha are in Zamboanga (PSA, 2021). If policies on *H. brasiliensis* wood utilization are expanded, nearly 6 million m³ of logs could be processed (PSA, 2021). Sustainable management strategies, including balancing latex production with wood processing, could optimize its potential as an alternative raw material for wood-

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based products such as furniture, panel boards, and construction materials (De Lima et al., 2023; Allwi et al., 2021).

Despite its abundance, a limited number of studies have been carried out to evaluate the wood properties of *H. brasiliensis* in the Philippines (Alipon and Bondad, 2008). In contrary, other countries utilize the *H. brasiliensis* wood for production of furniture and composite panels like particleboard and MDF (Ayrilmis et al., 2017).

The growing demand for sustainable wood sources has also led to research on genetically improved clones, which influence wood properties (Naji et al., 2014). Studies in Malaysia, Brazil, and Thailand have examined how different *H. brasiliensis* clones affect wood characteristics (Allwi et al., 2021; de Lima et al., 2023; Riyaphan et al., 2015). These studies highlight significant variations in anatomical, physical, and mechanical properties. For example, de Lima et al. (2023) found differences in relative density, shrinkage, fiber length, and vessel characteristics across five clones. Allwi et al. (2021) reported variations in moisture content, density, and shrinkage, while Riyaphan et al. (2015) observed differences in mechanical properties such as modulus of rupture, modulus of elasticity, hardness, and tensile strength.

In the Philippines, particularly in Zamboanga Sibugay, RRIM 600 and PB 260 are the most commonly planted *H. brasiliensis* clones. RRIM 600 has been extensively studied in other countries, with reported properties including a relative basic density of 0.59-0.63, 49.89% moisture content, and shrinkage values of 3.58% (radial), 4.70% (tangential), and 9.69% (volumetric) (Allwi et al., 2021). Its mechanical properties have been reported as a modulus of rupture (MOR) of 108.0 MPa, modulus of elasticity (MOE) of 9.40 GPa, tensile strength of 1.60 MPa, and surface hardness of 6.6 kN (Riyaphan et al., 2015). However, these values are based on studies conducted outside the Philippines. There is limited information on the wood properties of RRIM 600 grown under Philippine conditions, where climatic and site factors may influence its performance. PB 260, on the other hand, remains largely undocumented in literature. Including RRIM 600 in this study provides a reference clone for site-specific comparison and supports a better evaluation of PB 260's wood properties under local growing conditions.

Despite the availability of different clones of *H. brasiliensis* trees, research on their wood properties in the Philippines remains scarce. Since raw material quality influences final product performance, evaluating *H. brasiliensis* clones at different stem heights is essential for determining their suitability for specific applications. Therefore, this study aims to characterize and compare the anatomical, physical, and mechanical properties of two widely cultivated clones in the Philippines (i.e., RRIM 600 and PB 260) at different height levels. The findings are intended to guide the selection and utilization of suitable clones for various processing and products industry sectors.

2. METHODOLOGY

2.1 Collection and preparation of samples

Five 25 year old trees of *H. brasiliensis* clones (RRIM 600 and PB 260), with diameters greater than 25 cm, were selected from the Tambanan Agrarian Reform Beneficiaries Cooperative (TARBEMCO) in Barangay Tambanan, Naga, Zamboanga Sibugay. The description of the collection sites and trees is presented in Table 1. The average diameter and merchantable height of the logs used were 30.35 cm and 8.58 m for PB 260, and 28.95 cm and 8.55 m for RRIM 600, respectively (Table 1). Each tree trunk was divided into two portions-namely butt (2.4 m) and middle (4.8 m) from the base of the trunk. A total of 20 disks, each 152 mm thick, and 20 billets measuring 2.4 m were cut. The disks were assigned for the determination of the anatomical and physical properties, and billets were used for the testing and evaluation of mechanical properties. Figure 1 shows the sample scheme used.

2.2 Fiber and vessel measurement

From the disc, match-sized splits (25 mm long) were cut and submerged in test tubes containing a macerating solution of equal volumes of hydrogen peroxide and glacial acetic acid. Following the modified Franklin's (1945) method as applied by Alipon et al. (2021), the test tubes were placed in a hot water bath for an hour or until the samples became whitish and soft.

Once softened, the samples were thoroughly rinsed with distilled water to remove any residual acid. To separate the fibers and vessels, the samples were shaken in distilled water, and the resulting macerated material was stained with safranine to enhance visibility under the microscope. Using a Zeiss Primo Star microscope and Zen Lite software, fiber length, vessel length, and vessel width were measured at 10x magnification, while fiber diameter and lumen diameter were measured at 40x magnification (Figure 2). Fiber and vessel measurements followed the guidelines by the International Association of Wood Anatomists (IAWA) (Wheeler et al., 1989). Cell wall thickness was calculated as the difference between the fiber diameter and lumen diameter. A total of 250 individual fibers and 250 vessels were measured for each clone.

Table 1. Characteristics of the collection site and *H. brasiliensis* clones

Characteristics		Description
Region		9
Province		Zamboanga Sibugay
Municipality		Naga
Barangay		Tambanan
Latitude		7°48'59.3"N
Longitude		122°40'30.9"E
Climatic type		3 and 4
Elevation (m.a.s.l.)		49.3
Temperature (°C)		27.10 (1.5)
Average humidity (%)		77.99 (7.8)
Average precipitation (mm)		179.07 (7.06)
Estimated age of both clones (year old)		25
Average diameter (cm)	PB 260	30.35 (9.26)
	RRIM 600	28.95 (11.00)
Average merchantable height (m)	PB 260	8.58 (2.23)
	RRIM 600	8.55 (2.05)

Note: Inside the parenthesis is the standard deviation.

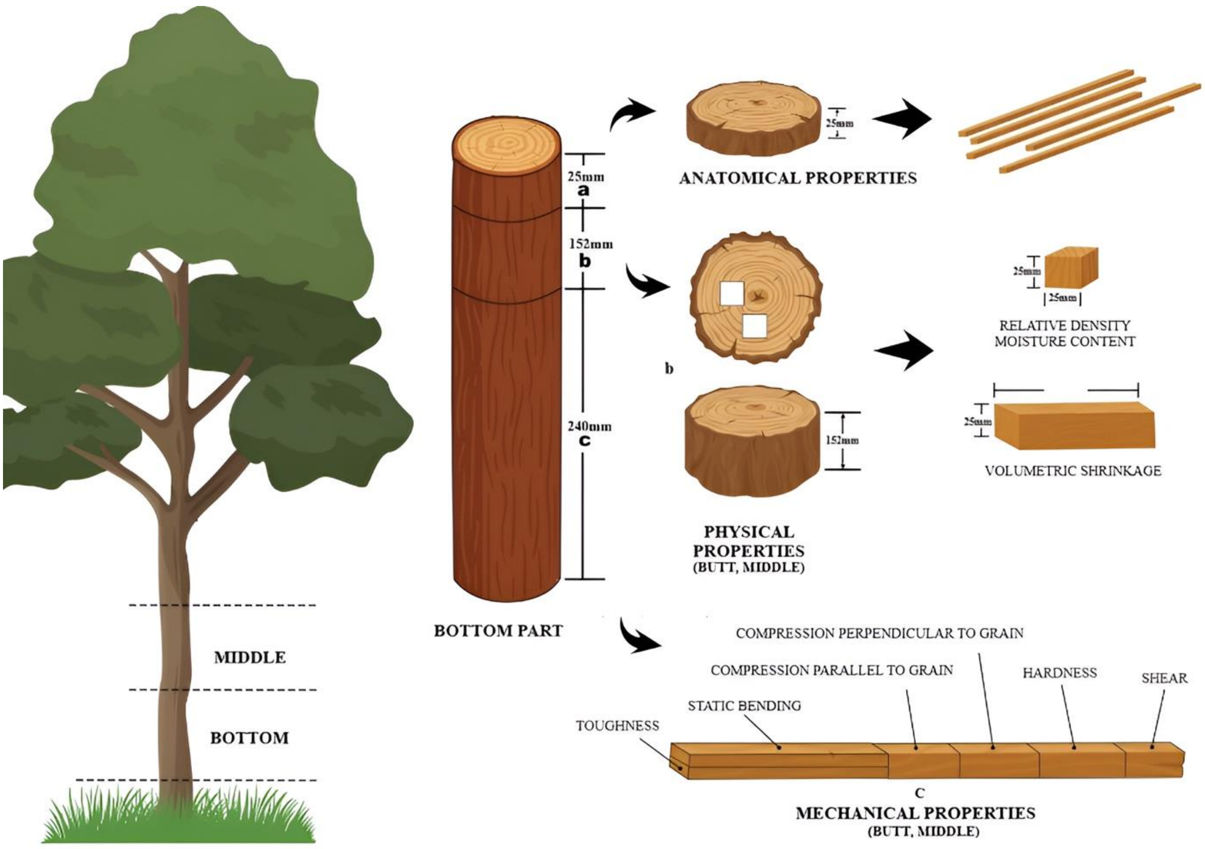

Figure 1. Sampling scheme used in the study (Marasigan and Mundin, 2024)

