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# Growth and wood physical properties of *Neolamarckia cadamba* under agroforestry system in a community forest in North Sumatra, Indonesia

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**Abstract.** *Anna N, Herawati E, Anggraini N, Sutiawan J, Bangun BON, Banjarnahor LD. 2025. Growth and wood physical properties of* Neolamarckia cadamba *under agroforestry system in a community forest in North Sumatra, Indonesia. Asian J For 9: 251-263.* Jabon (*Neolamarckia cadamba*) is among primary alternative fast-growing tree species to produce wood products. This tree can be planted under various monoculture and agroforestry sytems, which might result in the growth and quality of wood across plant parts such as base, middle, and top. Therefore, this study aimed to analyze the growth performance and physical properties of 13 years old jabon wood planted under agroforestry system in a community forest in North Sumatra, Indonesia. Measurement of growth characteristics and estimation of wood quality in stands were carried out using the census method to 161 trees. Physical properties were also assessed using destructive methods by felling three jabon trees to evaluate moisture content, density, specific gravity, and shrinkage. Testing was carried out per segment (from pith to outer bark) in each part of the base (B), middle (M), and top (T). The results showed that growth and physical properties of varied significantly. Growth characteristics for height ranged from 10.36-29.25 m with an average of 18 m and diameter ranged 0.19-0.81 m with an average of 0.36 m. The specific gravity was 0.23-0.94 with an average of 0.43. The density of wood was 0.43-1.50 g/cm$^3$ with an average of 0.80 g/cm$^3$. Analysis of variance showed that tree section had a significant effect on green moisture content (gMC), air dried moisture content (adMC), air dried density (adρ), oven dried density (odρ), green specific gravity (gG), air dried specific gravity (adG), oven dried specific gravity (odG) produced at 95% confidence level. However, the effect was not significant on green density (gρ) and wood shrinkage. In line with the results, the highest gG of 0.44 was obtained at the top, while the lowest of 0.36 was at the base. Regarding air adG, the highest value of 0.46 was found at the top while the lowest was at the base with 0.37. The highest odG was found at the top with 0.47, while the lowest was found at the base with 0.38. By comparing the tangential and radial (T/R) ratios, the dimensional stability of wood was determined, achieving the highest value was found at the base, and the lowest at the top. The results of this study suggest that agroforestry system do not inhibit the growth of jabon. Therefore, this system can be applied to produce wood-based products while optimizing land use, enhancing biodiversity and maintaining the microclimate.

**Keywords:** Agroforestry systems, growth performance, *Neolamarckia cadamba*, physical properties

## INTRODUCTION

Jabon (*Neolamarckia cadamba*) is a multipurpose tree species native to Indonesia, which every part of the plant organs, including roots, bark, fruit, leaves, and wood, can be used (Acharyya et al. 2013; Ganjewala et al. 2013; Chaubey et al. 2015; Anisah et al. 2015; Sutrisno et al. 2015; Mishra et al. 2023; Singh et al. 2023). Jabon has been used traditionally for medicinal purposes due to its phytochemical and pharmacological contents (Pandey and Negi 2016). Aside from the medicinal value, jabon can be cultivated on marginal soils and post-mining areas (Harmoko et al. 2020), showing its suitability in industrial forestry plantation and ecological restoration (Irawan and Purwanto 2014; Setyaningsih et al. 2018; Atunnisa et al. 2024). In addition, the stands can absorb carbon, which further enhances the environmental benefits (Bijalwan et al. 2014; Sandalayuk et al. 2020). Due to these numerous advantages, there is considerable interest in its planting.

In community forests, the farmers often apply agroforestry systems (Chavan et al. 2018; Karyati et al. 2018; Rajalingam et al. 2020; Jiang et al. 2022), including using jabon to enhance sustainability (Saravanan 2019; Parthiban et al. 2019; Tuheteru et al. 2019). Agroforestry systems significantly improve agricultural productivity by producing various agricultural crops and timber and non-timber products, while maintaining the sustainability of agroecosystems by protecting soil through organic carbon accumulation and nutrient retention. Thus, it can improve food security and the welfare of small farmers (Kuyah et al. 2019; Muchane et al. 2020; Duffy et al. 2021; Karyati et al. 2021; Castle et al. 2022; Farinaccio et al. 2023; Jung and Vendrametto 2025). Jabon is widely planted under agroforestry systems, not only to obtain short term and long term economic benefits (e.g. wood production), but also to enhance ecological resilient by avoiding pest and disease attacks (Utami and Ismanto 2015; Putra el al. 2024), stabilizing degraded landscapes and increasing carbon stocks (Sarjono et al. 2017; Krisnawati et al. 2019; Siarudin et al. 2021).

