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Growth Characteristics, Specific Gravity, and Stress Wave Velocity of 7-year-old Rosewood (*Dalbergia latifolia* Roxb.) Planted in Gunung Bromo Educational Forest

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ABSTRACT

Despite its IUCN status as a vulnerable species, rosewood (*Dalbergia latifolia*) remains highly valued for premium timber, making genetic conservation vital. Evaluating wood property traits is essential in tree breeding programs to ensure product quality. This study aims to determine the correlation between growth characteristics (tree height and diameter) and Stress-Wave Velocity (SWV), and to assess the physical properties (moisture content and specific gravity) of rosewood from the pith to the bark. The study was conducted using tree height and diameter censuses, and trees were then selected based on different growth rate categories: slow-, middle-, and fast-growth. Wood core samples were collected from three selected trees in each growth-rate category to measure the physical properties of wood. A significant, strong positive correlation was found between DBH and tree height. Meanwhile, no significant correlation was found between SWV, DBH, and tree height. The average fresh moisture content decreases from the pith (75%) to the bark (54%), while the air-dry moisture content increases from the pith (16%) to the bark (19%). The average specific gravity in fresh, air-dry, and kiln-dry conditions from near the pith to the bark remains constant, ranging from 0.63–0.66, 0.67–0.71, and 0.75–0.83, respectively.

1. Introduction

Gunung Bromo Educational Forest is a forest area dedicated to forestry education and training (in Bahasa Indonesia, Kawasan Hutan dengan Tujuan Khusus, or KHDTK). The area is dominated by *Pinus merkusii, Dalbergia latifolia,* and *Swietenia macrophylla. Dalbergia latifolia* has an average specific gravity of 0.83, a durability class of I, and a strength class of II, so it is often referred to as the second most luxurious wood after teak (Adema *et al.* 2016). Rosewood (*Dalbergia latifolia*) has dark brown heartwood with black lines, beautiful decorative patterns, and a slight sheen, making it suitable for high-quality wood products at a lower cost than teak (Bahanawan *et al.* 2022; Riastiwi and Damayanto 2022). In addition, *D. latifolia* wood is stronger than other woods because it is resistant to decay caused by termite and fungal attacks (Safitri 2019).

Excessive exploitation of *D. latifolia* wood across various regions has led to an annual decline in the *D. latifolia* population. Based on historical deforestation, this species is estimated to have experienced at least a 50% population decline in Nepal (Lakhey *et al.* 2020). In India, reports from states where this species was once common indicated continued decline over the last ten years (Lakhey *et al.* 2020). According to the IUCN (2020), *D. latifolia* has been designated as a Vulnerable (VU) species. In this regard, efforts are needed to conserve *D. latifolia*, including its genetic resources (Poerwanto *et al.* 2012). Wood property traits are of particular importance in forest tree breeding programs because they are highly

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relevant to the physical and mechanical properties of wood products. Wood properties have generally been evaluated using destructive tests of felled trees. Therefore, non-destructive tests have been developed to determine the traits of standing trees in tree species.

Previous studies have examined the growth and wood characteristics of *D. latifolia.* Rowth (2016) reported considerable variation between regions and between individual trees of *D. latifolia* in tree height, clear bole length (CBL), basal area, volume, basic density, moisture content, and specific gravity. Research by Iswanto (2008) also reported the moisture content and specific gravity of *D. latifolia*. Meanwhile, Feliana (2014) found the mechanical properties of *D. latifolia*, specifically its modulus of elasticity (MOEd) and modulus of rupture (MOR). Other studies have focused on the utilization of *D. latifolia*. To date, the relationship between growth characteristics and stress wave velocity (SWV) of *D. latifolia*, the proportion of heartwood and sapwood, as well as the radial variation of *D. latifolia* wood properties, has not been investigated.

Superior genetic resources were obtained through the selection of trees with high DBH, tree height, SWV, and specific gravity. A positive correlation between DBH and tree height was reported (Arifin *et al.* 2022). Hidayati *et al.* (2013) reported no significant correlation among SWV, DBH, and height. Research on specific gravity was conducted by Siarudin & Widiyanto (2012). They reported that specific gravity consistently increases from pith to bark. This study was carried out at the Gunung Bromo Educational Forest. In addition, this research on *D. latifolia* is important because it is a high-quality timber species, yet studies similar to the present investigation have not been conducted before. This study aims to investigate the correlation between growth characteristics (tree height and diameter) and SWV, and to examine the physical properties (moisture content and specific gravity) of *D. latifolia* wood from the pith to the bark.