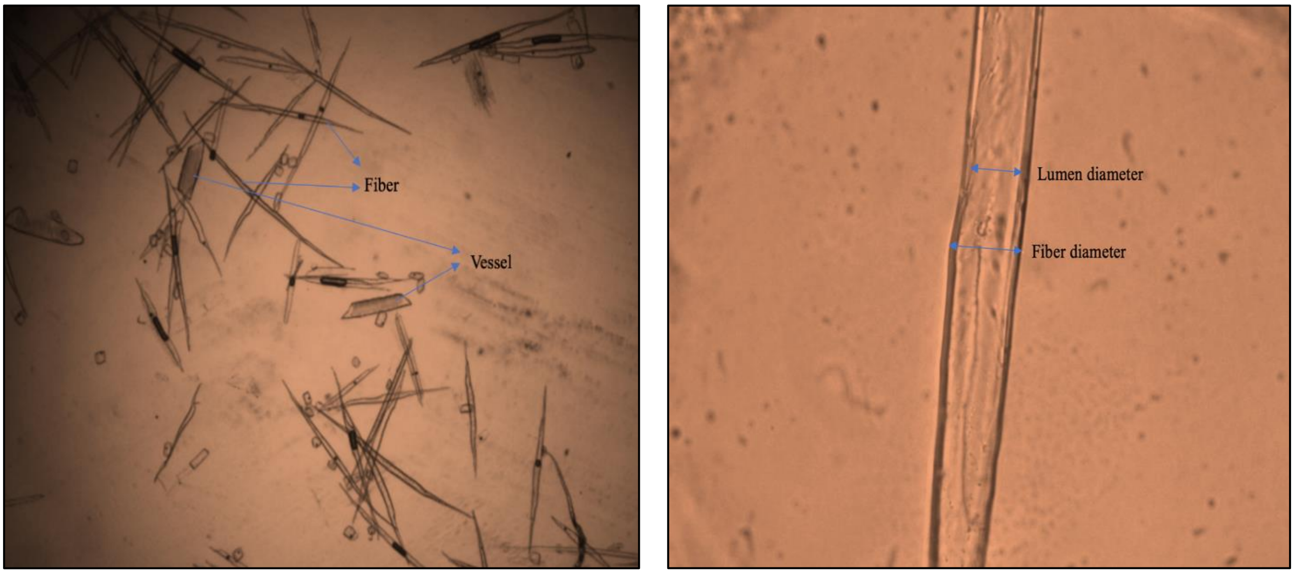

Figure 2. Sample photograph depict the fiber and vessel of the *H. brasiliensis* clones

2.3 Derived values

Based on the fiber morphology data, the derived values such as Runkel ratio (1), Slenderness ratio (2), and Mulhsteph ratio (3) were computed using the equation below:

$$\text{Runkel ratio} = \frac{2 \times \text{cell wall thickness}}{\text{Lumen diameter}} \quad (1)$$

$$\text{Slenderness ratio} = \frac{\text{Fiber length}}{\text{Fiber diameter}} \quad (2)$$

$$\text{Mulhsteph ratio (\%)} = \frac{\text{Fiber diameter}^2 - \text{lumen diameter}^2}{\text{Fiber diameter}^2} \times 100 \quad (3)$$

2.4 Physical properties determination

The physical properties were assessed following the ASTM D143-52 standard (ASTM 2019). A 25 mm × 25 mm × 25 mm sample was extracted from the disc for analyzing green moisture content (MC) and basic relative density (RD). The initial mass of the samples was measured, and their volume was determined using the water displacement method. The samples were then oven-dried at 103±2°C until a constant weight was reached, and their oven-dry mass was recorded. The green MC was calculated as the percentage reduction in mass relative to the oven-dry weight, while the basic RD was obtained as the ratio of the oven-dry weight to the green volume of the sample. One hundred samples from each clone were analyzed to determine green MC and basic RD. The calculations were based on the following equations:

$$\text{MC (\%)} = \frac{W_i - W_o}{W_o} \times 100 \quad (4)$$

$$\text{RD} = \frac{W_o}{V_g} \quad (5)$$

Where; MC represents green moisture content, RD represents basic relative density, W_i represents initial weight (g), W_o represents oven-dry weight (g), and V_g represents green (wet) volume from displaced water (g).

The shrinkage values from green to oven-dry conditions were determined using blocks measuring 25 mm (R) × 25 mm (T) × 102 mm (L). The radial (R), tangential (T), and longitudinal (L) directions of each sample were marked and measured with a dial gauge with a precision of 0.0254 mm. For each clone, a total of 100 samples were used. The directional shrinkage values were calculated using the following equations:

$$S_a\,(\%) = \frac{D_i - D_o}{D_i} \times 100 \quad (6)$$

Where; S_a represents shrinkage from green to oven-dry conditions, D_i represents initial dimension (mm), and D_o represents oven-dry dimension (mm).

Volumetric shrinkage (VS) was calculated using the change in specimen volume between green and oven-dry conditions, using the formula:

$$V_s\,(\%) = \frac{V_i - V_o}{V_i} \times 100 \quad (7)$$

Where; V_i is the initial green volume (mm^3), and V_o is the oven-dry volume (mm^3).

2.5 Determination of mechanical properties

The mechanical properties of the samples were determined according to ASTM D143-52 (ASTM, 2019). For each clone, two sets of samples (green and 12% MC) were prepared, with each clone consisting of 20 samples. These samples were tested for various mechanical properties, including static bending (stress at the proportional limit, modulus of rupture, modulus of elasticity), compression strength (parallel and perpendicular to the grain), hardness (side and end), shear strength, and toughness. The specimen dimensions for each mechanical test are summarized in Table 2, following the specifications of ASTM D143-52 (2019). All tests were conducted using an Universal Testing Machine (Shimadzu UH-300kNx series), except for the toughness test, which was performed using the U.S. Forest Products Laboratory's Product Testing Machine, developed by Sonntag Scientific Corporation (Serial No. 872286). The loading rates for the tests were as follows: 1.3 mm/min for static bending, 0.30 mm/min for compression tests (both parallel and perpendicular), 0.6 mm/min for shear tests, and 6.0 mm/min for hardness testing.

Table 2. Dimensions of test-specimens for the various tests

Mechanical test	Dimensions (L × W × H) (mm)
Static bending	400 × 25 × 25
Compression parallel to grain	100 × 25 × 25
Compression perpendicular to grain	150 × 50 × 50
Shear strength	60 × 50 × 50
Hardness	150 × 50 × 50
Toughness	280 × 20 × 20

2.5 Statistical analysis

Statistical analysis was carried out using R Studio version 4.2.1 (R Core Team, 2020). The data were analyzed using a Factorial Completely Randomized Design (Factorial CRD) with two factors: clone and height level. Before conducting the analysis of variance (ANOVA), the Kolmogorov-Smirnov test for normality showed no significant deviation ($p>0.05$), indicating that the data followed a normal distribution. ANOVA was then applied to evaluate the significance of mean differences across clones, height levels, and their interaction. To identify which specific means were significantly different, Tukey's honestly significant difference (HSD) test was performed.

3. RESULTS AND DISCUSSION

3.1 Anatomical properties

The results of the ANOVA and Tukey's HSD for the anatomical properties between clones of *H. brasiliensis* wood were shown in Table 3. The average fiber characteristics of clone PB 260, including fiber length (1.28 mm), fiber diameter (2.97 µm), and lumen diameter (2.18 µm), were significantly higher, being 6.42% longer and 9.42% and 22.47% larger, respectively, compared to the RRIM 600 clone, which had averages of 1.20 mm, 2.69 µm, and 1.78 µm, respectively. Conversely, the cell wall thickness (CWT) of PB 260 (3.9 µm) was significantly smaller, showing a 13.33% lower compared to RRIM 600 (4.50 µm). Furthermore, PB 260 displayed a significantly higher vessel characteristics, with a vessel length of 0.75 mm and width of 0.26 mm, which were 14.05% longer and 11.83% larger, respectively, than those of RRIM 600 (0.66 mm and 0.23 mm, respectively).