Based on its anatomical properties, jabon's wood has cream color with a smooth surface, making it appropriate for use as the front and rear veneer. Furthermore, based on physical performances, its wood is classified as class III-IV for strength and class V for durablility. Several studies have explored the properties of jabon, focusing on mechanical (Herawati et al. 2023), physical (Anna et al. 2023), chemical, crystallinity, and fiber biometry aspects (Darwis et al. 2023), and anatomical structure (Anna et al. 2025). To enhance strength and durability, jabon wood can be subjected to modification and impregnation treatments (Hadi et al. 2013, 2015, 2019, 2021; Komariah et al. 2015; Hadiyane et al. 2018; Lestari et al. 2018; Arsyad et al. 2019; Malik and Ozarska 2019; Prihartini et al. 2020; Malik et al. 2022; Basri et al. 2023; Hidayat et al. 2023; Alamsyah et al. 2024). With such adventages, jabon can be developed to meet the increasing demand for wood based products. Nevertheless, the quality of jabon's wood is influenced by several factors, one of which is the silvicultural treatment and maintenace during the planting.

Growth and quality of wood differ among tree genera and species as well as among individuals and tree parts, such as base, middle, and top (Uar et al. 2015; Dold et al. 2019). Several studies have explored the variation in growth within species, including Anna et al. (2018, 2020) which looked at the provenance of jabon aged 36 and 42 months, Que et al. (2022) and Suhaya et al. (2024) which found that environmental factors significantly affect the growth characteristics and wood properties of jabon. Variations in the wood quality of the same species have been found in *Picea glauca* (Lenz et al. 2013), *Acacia mangium* (Nurhasybi and Sudrajat 2019), *Swietenia macrophylla* (Sudrajat et al. 2021), and *N. cadamba* (Anna et al. 2023). This variation can be attributed to growth disparities driven by genetics, environmental factors (e.g. soil, water), geographic origins, management systems (e.g. agroforestry, monoculture plantation) and silvicultural treatment (You et al. 2021).

Assessing wood quality by testing the physical properties using destructive and nondestructive techniques is important to effectively envisage silvicultural treatments, particularly in community forests to increase productivity and economic value. Therefore, this study aimed to analyze the growth characteristics and the physical properties of wood (i.e. moisture content, density, specific gravity, and shrinkage) of a 13-years jabon stand established under agroforestry systems in community forest in North Sumatra Province, Indonesia. This community forest, named Citra Pesona Ladangku, provides an excellent context of as study area because it has unique biodiversity and ecosystem characteristics. The results of this study can contribute to being used as a model for studies on sustainability, land use, and empowerment of local communities.

## MATERIALS AND METHODS

### Study area

This study was conducted in the Citra Pesona Ladangku Community Forest, Deli Serdang District, North Sumatra, Indonesia (Figure 1). Data collection was carried out at an agroforestry system of jabon planted at a space of 3×3 m along with coffee. A total of 161 trees with age of 13 years old were used in this study with specific site conditions are presented in Table 1.