2. Materials and Methods

2.1. Location

The research was conducted at Gunung Bromo Educational Forest, Karanganyar District, Karanganyar Regency, Central Java Province, Indonesia (Figure 1), which is located between 7°34'21.93" S - 7°35'38.90" S and 110°59'40.39" E - 111°0'49.36" E.

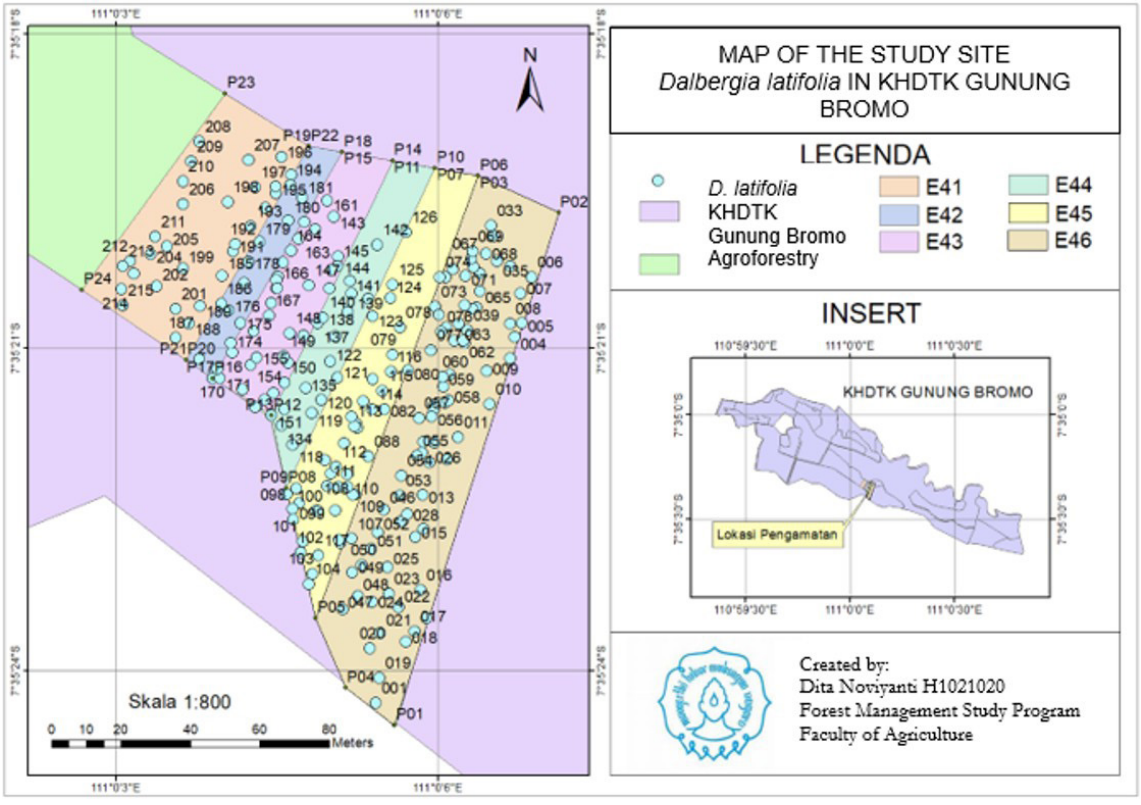


Figure 1. Map of the study site at Gunung Bromo Educational Forest

2.2. Materials

In this study, *Dalbergia latifolia* was examined and planted in blocks E41-E46 of the Gunung Bromo Educational Forest, with a planting distance of 3 × 5 m^2. In total, 312 trees of 7-year-old *D. latifolia* were evaluated in this study. The trees were measured using tree height and diameter censuses, then selected based on different growth rate categories – slow-growth, middle-growth, and fast-growth (Istikowati *et al.* 2014). The calculation of growth rate category based on radial growth rate was shown in Table 1. From three selected trees in each growth rate category, wood core samples were collected for further investigation.

2.3. Data Collection

2.3.1. Field Experiment

Tree growth parameters for each category examined in this study included total tree height and clear bole tree length (CBL) using a hagameter, stem diameter (cm) at breast height (DBH 1.3 m) using a diameter tape, and SWV using a FAKKOP Microsecond Timer (Figure 2). SWV was calculated using Equation (1). The wood core samples from each stem were collected using a 0,5 cm increment borer.