Table 4 presents a comparison of the anatomical properties obtained in the present study with values reported in previous studies. Compared to the 33 year old *H. brasiliensis* clones studied by de Lima et al. (2023) in Brazil, the fiber length of *H. brasiliensis* clones in the present study was longer than RRIM 600 (1.18 mm) and IAN 873 (1.17 mm) but shorter than LCB510 (1.25 mm) and GT1 (1.34 mm). Additionally, the fiber length of PB 260 exceeded that of IAN 717 (1.23 mm). Regarding CWT, PB 260 exhibited a smaller value compared to the clones examined by de Lima et al. (2023). In contrary, RRIM 600 in the present study showed a larger CWT compared to IAN 873 (4.05 µm) and GT 1 (4.31 µm) and was comparable to IAN 717 (4.50 µm).

Table 3. Anatomical and physical properties of *H. brasiliensis* clones

Wood properties	Clones			
	PB 260		RRIM 600	
Anatomical properties				
Fiber length (mm)	1.27[a]	(0.02)	1.20[b]	(0.04)
Fiber diameter (µm)	29.70[a]	(0.02)	26.90[b]	(0.04)
Lumen diameter (µm)	21.80[a]	(1.54)	17.80[b]	(0.61)
Cell wall thickness (µm)	3.90[b]	(0.22)	4.50[a]	(0.18)
Vessel length (mm)	0.75[a]	(0.02)	0.66[b]	(0.03)
Vessel width (mm)	0.26[a]	(0.01)	0.22[b]	(0.00)
Physical properties				
Moisture content (%)	126.14[a]	(7.13)	102.15[b]	(7.69)
Basic relative density	0.48[b]	(0.04)	0.53[a]	(0.02)
Radial shrinkage (%)	2.81[a]	(0.79)	2.81[a]	(0.88)
Tangential shrinkage (%)	4.52[b]	(0.83)	4.91[a]	(1.08)
Longitudinal shrinkage (%)	0.50[a]	(0.55)	0.41[a]	(0.32)
Volumetric shrinkage (%)	7.21[b]	(0.72)	7.58[a]	(0.93)

Note: Values with different superscripts in the same row are significantly different (p=0.05). Values inside the parenthesis indicate standard deviation.

Table 4. Anatomical properties of *Hevea brasiliensis* clones compared with other reported values

Clones	Fiber length (mm)	Fiber diameter (µm)	Lumen diameter (µm)	Cell wall thickness (µm)	Vessel length (mm)	Vessel diameter (mm)
PB 260*	1.27	29.70	21.80	3.90	0.75	0.26
RRIM 600*	1.20	26.90	17.80	4.50	0.66	0.22
LCB 510[a]	1.25	-	-	4.89	0.76	0.17
RRIM 600[a]	1.19	-	-	4.65	0.73	0.18
IAN 873[a]	1.17	-	-	4.05	0.69	0.16
IAN 717[a]	1.24	-	-	4.50	0.74	0.18
GT1[a]	1.37	-	-	4.31	0.85	0.19
RRIM 2020[b]	1.24	29.63	20.28	4.88	-	0.177
RRIM 2025[b]	1.34	28.54	18.92	4.71	-	0.186

Source: * - present study; a - De Lima et al. (2023); b - Naji et al. (2014)

Furthermore, the fiber lengths observed in the present study (1.27 mm for PB 260 and 1.20 mm for RRIM 600) were shorter compared to the 1.50 mm reported by Onakpoma et al. (2023) for 25-year-old *H. brasiliensis* trees in Nigeria. The CWT of RRIM 600 (4.50 µm) closely aligned with their reported value of 4.85 µm, while PB 260 exhibited a thinner CWT of 3.90 µm. These differences may also reflect genetic variation among clones or the influence of local growing conditions (Panshin and de Zeeuw, 1980).

In terms of fiber diameter, the present study (26.90-29.70 µm) observed a wider value compared to the 24.86 µm reported by Onakpoma et al. (2023) for 15-year-old *H. brasiliensis*, but thinner than the 27.23 µm reported for 25-year-old trees. The observed fiber diameter was narrower than the ranges reported by Teoh et al. (2011) and Naji et al. (2014), who found values between 26.0 to 30.0 µm and 26.33 to 32.84 µm, respectively, but thicker than the values reported by Izani and Sahri (2008), which ranged from 23.5 to 24.9 µm.

The lumen diameter in the present study (17.80-21.80 µm) was thicker than the range of 12.93 to 21.31 µm reported by Onakpoma et al. (2023). Additionally, it was thicker than the lumen width values reported by Izani and Sahri (2008), ranging from 10.0 to 12.0 µm, and Naji et al. (2014), who reported a higher range of 16.43 to 26.56 µm.

In terms of vessel characteristics, the vessel length of PB 260 (0.75 mm) was longer than that of the clones studied by de Lima et al. (2023), such as RRIM 600 (0.73 mm), IAN 873 (0.699 mm), and IAN 717 (0.74 mm), but shorter compared to LCB 510 (0.76 mm) and GT 1 (0.85 mm) (Table 4). However, the vessel length of PB 260 (0.66 mm) was shorter than the values reported for the clones studied by de Lima et al. (2023). Regarding vessel diameter, the results of the present study (0.23-0.25 mm) were wider than the values reported by de Lima et al. (2023), which ranged from 0.16 to 0.19 mm.

Significant variations in anatomical properties were observed across the height levels (p=<0.05). Fiber length and CWT increased significantly toward the middle portion in both clones (Figure 3). For RRIM 600, fiber length and CWT increased by 4.27% and 4.44%, respectively, while for PB 260, the increases were more pronounced at 11.79% and 13.51%, respectively. In contrast, fiber and lumen diameter decreased significantly toward the middle portion (Figure 3). In RRIM 600, fiber and lumen diameter decreased slightly by 1.10% and 3.84%, respectively, whereas in PB 260, the reductions were 1.00% and 15.44%, respectively (Figure 3).