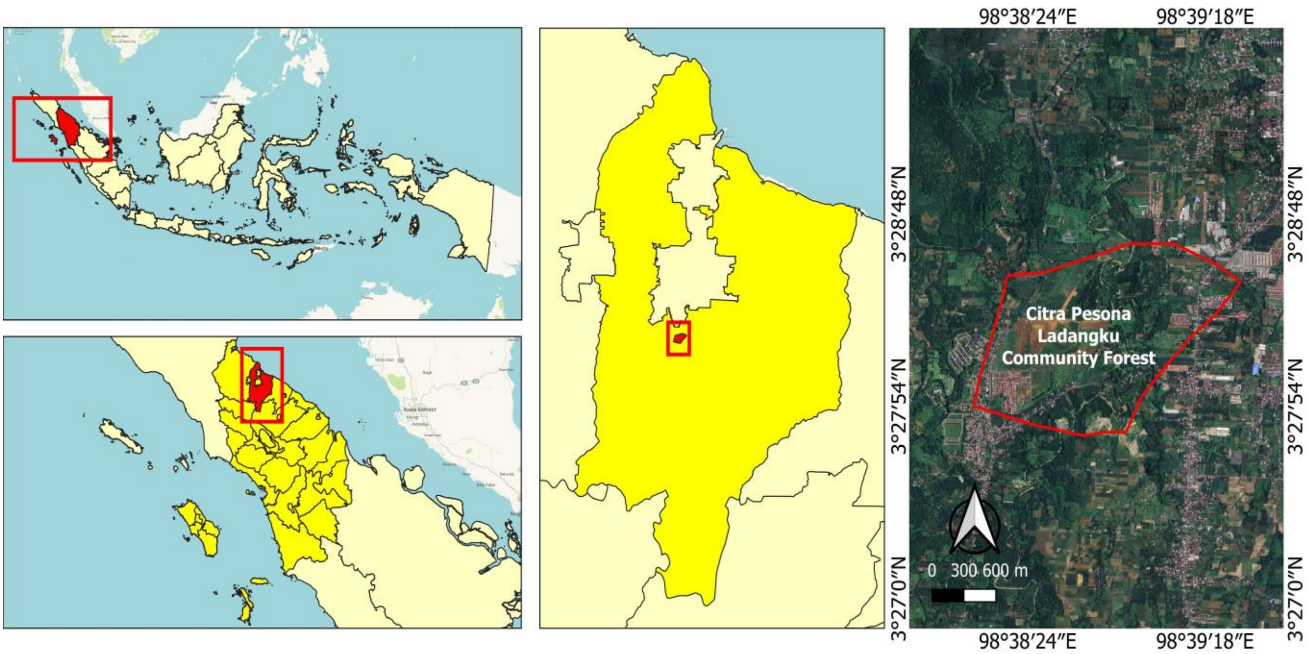


**Figure 1.** Map of study location in the Citra Pesona Ladangku Community Forest, North Sumatra Province, Indonesia

**Table 1.** Environmental conditions of jabon agroforestry in Citra Pesona Ladangku Community Forest, North Sumatra Province, Indonesia

| Biophysical characteristics | Result |
|---|---|
| Geographical location | N= 3°28'6.87", E= 98°38'48.98" |
| The altitude, m asl | 64 |
| Rainfall, mm month | 171 |
| Average temperature | 29°C |
| Soil pH | Low |
| Drainage | Moderate, no puddles occurred when it rained |
| Other descriptions | The research location is a community forest planted with jabon under an agrosilviculture system along with coffee, relatively flat |
| Soil chemical properties | |
| pH ($H_2O$) | Low |
| C-Organic (Walkey & Black) | High |
| N-total (Kjeldahl) | Moderate |
| P (Bray I) | Low |
| Ca | High |
| Mg | High |
| K | High |
| Na | Low |
| Cu | Low |
| Zn | High |
| Mn | High |
| Fe | Moderate |
| Al | Low |

**Data collection procedure**

Measurements were conducted using two methods, namely nondestructive and destructive. The nondestructive method was conducted on all jabon trees by measuring growth characteristics and testing the physical properties of the wood by taking the core samples. While the destructive method was carried out by cutting down three jabon trees for further analysis.

*Growth characteristics and physical properties using nondestructive methods*

Measurement of growth characteristics (height and diameter), as well as physical properties (density, specific gravity) of wood from core sample, was carried out using the census method for all 161 trees. Total height was measured by numerical scale poles and diameter at breast height (1.3 m) using caliper. The small core wood samples with a diameter of 2 cm at a height of 1.3 m were taken out from 161 standing trees.