Table 1. Calculation of growth rate category based on radial (DBH) growth rate

Slow-growth	DBH < (mean DBH − SD)
Middle-growth	(mean DBH − SD) < DBH < (mean DBH + SD)
Fast-growth	DBH > (mean DBH + SD)

DBH: Diameter at breast height, SD: standard deviation

$$SWV = \frac{\text{Length distance (km)}}{\text{Treading (s)}} \quad \text{Eq. (1)}$$

2.3.2. Laboratory Experiment

The core samples were processed to determine wood proportions (heartwood and sapwood) and physical properties. Heartwood and sapwood percentages were calculated using Equations (2) and (3). All test specimens were weighed to obtain the fresh weight, then air-dried until a constant weight was reached. The samples were then oven-dried at 103±2°C to a constant weight to obtain the dry weight. These data were used to calculate the physical properties, which were derived from Equations (4)-(8).

$$\%\ \text{sapwood} = \frac{\text{Length sapwood} \times 2}{\text{DBH}} \times 100\% \quad \text{Eq. (2)}$$

$$\%\ \text{heartwood} = 100\% - \%\ \text{sapwood} \quad \text{Eq. (3)}$$

$$\text{Fresh moisture content} = \frac{\text{Fresh weight} - \text{oven-dry weight}}{\text{oven-dry weight}} \times 100\% \quad \text{Eq. (4)}$$

$$\text{Air-dry moisture content} = \frac{\text{Air-dry weight} - \text{oven-dry weight}}{\text{oven-dry weight}} \times 100\% \quad \text{Eq. (5)}$$

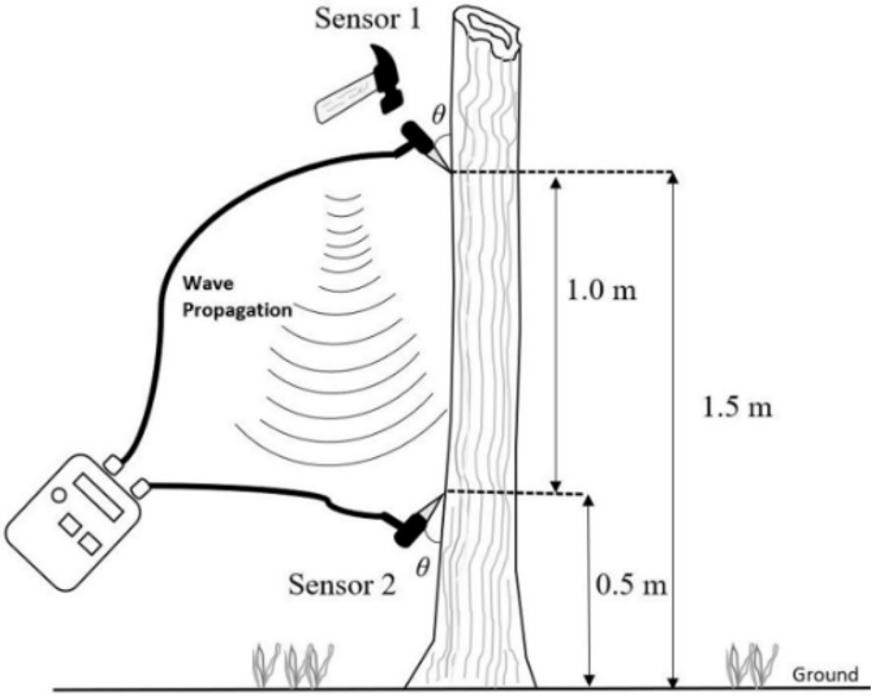


Figure 2. Illustration measurement of SWV (Seta *et al.* 2016)

$$\text{Fresh specific gravity} = \frac{\text{oven-dry weight} / \text{fresh volume}}{\text{Water density}} \times 100\% \quad \text{Eq. (6)}$$

$$\text{Air-dry specific gravity} = \frac{\text{oven-dry weight} / \text{air-dry volume}}{\text{Water density}} \quad \text{Eq. (7)}$$

$$\text{Kiln-dry specific gravity} = \frac{\text{oven-dry weight} / \text{oven-dry volume}}{\text{Water density}} \quad \text{Eq. (8)}$$

2.4. Statistical Data Analysis

The data on growth parameters, including total tree height, DBH, CBL, and SWV, were analyzed using regression and correlation analyses to determine the degree of association and the strength of relationships among variables. The analysis of variance (ANOVA) at the 5% level of significance was performed to examine variation in wood proportion, moisture content, and specific gravity across growth rate categories. Radial variation from pith to bark was analyzed by simple non-linear regression.