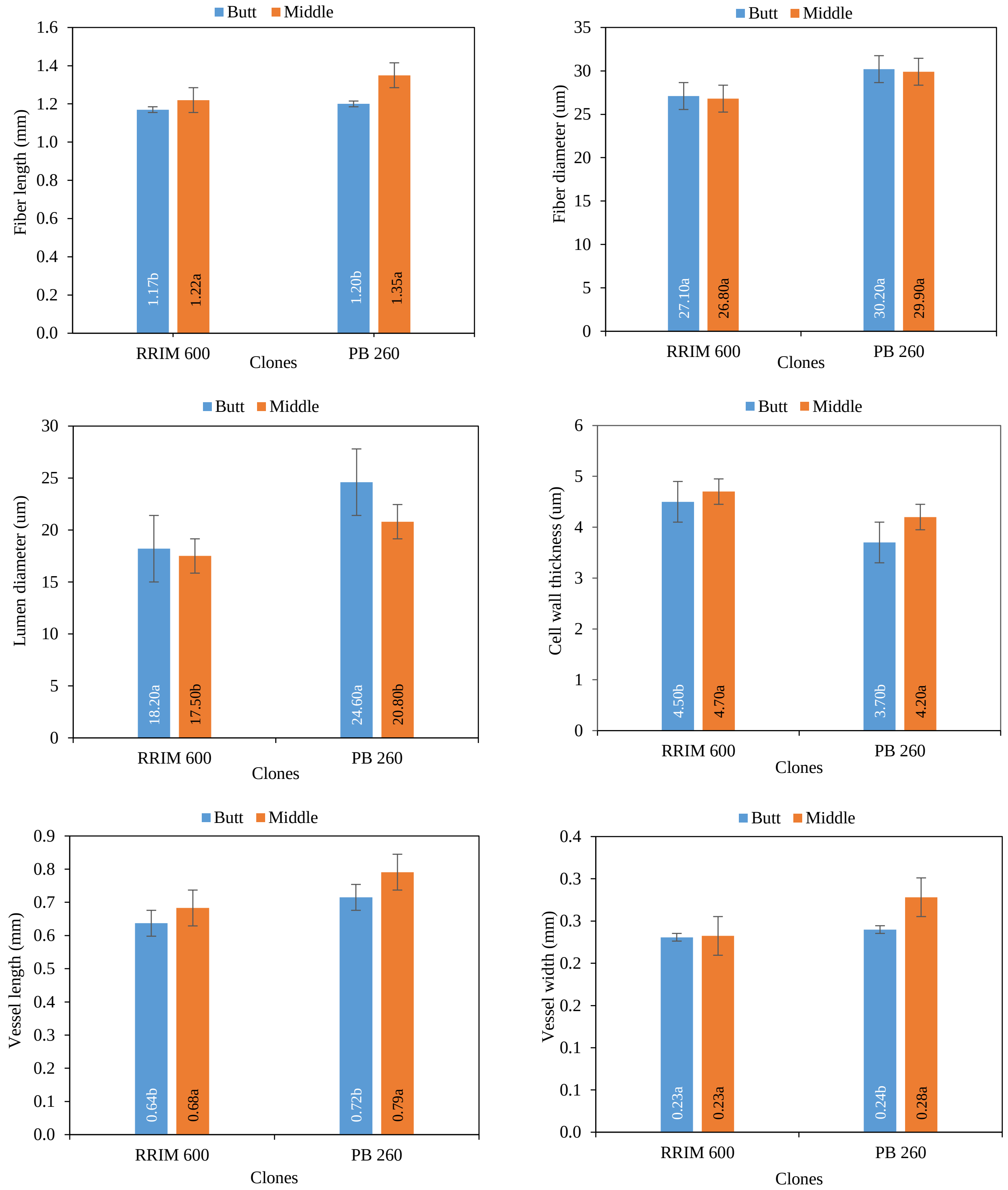

Figure 3. Anatomical properties of *H. brasiliensis* clones at different height levels. Within each clone, bars with different superscripts (a, b) are significantly different (p≤0.05)

The trends observed in the present study contrast with the findings of Onakpoma et al. (2023), who reported longer fibers, as well as thicker fiber, lumen diameter, and CWT at the butt portion of *H. brasiliensis* grown in Nigeria. This discrepancy could likely be attributed to inherent differences in wood properties among trees, as well as the influence of environmental factors, such as climate, soil conditions, and growing practices, on wood development (Dinwoodie, 2000).

Vessel characteristics also exhibited significant variation along the height levels (Figure 3) (p=<0.05). Vessel length increased notably toward the middle portion, with increments of 7.06% in RRIM 600 and 10.78% in PB 260. Vessel width also increased in both clones, despite to varying extents. For RRIM 600, the increase was insignificant at 0.69%, while for PB 260, it was significant at 15.95%.

The fiber length of the clones in this study fell under Class II based on the Indonesian Timber Assessment Criteria as Raw Materials for Pulp and Paper (Hartono et al., 2022), which categorizes fiber length between 1.00-2.00 mm as moderately suitable for pulp and paper production. In this classification, Class I (>2.00 mm) indicates high suitability, Class II (1.00-2.00 mm) indicates moderate suitability, and Class III (<1.00 mm) indicates low suitability. Suansa and Al-Mefarrej (2020) emphasized that fibers with an average length greater than 0.4 mm are suitable for papermaking, a claim supported by the low Runkel and Muhlsteph ratios of the clones. RRIM 600 exhibited averages of 0.51 and 56.05, while PB 260 had 0.36 and 42.63, respectively (Table 5). According to Runkel and Muhlsteph ratios classification of DOST-FPRDI (2007), these values categorized the clones as very promising raw material for papermaking, as long fibers with thin cell walls improve tearing, tensile, bursting strength, and folding endurance (Sharma et al., 2011).

Table 5. Derived ratio of *H. brasiliensis* clones

Clone	Slenderness ratio	Runkel ratio	Muhlsteph ratio
RRIM 600	44.52	0.51	56.05
PB 260	43.07	0.36	45.62

In addition to their potential for papermaking, the fiber dimensions of the two clones also align with criteria suitable for composite materials with in plane isotropic properties, which typically require fiber lengths between 1 and 5 mm (Madsen et al., 2013). Although the processing and performance requirements differ from those of papermaking, the high slenderness ratios observed: 44.52 for RRIM 600 and 43.07 for PB 260, are considered advantageous for composite applications, as they contribute to improved fiber bonding and bending strength in wood based panels (Ayrilmis et al., 2017).

Onakpoma et al. (2023) and Amorim et al. (2021) highlighted the suitability of *H. brasiliensis* fibers for composite board production. Longer fibers are particularly advantageous in composite boards as they are less likely to deviate from the horizontal plane, leading to a larger contact area between fibers (Onakpoma et al., 2023). This reduces thickness swelling and enhances dimensional stability under loading. Additionally, longer fibers offer higher resin content per unit surface area compared to shorter fibers, resulting in panels with superior mechanical properties. Composite board produced from longer fibers also exhibit higher internal bond strength than those made from shorter fibers (Ayrilmis et al., 2017).

Fiber diameter significantly influences the mechanical properties of wood and composite materials. A large fiber diameter can weaken inter-fiber bonding due to a smaller surface area compared to volume, reducing stress transfer efficiency. On the other hand, lumen diameter, also plays a vital role in pulp and paper manufacturing and composite production. A larger lumen improves pulp beating by allowing liquids to penetrate fiber voids (Riki et al., 2019) and can lower wood's specific gravity (Izani and Sahri, 2008), which may affect the mechanical properties of composite board.

Regarding CWT, thick fibers are undesirable for pulp and paper production, as well as composite board applications, because they are less flexible, resistant to collapse, and difficult to pulp (Onakpoma et al., 2023). This hinders effective inter-fiber bonding, whereas thin-walled fibers promote better bonding (Sharma et al., 2011). Pulps made from thin-walled fibers are smoother and more suitable for producing a variety of paper grades (Riki et al., 2019). On the other hand, thick-walled fibers result in paper with poor printing surfaces, higher bulk weight, lower tensile strength, poor burst strength, high tearing strength, and low folding endurance (Pulkkinen et al., 2008). However, for composite board, lumber, and furniture production, thick-walled fibers are beneficial as they enhance load-carrying capacity. Thick-walled fibers tend to have fewer voids and pores, making them better at resisting applied external loads compared to thin-walled fibers (NagarajaGanesh and Rekha, 2020).

3.2 Physical properties

The descriptive statistics and analysis of variance (ANOVA) results for the physical properties between clones of *H. brasiliensis* are presented in Table 3. Significant variations were observed between clones in basic relative density (RD), green moisture content (MC), tangential shrinkage (TS), and volumetric shrinkage (VS) (p=<0.05). The RRIM 600 clones exhibited significantly higher basic RD, TS, and VS compared to the PB 260 clones, while the PB 260 clones displayed significantly higher green MC than the RRIM 600 clones. On the other hand, significant variation along the height was only observed in green MC (Figure 4).

The basic RD of RRIM 600 (0.53) was significantly higher than that of PB 260 (0.48). Conversely, the green MC of RRIM 600 (102.15%) was significantly lower compared to PB 260 (126.14%). Similar significant variations in the basic RD of *H. brasiliensis* clones were reported by Allwi et al. (2021) and de Lima et al. (2023). However, the average basic RD observed in the present study was lower than the values reported by these studies (Table 6).

Table 6. Physical and mechanical properties of *Hevea brasiliensis* clones compared with other reported values

Clones	Physical properties					Mechanical properties				
	RD	RS	TS	LS	VS	$C_{//}$	C_L	SS	MOR	MOE
PB 260*	0.48	2.81	4.52	0.50	7.21	25.97	6.01	6.10	56.00	6.54
RRIM 600*	0.53	2.81	4.91	0.41	7.58	29.65	6.00	6.91	62.93	8.12
LCB 510[a]	0.60	-	-	-	8.11	-	-	-	-	-
RRIM 600[a]	0.59	-	-	-	9.69	-	-	-	-	-
IAN 873[a]	0.57	-	-	-	9.18	-	-	-	-	-
IAN 717[a]	0.57	-	-	-	7.54	-	-	-	-	-
GT1[a]	0.56	-	-	-	7.07	-	-	-	-	-
GT1[b]	0.63	1.82	4.00	0.76	-	48.74	15.69	-	85.26	8.05
RRIM 600[b]	0.62	2.98	4.86	0.72	-	48.90	18.18	-	79.84	8.29
RRIT 251[c]	-	-	-	-	-	-	-	-	100.00	9.40
RRIM 600[c]	-	-	-	-	-	-	-	-	108.00	10.40
R59[c]	-	-	-	-	-	-	-	-	103.00	10.50
R650[c]	-	-	-	-	-	-	-	-	91.00	8.80
R1397[c]	-	-	-	-	-	-	-	-	101.00	9.70
R1757[c]	-	-	-	-	-	-	-	-	111.00	10.40
R2086[c]	-	-	-	-	-	-	-	-	109.00	10.30
GT1[d]	0.54	-	-	-	-	48.83	11.24	9.43	-	-
RRIM 600[d]	0.55	-	-	-	-	43.53	11.38	9.60	-	-