*Physical properties using destructive methods*

The test was carried out by cutting down three jabon trees. Each base, middle, and top were measured to be 160 cm, and the distance of 3 m. The wood was evaluated for moisture content, density, specific gravity, and shrinkage using ASTM D 4442-92 (ASTM 2005) and ASTM D 2395-02 (ASTM 2005). Subsequently, tests were carried out to each segment (from pith to outer bark; each segment was 2 cm) in each part of base (B), middle (M), and top (T). Moisture content, density, specific gravity, and shrinkage were estimated using 45 samples measuring 2×2×2 cm each, consisted of three parts (B, M, T) with 5 segments and 3 replicates. Moisture content of wood was obtained based on green and air-dried conditions. The test samples were weighed fresh, then air dried in a room for 14 days, after which they were dried in an oven at 103±2°C for 2 x 24 hours. Moisture content was calculated using the equation below:

$$\mathrm{gMC} = \frac{\mathrm{gW} - \mathrm{odW}}{\mathrm{odW}} \times 100\%$$

$$\mathrm{adMC} = \frac{\mathrm{adW} - \mathrm{odW}}{\mathrm{odW}} \times 100\%$$

Where:
gMC: Green moisture content (%)
adMC: Air dried moisture content (%)
gW: Green weight (g)
adW: Air dried weight (g)
odW: Oven dry weight (g)

Wood density was tested based on three wood conditions: fresh (ρs), air dried (ρku) and oven dried (ρko). Wood density was calculated using the formula:

$$\boldsymbol{\rho}\ (\mathrm{g}\rho, \mathrm{ad}\rho, \mathrm{od}\rho) = \frac{\mathbf{W}\ (\mathrm{gW}, \mathrm{adW}, \mathrm{odW})}{\mathbf{V}\ (\mathrm{gV}, \mathrm{adV}, \mathrm{odV})}$$

Where:
ρ: Wood density (g/cm$^3$)
W: Wood weight (g)
V: Wood volume (cm$^3$)

The specific gravity of wood was calculated based on three wood conditions, namely in green (gG), air dried (adG) and oven dried (odG) conditions. Specific gravity calculated with the formula:

$$\mathbf{G}\ (\mathrm{gG}, \mathrm{adG}, \mathrm{odG}) = \frac{\mathbf{odW}}{\mathbf{V}\ (\mathrm{gV}, \mathrm{adV}, \mathrm{odV})} : \boldsymbol{\rho}\ \mathbf{water}$$

Where:
G: Specific gravity
odW: Oven dried weight (g)
V: Volume (cm$^3$)
ρ water: Water density (1 g/cm$^3$)

The shrinkage was measured from the green condition to the air dried condition, namely longitudinal (L) shrinkage, radial (R) shrinkage, and tangential (T) shrinkage. The shrinkage was calculated with the equation:

$$\%\ \mathrm{R} = \frac{\mathrm{gD(R)} - \mathrm{adD(R)}}{\mathrm{gD(R)}} \times 100\%$$

$$\%\ \mathrm{L} = \frac{\mathrm{gD(L)} - \mathrm{adD(L)}}{\mathrm{gD(L)}} \times 100\%$$

$$\%\ \mathrm{T} = \frac{\mathrm{gD(T)} - \mathrm{adD(T)}}{\mathrm{gD(T)}} \times 100\%$$

Where:
gD: Green condition dimension (cm)
adD: Air dried condition dimension (cm)
L: Longitudinal
R: Radial
T: Tangential

**Data analysis**

Data of tree growth and wood physical properties were analyzed using Excel 2013 and R Statistical Software. Destructive testing of wood physical properties (base, middle and tip) was analyzed using a Completely Randomized Design (CRD) Nested Pattern, consisting of factor S (segment) nested in factor B (tree section) with a significance level of 5%. If there were significantly different results, the Duncan test was then applied. All statistical tests were conducted using IBM SPSS statistics 25 software. The statistical model of this experimental design was as follows (Sudjana 2002):

$$Yijk = \mu + \alpha i + \beta j(i) + \varepsilon k(ij)$$

Where :
Yijk: Observation value of factor S nested in factor B
μ: General mean value α
αi: Effect of factor B at level i
βj(i): Effect of factor S nested in factor B
Ɛk(ij): Effect of trial error