3. Results

3.1. Growth Characteristics and Stress Wave Velocity of 7-year-old *Dalbergia latifolia*

Table 2 shows DBH, tree height, CBL, and SWV. Furthermore, Figure 3 shows correlation between tree growth characteristics and SWV. DBH and tree height show an r = 0.411, indicating a significant correlation. SWV and tree growth characteristics show a positive correlation, although it is very weak. No significant correlation was found between

Table 2. Growth Characteristics and SWV of *Dalbergia latifolia* in Gunung Bromo Educational Forest

	Min	Max	Avg	SD
DBH (cm)	8.5	22.0	13.4	2.17
Height (m)	4.0	18.1	10.9	2.74
CBL (m)	1.5	9.0	3.8	1.41
SWV (km/s)	2.54	3.93	3.09	0.21

Min-Minimum, Max-Maximum, Avg-Average, SD-Standard deviation, DBH: Diameter of Breast Height, CBL: Clear Bole Length, SWV: Stress Wave Velocity

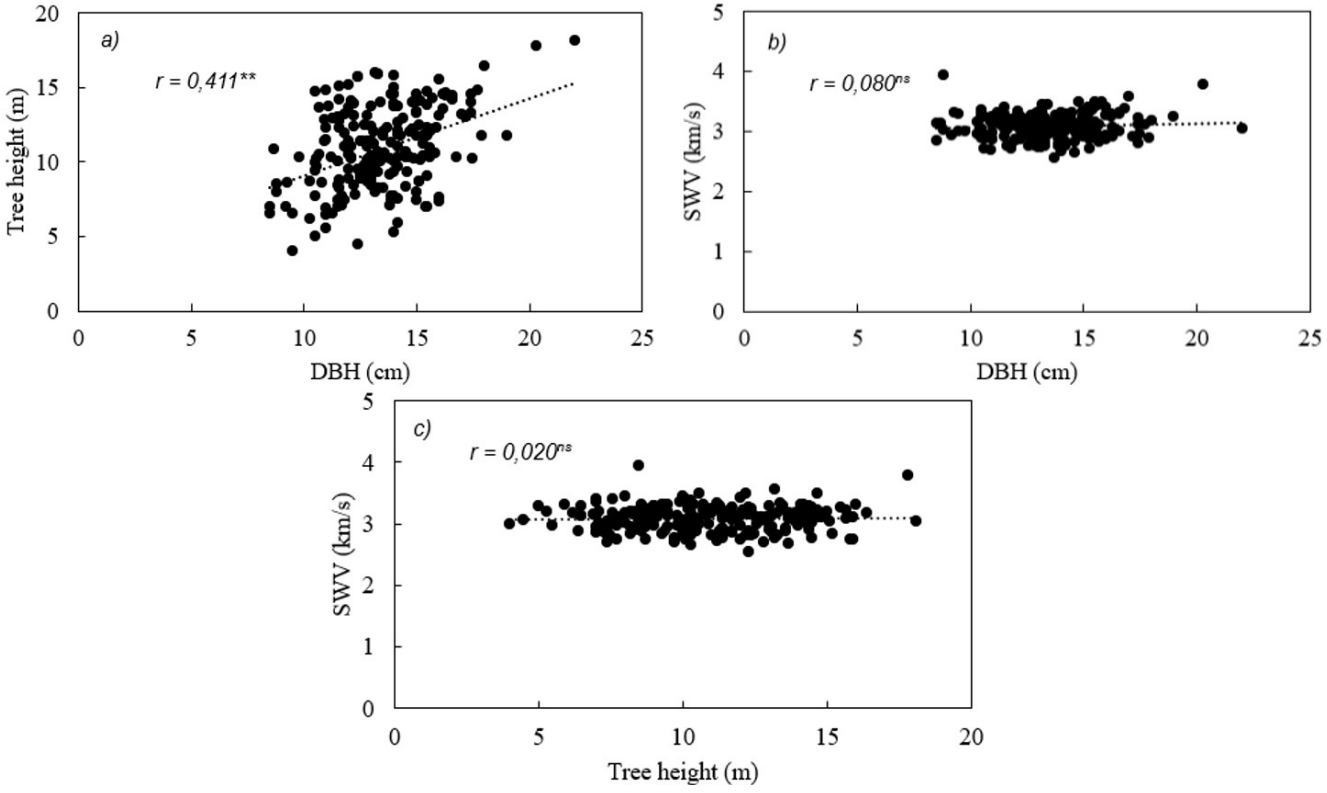


Figure 3. Correlation between tree growth characteristics and SWV. (A) DBH and tree height, (B) DBH and SWV, (C) tree height and SWV, r-correlation coefficient, **: correlation is significant at the 0.05 level, *: Correlation is significant at the 0.05 level, ns: not significant

tree growth characteristics (tree height and DBH) and SWV.