Source: * - present study; a - De Lima et al. (2023); b - Allwi et al. 2021; c - Riyaphan et al. (2015); d - Eufrade et al. (2015).
Note: RD - Basic relative density; RS - Radial shrinkage (%); TS - Tangential shrinkage (%); LS - Longitudinal shrinkage (%); VS - Volumetric shrinkage; $C_{//}$ - Compression parallel to the grain (MPa); C_L - Compression perpendicular to the grain (MPa); SS - Shear strength (MPa); MOR - Modulus of rupture (MPa); MOE - Modulus of elasticity (GPa)

The significantly higher RD in RRIM 600 can likely be attributed to its thicker cell wall and narrower vessel diameter compared to PB 260. As shown in Table 7, basic RD exhibited a positive correlation with CWT and a negative correlation with vessel diameter. This aligns with findings by Van Duong et al. (2021), who reported that RD is positively correlated with CWT but negatively correlated with vessel diameter. Similarly, Hamdan et al. (2020) found that CWT is directly related to RD, and de Lima et al. (2023) observed the highest RD in *H. brasiliensis* clones with thicker cell walls and narrower vessel diameters.

Table 7. Correlation matrix of wood properties of *H. brasiliensis* clones

Properties	FL	FD	LD	CWT	VL	VW	RD	MC	TS	RS	LS	VS	MOR	SPL	MOE	Comp Par	Comp Per	SS	HS	HE
FD	0.99^{*}	—																		
LD	0.67^{*}	0.69^{*}	—																	
CWT	-0.55^{ns}	-0.56^{ns}	-0.91^{*}	—																
VL	0.73^{*}	0.70^{*}	0.84^{*}	-0.79^{*}	—															
VW	0.92^{*}	0.89^{*}	0.78^{*}	-0.60^{ns}	0.89^{*}	—														
RD	-0.50^{ns}	-0.52^{ns}	-0.90^{*}	0.86^{*}	-0.61^{*}	-0.57^{ns}	—													
MC	0.61^{ns}	0.63^{ns}	0.92^{*}	-0.88^{*}	0.67^{*}	0.65^{*}	-0.99^{*}	—												
TS	-0.64^{*}	-0.60^{ns}	-0.34^{ns}	0.31^{ns}	-0.38^{ns}	-0.55^{ns}	0.38^{ns}	-0.48^{ns}	—											
RS	0.21^{ns}	0.24^{ns}	-0.09^{ns}	-0.09^{ns}	-0.28^{ns}	-0.14^{ns}	-0.06^{ns}	0.14^{ns}	-0.34^{ns}	—										
LS	0.61^{ns}	0.53^{ns}	-0.05^{ns}	0.07^{ns}	0.18^{ns}	0.45^{ns}	0.03^{ns}	0.08^{ns}	-0.65^{*}	0.33^{ns}	—									
VS	-0.50^{ns}	-0.44^{ns}	-0.40^{ns}	0.25^{ns}	-0.58^{ns}	-0.65^{*}	0.33^{ns}	-0.39^{ns}	0.76^{*}	0.36^{ns}	-0.42^{ns}	—								
MOR	-0.69^{*}	-0.61^{ns}	-0.51^{ns}	0.46^{ns}	-0.62^{ns}	-0.74^{*}	0.57^{ns}	-0.62^{ns}	0.73^{*}	0.02^{ns}	-0.70^{*}	0.74^{*}	—							
SPL	-0.72^{*}	-0.68^{*}	-0.73^{*}	0.69^{*}	-0.80^{*}	-0.80^{*}	0.71^{*}	-0.76^{*}	0.65^{*}	0.03^{ns}	-0.48^{ns}	0.67^{*}	0.84^{*}	—						
MOE	-0.61^{ns}	-0.56^{ns}	-0.54^{ns}	0.67^{*}	-0.63^{*}	-0.59^{ns}	0.53^{ns}	-0.63^{ns}	0.81^{*}	-0.22^{ns}	-0.46^{ns}	0.64^{*}	0.76^{*}	0.70^{*}	—					
Comp Par	-0.90^{*}	-0.90^{*}	-0.84^{*}	0.77^{*}	-0.79^{*}	-0.88^{*}	0.75^{*}	-0.84^{*}	0.60^{ns}	-0.19^{ns}	-0.47^{ns}	0.46^{ns}	0.74^{*}	0.85^{*}	0.69^{*}	—				
Comp Per	-0.88^{*}	-0.90^{*}	-0.79^{*}	0.69^{*}	-0.68^{*}	-0.81^{*}	0.70^{*}	-0.77^{*}	0.52^{ns}	-0.15^{ns}	-0.37^{ns}	0.41^{ns}	0.65^{*}	0.64^{*}	0.62^{ns}	0.90^{*}	—			
SS	-0.66^{*}	-0.66^{*}	-0.79^{*}	0.85^{*}	-0.73^{*}	-0.64^{*}	0.68^{*}	-0.76^{*}	0.41^{ns}	-0.09^{ns}	-0.19^{ns}	0.34^{ns}	0.55^{ns}	0.67^{*}	0.73^{*}	0.85^{*}	0.84^{*}	—		
HS	-0.74^{*}	-0.70^{*}	-0.62^{ns}	0.49^{ns}	-0.72^{*}	-0.83^{*}	0.59^{ns}	-0.63^{ns}	0.47^{ns}	0.19^{ns}	-0.60^{ns}	0.60^{ns}	0.89^{*}	0.85^{*}	0.53^{ns}	0.81^{*}	0.73^{*}	0.61^{ns}	—	
HE	-0.70^{*}	-0.67^{*}	-0.75^{*}	0.67^{*}	-0.73^{*}	-0.77^{*}	0.77^{*}	-0.81^{*}	0.54^{ns}	0.00^{ns}	-0.47^{ns}	0.55^{ns}	0.83^{*}	0.96^{*}	0.58^{ns}	0.87^{*}	0.68^{*}	0.65^{*}	0.90^{*}	—
T	-0.44^{ns}	-0.45^{ns}	-0.20^{ns}	-0.08^{ns}	-0.25^{ns}	-0.47^{ns}	0.03^{ns}	-0.04^{ns}	-0.21^{ns}	0.25^{ns}	-0.28^{ns}	-0.03^{ns}	0.15^{ns}	0.18^{ns}	-0.34^{ns}	0.34^{ns}	0.34^{ns}	0.07^{ns}	0.51^{ns}	0.33^{ns}

Note: ***** - significant at the 95% confidence level; ns - not significant. FL - Fiber length; FD - Fiber diameter; LD - Lumen diameter; CWT - Cell wall thickness; VL - Vessel length; VW - Vessel width; RD - Basic relative density; MC - Moisture content; TS - Tangential shrinkage; RS - Radial shrinkage; LS - Longitudinal shrinkage; VS - Volumetric shrinkage; MOR - Modulus of rupture; SPL - Stress at the proportional limit; MOE - Modulus of elasticity; Comp Par - Compression parallel to the grain; Comp Per - Compression perpendicular to the grain; SS - Shear strength; HS - Hardness: Side; HE - Hardness: End; T - Toughness.

According to the RD classification of Alipon and Bondad (2008), the *H. brasiliensis* clones in this study fall under the moderately high classification, with basic RD ranging from 0.46 to 0.54. The RD of the clones were comparable to species such as *Parashorea malaanonan*, *Rubroshorea negrosensis*, *Pentacme contorta*, *Rubroshorea polysperma*, *Swietenia macrophylla*, *Gmelina arborea*, and *Acacia mangium*. However, it was higher than the RD of *Rubroshorea almon*, *Rubroshorea palosapis*, and *Eucalyptus deglupta*, classified as moderately low, and *Rubroshorea ovata* and *Falcataria moluccana*, classified as low (Alipon and Bondad, 2008). Notably, the RD classification for *H. brasiliensis* by Alipon and Bondad (2008) was under moderately low. The findings of the present study can serve as a basis for updating the RD classification of *H. brasiliensis* grown in Philippines.

The significant variation in green MC between clones is likely due to differences in anatomical properties. As shown in Table 7, green MC was positively correlated with lumen diameter and negatively correlated with CWT. This observation is consistent with Aiso et al. (2016), who found that MC is positively correlated with lumen diameter and negatively correlated with CWT. Larger lumen diameters enable wood to retain more water. In this study, the PB 260 clone had larger lumen diameters compared to RRIM 600, while RRIM 600 exhibited thicker cell walls than PB 260 (Table 3). Additionally, the results of this study can aid the industry in estimating transportation, sawmilling, and drying costs (Shmulsky and Jones, 2019).