## RESULTS AND DISCUSSION

**Height, diameter, specific gravity and wood density of jabon**

Jabon is known for its fast growth and is often used in agroforestry systems for various purposes due to its ecological adaptability and economic profitability. In this study, the study location was considered suitable for jabon growth, with temperature of approximately 29°C, altitude of 64 meters above sea level, and rainfall of 171 mm/month (Table 1). According to Krisnawati et al. (2011), jabon grows well at maximum temperature of 32-42°C, altitude in the equatorial region at 0-1000 meters above sea level, and annual rainfall of 1500-5000 mm/year (125-417 mm/month). The soil organic matter content at the study location was good and also corresponded to appropriate drainage conditions (Table 1). Anggraini and Syahputra (2022) stated that higher content of organic matter in the soil correlated with improved water-holding capacity, increasing water availability for plant growth.

The results showed that growth and physical properties of jabon wood varied (Table 2, Figure 2). Jabon growth at the age of 13 varied significantly as shown in the height and diameter of 18 m and 36 cm, respectively. The most dominant height was in class 6 with 41 trees, followed by class 5 and 6 comprising 33 and 28 trees, respectively. Meanwhile, the most dominating diameter was in level 4 with 48 trees, followed by class 3 and 5 with 43 and 36 trees, respectively. The average density and specific gravity of jabon wood were 0.80 gr/cm$^3$ and 0.43. The dominant wood density was obtained in class 3 with 65 trees, followed by class 4 with 60 trees, and class 2 comprising 14 trees. The dominant specific gravity, was found in class 3 with 79 trees, followed by class 2, comprising 42 trees, and class 4 with 24 trees (Table 2).

Anna et al. (2018, 2020) reported variations in the growth of 36 months old and 42 months old jabon provenance, planted with a monoculture system. Chaerani et al. (2019), Krisnawati et al. (2019), Sudrajat et al. (2019), and Junaedi et al. (2021) identified variability in jabon growth parameters despite the same treatment. This is because growth is generally influenced by genetics, environmental conditions, management interventions and their interactions. For example, the application of fertilizers and silvicultural practices can influence plant development (Tuheteru et al. 2019; Irawan et al. 2019). Other factors that can affect the growth and quality of jabon wood planted with an agroforestry system include planting distance. Excessive competition for light and nutrients has the potential to affect the diameter and quality of wood produced. Trees planted in agroforestry systems generally showed good growth in stem diameter and height due to more optimal availability of resources, such as light, water, and nutrients, compared to monoculture plantations which tend to be more competitive among trees (Lopez-Diaz et al. 2020; Kouassi et al. 2025). In this context, planting coffee plants under jabon trees seemed to enrich soil structure, as the root systems of both plants strengthen each other in preventing landslides or degradation. Additionally, coffee can maintain the humidity of microclimate around jabon, leading to a stable microclimate condition by reducing, water stress on plants, and maintaining soil moisture. Jabon and coffee agroforestry system creates a mutually beneficial relationship where both plants can grow together with better support in terms of nutrition, pest control, as well as more optimal environmental and resource management. In addition to growth, several studies had shown that trees in agroforestry systems were able to produce wood with competitive fiber quality, density, and anatomical structure (Bader et al. 2023). Factors such as wider spacing, regular pruning, and a combination of annual crops under the tree stand help reduce competitive stress and improved the quality of branch-free stems, which are very important in high-value wood production. In addition, the diversity of agroforestry systems contributes to increasing soil fertility and ecosystem balance, which indirectly improves tree growing conditions and affects the quality of their wood. Thus, agroforestry not only plays a role in environmental conservation and product diversification, but also becomes an effective strategy in improving tree growth and wood quality sustainably.

Growth factors have a close correlation with the physical properties of jabon wood. This is because trees that grow quickly due to genetic or environmental factors can produce wood with suboptimal physical properties, such as low density. The Principal Component Analysis (PCA) results explain a positive relationship between growth characteristics, where greater diameter correlates with higher height and volume of tree. However, there was a negative correlation between growth characteristics and the physical properties of wood such as density, specific gravity, and fresh moisture content (Figure 3). This shows that fast-growing characteristics correlate with lower physical properties of the wood, and vice versa. Anna et al. (2018) also reported that growth characteristics of jabon provenance were correlated with the quality of wood produced. Specifically, wood from fast-growing trees tends to have lower density than slower-growing. Rapid growth produces wood tissue with a more significant proportion of juvenile wood, which tends to be less dense. Fast-growing jabon trees tend to produce lower density due to the high proportion of juvenile wood. Additionally, large diameters are often associated with variations in tree growth ring, showing the formation of wood with thinner cell walls and lower density (Priyadi and Santoso 2017).