3.2. Proportion of Heartwood and Sapwood

A total of nine trees from the fast-, middle-, and slow-growth categories were selected to obtain core borer samples at DBH. Table 3 shows that 7-year-old *Dalbergia latifolia* has a smaller proportion of heartwood compared to sapwood. The average proportions of *D. latifolia* heartwood in the slow, middle, and fast categories were 19.85%, 17.45%, and 18.02%, respectively. The heartwood in several trees of the middle and fast-growth categories was absent (Table 3).

3.3. Moisture Content

Table 4 shows that the P-value of fresh and air-dry moisture content were 0.12 and 0.16, indicating that there were no significant differences between slow, middle, and fast-growth *Dalbergia latifolia* in terms of fresh and air-dry moisture content.

The fresh moisture content from pith to bark decreases to 4 cm near the pith and then evens out towards the bark (Figure 4A). Meanwhile, the air-dry moisture content

Table 3. Proportion of heartwood and sapwood based on growth rate categories in *Dalbergia latifolia*

Growth rate categories		Proportion (%)			
		I	II	III	Average
Fast-growth	Heartwood	25.71	0.00	28.36	18.02
	Sapwood	74.29	100.00	71.64	81.98
Middle-growth	Heartwood	30.77	0.00	21.57	17.45
	Sapwood	69.23	100.00	78.43	82.55
Slow-growth	Heartwood	14.29	21.95	22.50	19.58
	Sapwood	85.71	78.05	77.50	80.42
Average	Heartwood				18.35
	Sapwood				81.65

The proportion was obtained by comparing the length of the heartwood with the total length. I, II, and III were individual trees as replicates

Table 4. Fresh and air-dry moisture content based on growth rate categories in *Dalbergia latifolia*

Categories		Growth rate categories			Average	P-value
		Slow	Middle	Fast		
Fresh moisture content	Min	54%	52%	44%	50%	0.12^{ns}
	Max	82%	96%	82%	87%	
	Average	65%	67%	60%	64%	
	SD	0.08	0.12	0.11	10%	
Air-dry moisture content	Min	13%	15%	14%	14%	0.16^{ns}
	Max	20%	20%	21%	20%	
	Average	18%	18%	19%	18%	
	SD	0.03	0.01	0.01	2%	

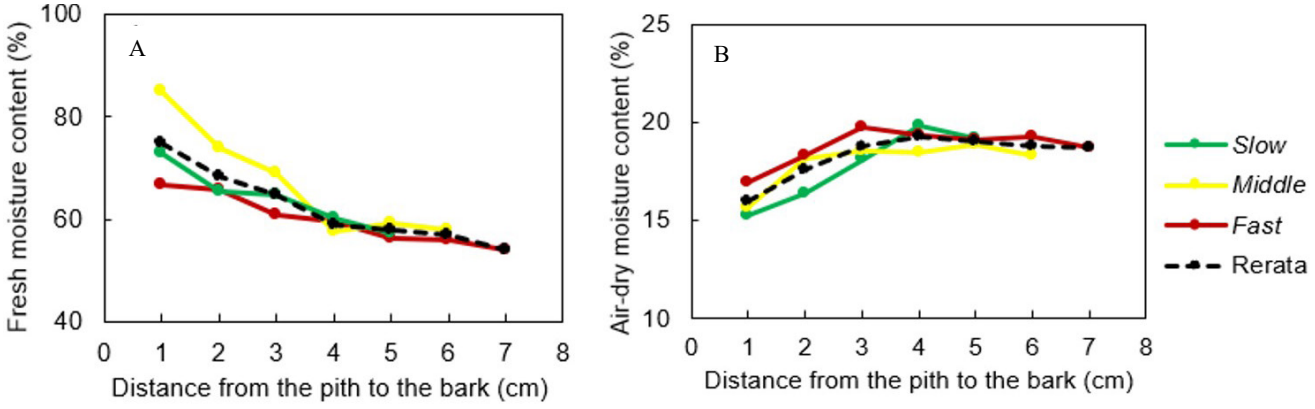


Figure 4. Radial variation in *Dalbergia latifolia* moisture content across various growth categories: (A) fresh moisture content (B) air-dry moisture content

from pith to bark increased by up to 3 cm from near the pith and then evened out towards the bark (Figure 4B).