No significant variation in basic RD was observed along the height levels (Figure 4). This finding is consistent with the results of Allwi et al. (2021), who reported no significant variation in basic RD in the RRIM 600. However, significant variation in green MC was observed along the height of the stem, with the butt portion exhibiting the higher MC (Figure 4). A similar pattern in MC variation along the height of *H. brasiliensis* clones was also noted by Allwi et al. (2021). Anatomical characteristics may have contributed to this moisture distribution. The butt portion showed thinner CWT and wider LD compared to the middle portion (Figure 3). These characteristics are consistent with the observed correlations, where MC decreased with increasing CWT and increased with larger LD (Table 7). This indicates that the butt portion of *H. brasiliensis* clones in the present study may require a longer drying time compared to the middle portion.

In terms of shrinkage properties, no significant difference was observed in RS and LS of both species (Table 3). This indicates that both RRIM 600 and PB 260 may respond similarly to the changes in MC in terms of RS and LS. On the other hand, RRIM 600 clones recorded significantly higher TS and VS with an average of 4.91% and 7.58%, respectively, than PB 260 (4.52% and 7.21%, respectively) (Table 3).

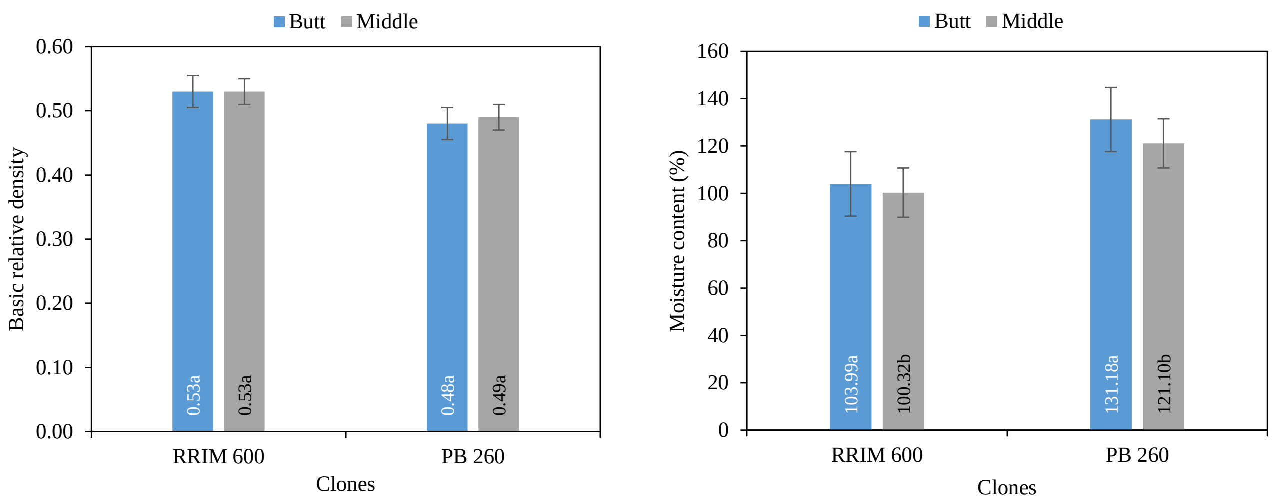

Figure 4. Physical properties of *H. brasiliensis* clones at different height levels. Within each clone, bars with different superscripts (a, b) are significantly different (p≤0.05)

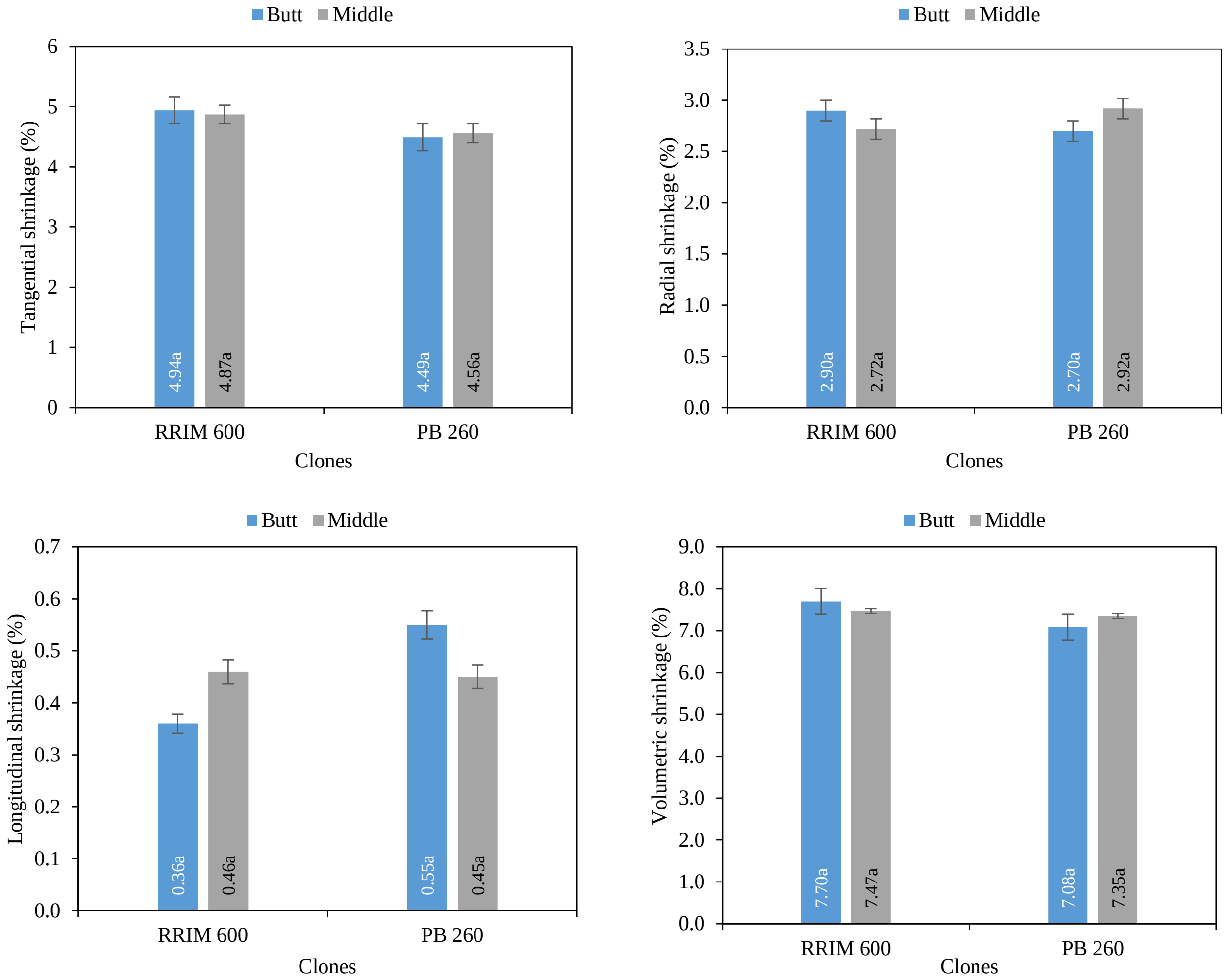

Figure 4. Physical properties of *H. brasiliensis* clones at different height levels. Within each clone, bars with different superscripts (a, b) are significantly different (p≤0.05) (cont.)

Table 6 present a comparison of the physical properties obtained in the present study with values reported in previous studies. Compared to the *H. brasiliensis* clones studied by Allwi et al. (2021), the present study observed a RS of 2.81%, which was higher than the 1.82% reported for the GT 1 clones but slightly lower than the 2.98% for RRIM 600. In terms of TS, RRIM 600 in present study exhibited a higher value of 4.91% compared to 4.0% for GT 1 and 4.68% for RRIM 600, while PB 260 had a lower TS of 4.52% than RRIM 600. Regarding LS, the present study recorded LS values of 0.50% for PB 260 and 0.41% for RRIM 600, although non-significant, both of which were lower than the LS values for GT 1 (0.76%) and RRIM 600 (0.72%) clones. On the other hand, compared to the five clones studied by de Lima et al. (2023), the VS of the present study was lower except for GT 1 (7.07%).