### Physical properties of jabon wood tested using destructive methods

The physical properties of jabon wood from three different trees and different parts (base, middle, top) varied in variables measured including (moisture content, density, specific gravity, wood shrinkage). Analysis of variance showed that the tree part had a significant effect on green moisture content (gMC), air dried moisture content (adMC), air dried density (adρ), oven dried density (odρ), green specific gravity (gG), air dried specific gravity (adG), oven dried specific gravity (odG) produced at the 95% confidence level. However, the effect was not significant on green density (gρ) and wood shrinkage (Table 3). Furthermore, the results of Duncan's test explained that gMC and adMC of jabon wood were significantly different at the top and middle to the base of the tree. In term of wood density, adρ and odρ of jabon were significantly different at the base to the middle and top of the tree. In sterm of pecific gravity, gG, adG and odG of jabon were significantly different at the base to the middle and top of the tree. Differences in moisture content, density, specific gravity and shrinkage values at the base, middle and end of the log are due to physiological and structural variations during tree growth. Environmental factors and genetics can also influence the heterogeneity of these traits within the same stem (Zobel and van Buijtenen 1989). The chemical content, soil type, and applied silvicultural techniques can affect the properties of wood (Cienciala et al. 2016; Ramananantoandro et al. 2016; Zhang et al. 2017; Zhou et al. 2019).

**Table 2.** Height, diameter, specific gravity and wood density of jabon planted under agroforestry system

| **Level** | **Parameters** | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **Height (m)** | | **Diameter (m)** | | **Specific gravity** | | **Wood density (gr/cm³)** | |
| | **Range (m)** | **Number of trees** | **Range (m)** | **Number of trees** | **Range** | **Number of trees** | **Range (gr/cm³)** | **Number of trees** |
| 1 | 10.36-12.45 | 5 | 0.19-0.25 | 5 | 0.23-0.30 | 7 | 0.43-0.54 | 2 |
| 2 | 12.46-14.55 | 8 | 0.26-0.32 | 11 | 0.31-0.38 | 42 | 0.55-0.66 | 14 |
| 3 | 14.56-16.65 | 28 | 0.33-0.39 | 43 | 0.39-0.46 | **79** | 0.67-0.78 | **65** |
| 4 | 16.66-18.75 | 22 | 0.40-0.46 | **48** | 0.47-0.54 | 24 | 0.79-0.90 | 60 |
| 5 | 18.76-20.85 | 33 | 0.47-0.53 | 36 | 0.55-0.62 | 4 | 0.91-1.02 | 11 |
| 6 | 20.86-22.95 | **41** | 0.54-0.60 | 13 | 0.63-0.70 | 3 | 1.03-1.14 | 4 |
| 7 | 22.96-25.05 | 14 | 0.61-0.67 | 4 | 0.71-0.78 | 1 | 1.15-1.26 | 1 |
| 8 | 25.06-27.15 | 7 | 0.68-0.74 | 0 | 0.79-0.86 | 0 | 1.27-1.38 | 2 |
| 9 | 27.16-29.25 | 3 | 0.75-0.81 | 1 | 0.87-0.94 | 1 | 1.39-1.50 | 2 |