3.4. Specific Gravity

In the present study, fast-growing trees have a higher specific gravity than slow-growing and middle-growing trees. Table 5 shows that the specific gravity of fast-growing wood is higher than that of slow-growth and middle-growth wood. Figure 5 shows radial variation in *Dalbergia latifolia* specific gravity across various tree growth categories from pith to bark; it was constant in each condition.

Table 5. Fresh, air-dry, and kiln-dry specific gravity based on growth rate categories of *Dalbergia latifolia*

Categories		Growth rate categories			Average	P-value
		Slow	Middle	Fast		
Fresh specific gravity	Min	0.60	0.47	0.57	0.55	0.21^{ns}
	Max	0.72	0.73	0.75	0.73	
	Average	0.66	0.63	0.66	0.65	
	SD	0.04	0.06	0.04	0.05	
Air-dry specific gravity	Min	0.63	0.57	0.62	0.60	0.03*
	Max	0.79	0.76	0.85	0.80	
	Average	0.70	0.67	0.71	0.69	
	SD	0.05	0.05	0.06	0.05	
Kiln-dry specific gravity	Min	0.68	0.62	0.68	0.66	0.02*
	Max	0.91	0.85	0.90	0.89	
	Average	0.77	0.73	0.80	0.77	
	SD	0.06	0.06	0.07	0.07	