The significantly higher TS and VS observed in RRIM 600 are likely attributed to their higher basic RD and thicker cell wall as the significant positive correlations between TS and VS with RD and CWT is observed (Table 7). The results of the present study suggest that shrinkage properties are strongly influenced by RD and CWT, with wood of higher RD and thicker cell wall exhibiting greater shrinkage. Hamdan et al. (2020) and Okon (2014) also noted that shrinkage properties are positively correlated with CWT. Other factors, such as high microfibril angle (MFA) and low extractive content, may also contribute to the wood's increased shrinkage (Shmulsky and Jones, 2019).

The VS of the *H. brasiliensis* clones in the present study was assessed using the classification of Alipon et al. (2005), placing the clones in the low shrinkage category. The results suggest that the clones may be suitable for applications where shrinkage is critical, such as in furniture, cabinetry, moldings, flooring and musical instruments. However, the suitability for specific applications may still depend on their mechanical properties. Notably, the shrinkage behavior of these clones is better to that of the Philippine mahogany group and other commercially used timber species (Alipon et al., 2005).

3.3 Mechanical properties

The mean values and analysis of variance for the mechanical properties of *H. brasiliensis* clones at both green and 12% MC conditions, as well as along different height levels, are presented in Table 8. At the 12% MC condition, significant differences between clones were observed in modulus of elasticity (MOE), compression parallel-to-grain, and shear strength. At the green condition, significant differences were recorded in all mechanical properties except toughness. However, significant variations along the height were observed only in shear strength at green condition and in hardness (side) at 12% MC condition.

At both green and 12% MC conditions, the mechanical properties of RRIM 600 were higher than those of PB 260. At the 12% MC condition, RRIM 600 exhibited a 21.55% higher MOE (8.12 GPa), 13.23 % higher compression parallel-to-grain (29.65 MPa) compared to PB 260 (6.54 GPa and 25.97 MPa). In terms of shear strength, RRIM 600 (6.91 MPa) was 12.45% stronger than PB 260 (6.10 MPa).

At the green condition, RRIM 600 showed a significant higher modulus of rupture (MOR) (42.73 MPa), MOE (5.49 GPa), and stress at the proportional limit (SPL) (20.07 MPa), which were 17.53%, 22.49%, and 39.78% higher, respectively, compared to PB 260 (35.85 MPa, 4.38 GPa, and 13.41 MPa). Additionally, RRIM 600 displayed greater compression strength, with values 41.11% higher for compression parallel-to-grain (18.24 MPa) and 53.49% higher for compression perpendicular-to-grain (3.72 MPa) compared to PB 260 (12.02 MPa and 2.15 MPa, respectively). RRIM 600 also exhibited a 30.46% higher shear strength (5.22 MPa), 29.31% greater hardness: side (2.66 kN), and 24.44% higher hardness: end (3.03 kN) compared to PB 260 (3.84 MPa, 1.98 kN, and 2.37 kN, respectively).

Table 6 presents a comparison of the mechanical properties obtained in this study with those reported in previous research. The MOE of RRIM 600 (8.12 GPa) at 12% MC was higher than that of the GT 1 clone (8.05 GPa) of *H. brasiliensis* but lower than RRIM 600 (8.28 GPa) (Allwi et al., 2021). Additionally, the MOE values of both clones in the present study at 12% MC were lower than those of the seven *H. brasiliensis* clones (Riyaphan et al., 2015). In contrast to above, the MOR at 12% MC for both RRIM 600 and PB 260 was lower than the values reported for the clones studied by Allwi et al. (2021) and Riyaphan et al. (2015).

The compression parallel-to-grain at 12% MC for RRIM 600 (29.65 MPa) and PB 260 (25.97 MPa) was lower than GT 1 and RRIM 600 clones, reported by Allwi et al. (2021) (48.74 MPa and 48.91 MPa) and Eufrade et al. (2015) (49.83 MPa and 43.53 MPa) (Table 6). Similarly, the compression perpendicular-to-grain for RRIM 600 (6.00 MPa) and PB 260 (6.01 MPa) was lower than GT 1 and RRIM 600 clones, reported by Allwi et al. (2021) (15.69 MPa and 18.18 MPa) and Eufrade et al. (2015) (11.24 MPa and 11.38 MPa). Moreover, shear strength at 12% MC of the present study (RRIM 600: 6.91 MPa, PB 260: 6.10 MPa) was lower compared to the shear strength observed by Eufrade et al. (2015) for GT 1 (9.43 MPa) and RRIM 600 (9.60 MPa) clones.

The high mechanical properties of RRIM 600 compared to PB 260, observed in both green and 12% MC conditions, are likely associated to its higher basic RD and anatomical characteristics. As shown in Table 7, all mechanical properties exhibited a positive correlation with RD and CWT, but a negative correlation with fiber diameter, lumen diameter, and vessel diameter. These findings align with previous studies by Eufrade et al. (2015) and Allwi et al. (2021), who reported a positive relationship between RD and mechanical properties of *H. brasiliensis*. Additionally, Nordahlia et al. (2014) found a positive correlation between mechanical properties and fiber diameter and CWT. Other studies have also highlighted the significant effect of fiber cell wall thickness, and vessel diameter on the mechanical properties of wood (Hamdan et al., 2020; Nordahlia et al., 2014).

At 12% MC, the mechanical properties of RRIM 600 and PB 260 clones improved, except for toughness. This improvement is likely due to the shortening and strengthening of hydrogen bonds between microfibrils, which enhance the wood's mechanical properties (Shmulsky and Jones, 2019). However, the reduction in toughness can be attributed to the lower MC, which increases the wood's brittleness (Shmulsky and Jones, 2019). Conditioning the wood of *H. brasiliensis* to 12% MC is therefore recommended to optimize its strength properties.

Table 8. Mechanical properties at green and 12% MC condition of *H. brasiliensis* clones at different height levels

Properties	Unit	MC Condition	Clone and height levels				Overall Mean	
			PB 260		RRIM 600		PB 260	RRIM 600
			Butt	Middle	Butt	Middle		
Modulus of rupture	MPa	Green	37.55^{a} (5.44)	34.16^{a} (4.38)	45.48^{a} (11.74)	40.00^{a} (7.28)	35.85^{b} (5.11)	42.74^{a} (9.92)
		12%	54.08^{a} (19.18)	57.92^{a} (11.86)	56.98^{a} (25.77)	68.88^{a} (15.61)	56.00^{a} (15.65)	62.93^{a} (21.62)
Modulus of elasticity	GPa	Green	4.39^{a} (0.82)	4.37^{a} (0.41)	5.59^{a} (1.27)	5.39^{a} (1.48)	4.38^{b} (0.63)	5.49^{a} (1.35)
		12%	6.10^{a} (1.64)	6.99^{a} (0.93)	7.39^{a} (2.80)	8.84^{a} (0.75)	6.54^{b} (1.37)	8.12^{a} (2.13)
Stress at the proportional limit	MPa	Green	13.28^{a} (2.67)	13.54^{a} (4.96)	20.73^{a} (2.14)	19.41^{a} (1.87)	13.41^{b} (3.88)	20.07^{a} (2.07)
		12%	24.68^{a} (6.98)	22.26^{a} (3.43)	21.95^{a} (6.71)	27.87^{a} (4.11)	23.47^{a} (5.49)	24.91^{a} (6.21)
Compression parallel to the grain	MPa	Green	11.71^{a} (1.79)	12.34^{a} (2.40)	18.25^{a} (3.29)	18.22^{a} (3.52)	12.02^{b} (2.09)	18.24^{a} (3.32)
		12%	25.32^{a} (5.06)	26.62^{a} (5.48)	28.25^{a} (7.75)	31.05^{a} (2.84)	25.97^{b} (5.17)	29.65^{a} (5.86)
Compression perpendicular to the grain	MPa	Green	2.61^{a} (0.57)	1.70^{a} (1.04)	3.41^{a} (0.99)	4.02^{a} (1.19)	2.15^{b} (0.94)	3.72^{a} (1.11)
		12%	6.23^{a} (0.95)	5.80^{a} (1.49)	6.64^{a} (2.05)	5.35^{a} (1.26)	6.01^{a} (1.23)	6.00^{a} (1.78)
Shear strength	MPa	Green	3.61^{b} (0.44)	4.06^{a} (0.96)	4.58^{b} (0.33)	5.87^{a} (0.97)	3.84^{b} (0.76)	5.22^{a} (0.97)
		12%	6.13^{a} (0.79)	6.07^{a} (0.82)	7.14^{a} (2.04)	6.67^{a} (0.95)	6.10^{b} (0.79)	6.91^{a} (1.57)
Hardness: side	kN	Green	2.13^{a} (0.33)	1.84^{a} (0.43)	2.66^{a} (0.54)	2.66^{a} (0.62)	1.98^{b} (0.40)	2.66^{a} (0.57)
		12%	3.25^{a} (0.86)	2.84^{b} (0.49)	3.59^{a} (0.81)	3.03^{b} (0.59)	3.05^{a} (0.71)	3.31^{a} (0.75)
Hardness: end	kN	Green	2.37^{a} (0.56)	2.36^{a} (0.38)	2.82^{a} (0.46)	3.24^{a} (0.42)	2.37^{b} (0.47)	3.03^{a} (0.48)
		12%	4.40^{a} (0.79)	4.70^{a} (0.73)	4.79^{a} (0.70)	4.47^{a} (0.72)	4.55^{a} (0.75)	4.63^{a} (0.71)
Toughness	J/spec	Green	12.85^{a} (3.87)	9.39^{a} (3.46)	10.06^{a} (3.53)	14.26^{a} (5.92)	11.12^{a} (3.99)	12.16^{a} (5.21)
		12%	12.39^{a} (5.62)	12.81^{a} (4.27)	12.58^{a} (3.34)	10.14^{a} (1.70)	12.60^{a} (4.86)	11.36^{a} (2.87)