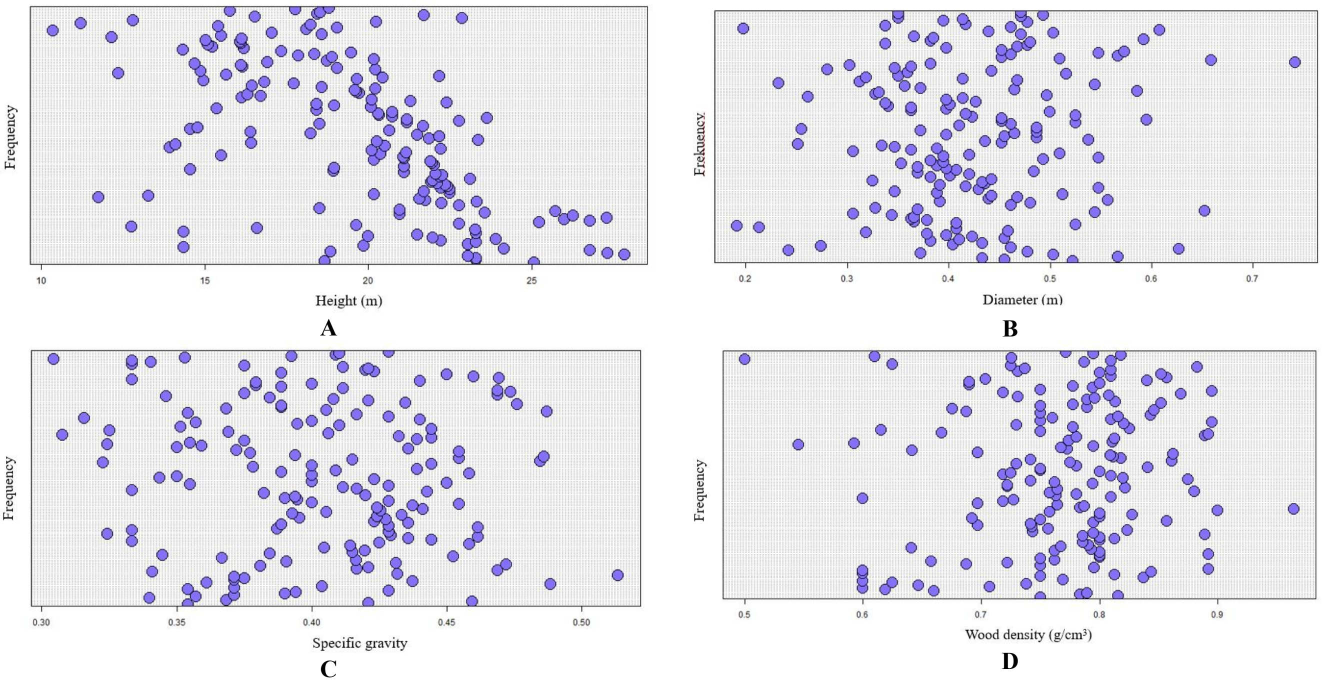


**Figure 2.** The distribution data of jabon planted under agroforestry system: A. Height, B. Diameter, C. Specific gravity and D. Wood density