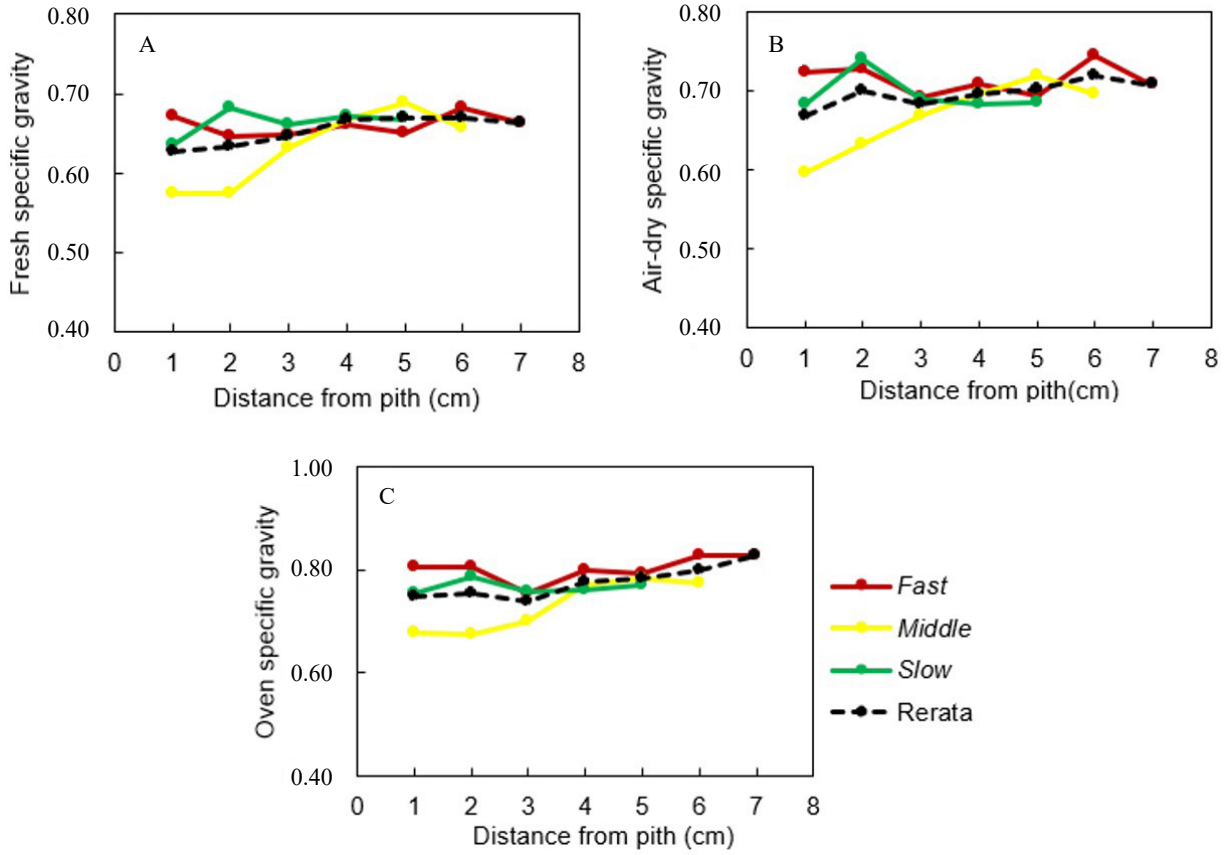


Figure 5. Radial variation in *Dalbergia latifolia* specific gravity across various growth categories: (A) fresh specific gravity, (B) air-dry specific gravity, (C) kiln-dry specific gravity

4. Discussion

4.1. Growth Characteristics and Stress Wave Velocity of 7-year-old *Dalbergia latifolia*

Growth characteristics are descriptions of the external form of trees that distinguish them from other trees. In the present study, data on three parameters of tree growth were collected: tree height, stem diameter at breast height (DBH), and clear bole length (CBL). Stress Wave Velocity (SWV) is a non-destructive test that estimates wood quality by measuring the speed of wave propagation without damaging the tree.

The present study found that the average DBH and tree height of *Dalbergia latifolia* were 13.4 cm (8.5–22 cm) and 10.9 m (4–18.1 m), respectively. According to Mali (2016), 10-year-old *D. sissoo* exhibited a comparable average DBH of 13.7 cm, while its average tree height was higher at 9.3 m. The average DBH and tree height can be used to calculate the Mean Annual Increment (MAI), which indicates the average annual growth rate. The MAI for DBH and tree height of *D. latifolia* was 1.9 cm/year and 1.6 m/year. These MAI for DBH were similar to the research by Arunkumar *et al.* (2022), which found that the MAI DBH of 1.8-3.2 cm/year in *D. latifolia*.

The SWV of *D. latifolia* standing trees ranged from 2.54 to 3.93 km/s, with an average of 3.09 km/s. This value is almost the same as that reported by Ishiguri *et al.* (2007) for *Falcataria falcata*, which ranged from 2.57-3.61 km/s, with an average of 3.08 km/s. The SWV of *D. latifolia* in this study was lower than that of ironwood (*Eusidroxylon zwageri*), which had an SWV of 4.11 km/s (Aiso-Sanada *et al.* 2020). However, it was higher than the average SWV of teak (*Tectona grandis*), which was 2.94 km/s (Seta *et al.* 2021).

SWV and tree growth characteristics show a positive but very weak correlation. No significant correlation was found between tree growth characteristics (tree height and DBH) and SWV. A similar result was reported by Pelawi *et al.* (2020) and Hidayati *et al.* (2013) on teak. They reported that SWV and growth characteristics (tree height and DBH) were not significantly correlated, indicating that increasing growth characteristics will improve the mechanical properties of the wood, but only to a very small extent. Similar results were reported by Suhartati *et al.* (2022), Seta *et al.* (2021), Aiso-Sanada *et al.* (2020), Hidayati *et al.* (2013), and Ishiguri *et al.* (2013) for teak, eucalyptus, and ironwood trees.

4.2. Heartwood and Sapwood Proportions

Table 3 shows that 7-year-old *Dalbergia latifolia* has a smaller proportion of heartwood compared to sapwood. The average proportions of *D. latifolia* heartwood in the slow, middle, and fast categories were 19.85%, 17.45%, and 18.02%, respectively. This condition was consistent with Darwis *et al.* (2005), who found that in young trees, the proportion of sapwood exceeds that of heartwood and decreases with age. The average proportion of heartwood in 7-year-old *D. latifolia* is 18.35%. Meanwhile, in the study by Meunpong *et al.* (2021), 15-year-old *D. cochinchinensis* wood has a heartwood proportion of 32%. This difference in values is because the older the tree, the greater the proportion of heartwood formed (Darwis *et al.* 2005).

The heartwood in several trees of middle and fast-growth categories was absent (Table 3). A similar finding was reported by Brito *et al.* (2019) in eucalyptus wood. This is thought to be due to wood with a large crown development, resulting in a higher percentage of sapwood. Other factors that influence the formation of heartwood and sapwood, according to Arisandi *et al.* (2023), are planting distance, environment, thinning activities, and fertilization. Additionally, according to Kampe and Magel (2013), changes in water content in each tracheid and water distribution in the xylem play a role in heartwood formation. In addition, previous studies reported that the discrepancy of heartwood proportion was presumably caused by various influences, such as growth rate, type of stands, characteristics of the individual tree, age, genotype, topography, and site quality (Pinto *et al.* 2004; Huh *et al.* 2020; Kim *et al.* 2020a, 2020b). Therefore, the absence of heartwood in some trees might be caused by one or a combination of those reasons that cause heartwood to form. In the present study, the variation in heartwood proportion in *D. latifolia* was suspected to be caused by growth rate, individual tree characteristics, and genotype.