Note: Within each clone and across height levels, as well as for the overall mean, values with different superscripts in the same row are significantly different ($p<0.05$). Values inside the parenthesis indicate standard deviation.

Across height levels, significant differences were observed in shear strength under green condition and side hardness at 12% MC (Table 8). For shear strength, values increased from 3.61 to 4.06 MPa in PB 260 and from 4.58 to 5.87 MPa in RRIM 600, indicating consistently higher strength in the middle portion. In contrast, side hardness at 12% MC slightly decreased from 3.25 to 2.84 kN in PB 260 and from 3.59 to 3.03 kN in RRIM 600. Similar trends of increased strength properties in the middle portion have also been reported for other species, including *Falcataria falcata* (Marasigan et al., 2022), and Eucalyptus species such as *E. gomphocephala*, *E. cladocalyx*, and *E. grandis* × *camaldulensis* (Wessels et al., 2016).

The observed differences in strength properties along the height levels can be attributed to variations in RD and anatomical characteristics, as indicated by the correlations in Table 7. Dinwoodie (2000) also reported a positive correlation between RD and strength properties across height levels. Furthermore, anatomical factors such as cell wall thickness, vessel frequency, and vessel diameter contribute to the differences in strength properties along the axial heights (Sseremba et al., 2016).

Based on the strength classification by Alipon and Bondad (2008), RRIM 600 and PB 260 are classified under medium and moderately low strength, respectively, in both green and 12% MC conditions (Table 9). The classification of PB 260 aligns with Alipon and Bondad's (2008) findings, but the classification of RRIM 600 differs from their classification. This suggests that factors such as clone type may influence the properties of *H. brasiliensis*. Other factors, such as age and location, could also contribute to variations in the wood's strength, a concept that can be explored in future studies.

On the basis of above-mentioned strength classification, RRIM 600 clones were ranked similarly to *S. macrophylla*, *G. arborea*, *A. mangium*, *P. malaanonan*, *R. negrosensis*, *P. contorta*, and *R. polysperma* while PB 260 was ranked similarly to *R. almon*, *R. palosapis*, and *E. deglupta*. Both clones were rated higher than *R. ovata* and *F. falcata*, which is classified as low strength (Table 9). Recommended uses for each clone based on their classification are provided in Table 9. Additionally, sample furniture made from RRIM 600 and PB 260 wood, including a center table, shelves, cabinets, and a picnic table, is shown in Figure 5. Given the current Philippine wood market, RRIM 600 has the potential to replace *S. macrophylla*, *G. arborea*, and *A. mangium*. Similarly, PB 260 could serve as a substitute for *E. deglupta*, and both species can be viable alternatives to *F. falcata*.

Figure 5. Different furniture made from the combination RRIM 600 and PB 260 rubber wood clones. (a) Coffee table, (b) shelves, (c) cabinet, and (d) picnic table.

Table 9. Strength classification of the *Havea brasiliensis* clones, Philippine mahogany group, and commercially used timber species and their recommended uses (Alipon and Bondad, 2008).

Strength classification	*Havea brasiliensis* clones	Philippine mahogany group	Commercially used timber species in the Philippines	Recommended Uses
Medium	RRIM 600	Bagtikan (*Parashorea malaanonan*)	Mahogany (*Swietenia macrophylla*)	General construction, doors, framing, paneling, flooring, planking, medium-grade furniture, cabinet, veneer, and plywood (face and core).
		Red lauan (*Rubroshorea negrosensis*)	Yemane/Gmelina (*Gmelina arborea*)	
		White lauan (*Pentacme contorta*)	Mangium (*Acacia mangium*)	
		Tanguile (*Rubroshorea polysperma*)		
Moderately low	PB 260	Almon (*Rubroshorea almon*)	Bagrass (*Eucalyptus deglupta*)	For pulp and paper production, wood carving and sculpture, conventional furniture, drafting boards, toys, venetian blinds, crates, pallets, form wood, and shingles.
		Mayapis (*Rubroshorea palosapis*)		
Low		Tiaong (*Rubroshorea ovata*)	Falcata (*Falcataria falcata*)	Light construction where strength hardness and durability are not critical requirements such as door and panel cores, moldings, ceiling, pulp and paper, and core veneer. It can also be used for interior construction, cheap types of furniture, window frames (treated), flooring, planking, and packing cases.

Zamboanga Sibugay is recognized as one of the leading regions for *H. brasiliensis* plantations in the Philippines (Mag-aso and Garcia, 2021). Utilizing the senile clones cultivated in this area could help meet the growing demand for wood resources in Mindanao and other regions across the country. According to DENR-FMB (2023), the average retail price of *H. brasiliensis* lumber (2” × 4” × 8’) is PHP 28.14 (USD 0.48) per bd ft. Based on the diameter and height measurements of the clones in the present study (Table 1), each tree is estimated to yield approximately 501.61 bd ft of lumber, generating an estimated income of PHP 14,113.23 (USD 239.74) per tree.

To ensure the effective utilization of this tree, appropriate prophylactic treatments are generally recommended after cutting to prevent attacks by xylophagous organisms, which are often attracted to the high carbohydrate content typically reported in rubberwood (Teoh et al., 2011). Although this study focuses solely on the anatomical, physical, and mechanical properties of *H. brasiliensis* clones, future research may evaluate their chemical composition and resistance to biological degradation. The application of conventional preservatives (e.g., propiconazole, deltamethrin, tebuconazole, permethrin, disodium octaborate tetrahydrate, and copper azole) or alternative heat-based treatments could also be explored to enhance durability.

4. CONCLUSION

The Philippine wood industry, along with plantation developers and farmers, could explore the use of senile *Hevea brasiliensis* clones as a source of additional raw materials for composite boards, furniture, cabinetry, flooring, paneling, construction materials, veneers, plywood, and door panels. This species, which is abundant in Mindanao, offers significant potential to provide farmers with additional income, reduce waste, and address the increasing wood demand in the country. The present study revealed notable differences in the wood properties of *H. brasiliensis* clones as well as along different stem height levels. Anatomically, PB 260 exhibited longer fibers and larger fiber diameter, lumen diameter, vessel length, and vessel diameter, whereas RRIM 600 had a thicker cell wall. Physically, RRIM 600 displayed higher basic relative density, tangential shrinkage, and volumetric shrinkage, while PB 260 recorded the highest green moisture content. Mechanically, at 12% MC, significant differences were observed between clones in MOE, compression parallel-to-grain, and shear strength, while in the green condition, all mechanical properties except toughness differed significantly. Variations along the height of the tree were also noted but were less pronounced in mechanical properties. Future studies should include chemical characterization (e.g., lignin, cellulose, and holocellulose content) and durability testing to further optimize the utilization of these clones for industrial applications.

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AUTHOR CONTRIBUTIONS

Conception and design of study: Marasigan OS, Alipon MA; Acquisition of data: Marasigan OS, Alipon MA; Analysis and/or interpretation of data: Marasigan OS, Alipon MA; Drafting the manuscript: Marasigan OS, Alipon MA; Revising the manuscript for significant intellectual content: Marasigan OS, Alipon MA; Approval of the version of the manuscript to be published: Marasigan OS, Alipon MA.

DECLARATION OF CONFLICT OF INTEREST

The authors declare no conflict of interest.

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