4.3. Moisture Content

In the present study, the average fresh moisture content of *Dalbergia latifolia* wood ranged from 60-67%. In a previous study, the fresh moisture content of *D. latifolia* was higher, as reported by Iswanto (2008), ranging from 65.09-74.32%. The variation in fresh moisture content is thought to be due to genetic factors, growing location, geographical location, and climate (Iswanto 2008). The air-dry moisture content in the present study averaged

18%, including slow-growth (13-20%), middle-growth (15-20%), and fast-growth (14-21%) (Table 4). This value was similar to that reported in Feliana's (2014) study, which found that the average air-dry moisture content of *D. latifolia* ranged from 12.7% to 18.8%. The air-dry moisture content in this study was within the standard for wood in Indonesia, which is 12-20% (Dewi *et al.* 2023). In the present study, the fresh and air-dry conditions of *D. latifolia* are shown in Table 4.

Figure 4A shows the radial variation of fresh moisture content in *D. latifolia* at various tree growth categories from pith to bark. The fresh moisture content from pith to bark decreases to 4 cm near the pith and then evens out towards the bark. The results of this study were similar to those of the previous studies on *Manglieta glauca* (Siarudin & Widiyanto 2012), *Artocarpus heterophyllus* (Rini *et al.* 2019), and *Duabanga moluccana* (Wulandari & Suastana 2022). Meanwhile, Figure 4B shows radial variation in *D. latifolia* air-dry moisture content in various tree growth categories from pith to bark. The air-dry moisture content from pith to bark increased by up to 3 cm from near the pith and then evened out towards the bark. The results of this study were similar to those of the previous study on *A. heterophyllus* (Rini *et al.* 2019). Prakosa *et al.* (2018) reported that the increase in moisture content near the pith was higher than that near the bark.

4.4. Specific Gravity

The average specific gravity of wood increased sequentially from fresh, air-dry, and kiln-dry conditions, namely 0.67, 0.69, and 0.77 (Table 5). Proves that the less moisture content in the wood, the higher the specific gravity. Iswanto (2008) stated that one of the factors affecting the difference in wood specific gravity is moisture content.

In this study, the air-dry specific gravity of *Dalbergia latifolia* wood is 0.69. Based on the classification by Den Berger (1923), it was classified as class II (specific gravity 0.66-0.99). The specific gravity of fast-growth wood is higher than that of slow-growth and middle-growth wood (Table 5). This is in accordance with the research of Scott & MacGregor (1952), Briscoe *et al.* (1963), King (1980), and Ruwanpathirana *et al.* (2002) in Amarasekera (2008) on teak, mahogany, *Eucalyptus saligna*, and *Eucalyptus grandis*, which found that fast-growth trees have a higher specific gravity than slow-growth and middle-growth trees. Ismayati *et al.* (2023) reported that fast-growth teak has better physical and mechanical properties than conventional teak wood.

Figure 5 shows radial variation in *D. latifolia* specific gravity across various tree growth categories; the pattern from pith to bark was constant in each condition. Based on the classification by Panshin & de Zeeuw (1980), this pattern indicates type IV, namely a constant or nearly unchanged specific gravity from the pith to the bark. These results were similar to those of *Myroxylon balsamum* (L.) Harms, as reported by Portal-Cahuana *et al.* (2025), which found that the specific gravity in the radial direction is relatively constant.

In conclusion, the average DBH, tree height, CBL, and SWV were 13.4 cm, 10.9 m, 3.8 m, and 3.09 km/s, respectively. Significantly strong positive correlations were found between DBH and height. Meanwhile, no significant correlation was found between SWV, DBH, and tree height. The average fresh moisture content decreased to 4 cm near the pith (75%) and then evened out towards the bark (54%), while the average air-dry moisture content increased by up to 3 cm from near the pith (16%) and then evened out towards the bark (19%). The average specific gravity in fresh, air-dry, and kiln-dry conditions was relatively constant from the pith to the bark, ranging from 0.63–0.66, 0.67–0.71, and 0.75–0.83, respectively.

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