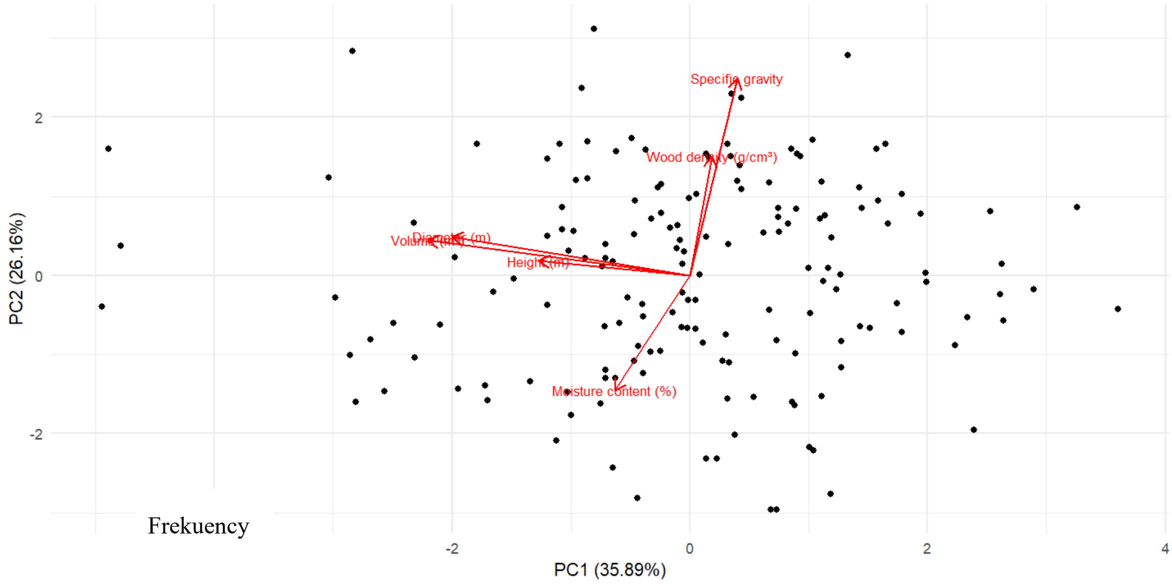


**Figure 3.** PCA results of growth and wood properties height, diameter, specific gravity and wood density of jabon planted under agroforestry system

**Table 3.** Analysis of variance of physical properties of jabon wood

| Variable | Treatment | | | p-value |
|---|---|---|---|---|
| | Base | Middle | Top | |
| Green moisture content (%) | 139.09[b] | 113.01[a] | 102.28[a] | 0.000* |
| Air dried moisture content (%) | 14.54[b] | 12.67[a] | 12.04[a] | 0.000* |
| Green density (g/cm$^3$) | 0.85 | 0.89 | 0.88 | 0.398[ns] |
| Air dried density (g/cm$^3$) | 0.43[a] | 0.50[b] | 0.51[b] | 0.018* |
| Oven dried density (g/cm$^3$) | 0.38[a] | 0.45[b] | 0.47[b] | 0.010* |
| Green specific gravity | 0.36[a] | 0.43[b] | 0.44[b] | 0.007* |
| Air dried specific gravity | 0.37[a] | 0.44[b] | 0.46[b] | 0.008* |
| Oven dried specific gravity | 0.38[a] | 0.45[b] | 0.47[b] | 0.010* |
| Longitudinal shrinkage (%) | 0.14 | 0.09 | 0.28 | 0.344[ns] |
| Radial shrinkage (%) | 1.1 | 1.27 | 1.15 | 0.343[ns] |
| Tangential shrinkage (%) | 2.55 | 2.71 | 2.65 | 0.430[ns] |

Note: *Significant at 5% level of significance

*Moisture Content (MC)*

The moisture content of jabon wood was measured using gMC and adMC, on three parts of tree, namely base, middle, and top (B, M, and T). Testing on these three parts was important to obtain complete information about the quality of the wood, because there were natural variations along the trunk that were influenced by internal factors (wood anatomy) and external (growing environment). Environmental factors such as light, water, nutrients, and soil contribute greatly to the differences in wood characteristics among parts of the trunk (Lachenbruch and McCulloh 2014; Kimberley et al. 2015). The tree's base produced the highest gMC at 139.09%, while the top had the lowest value of 102.28%. The highest adMC value of 14.54% was produced at the base, and the top showed the lowest value of 12.04%, as shown in Figure 4. The moisture content of jabon wood, both the gMC and adMC values, was greater at the base and decreased towards the top. Widiyanto and Siarudin (2016) reported that the base showed the highest moisture content and would continue to decrease regularly towards the top. This high moisture content at the base was attributed to the large cell cavity.

The highest gMC value of 172.55% was produced by segment 1 at the base and the lowest value of 86.75% was obtained by segment 4 at the top. Furthermore, the highest adMC value of 15.80% was produced by segment 1 at the base, and segment 4 at the middle had the lowest value of 11.17%. This suggests that the greatest moisture content value is obtained from the deepest part of the wood (pith). According to Indahsuary et al. (2014), the pith has a higher moisture content due to the presence of thin cell walls and low density, which prevent wood cell cavities from coalescing. Widiyanto and Siarudin (2016) also observed the same pattern in trees aged 7 years and Anna et al. (2023) in 42 months old. This suggests that the highest moisture content value is obtained in the pith section because there are thin cell walls with low density preventing wood cell cavities from coalescing.

Based on the results, gMC values ranged from 78.39-183.50% and adMC varied between 10.18 and 16.25%

among the three jabon trees studied. Similarly, Hadi et al. (2013) observed that, with methyl methacrylate impregnation treatment for 10 minutes and 30 kGy radiation obtained adMC of 13.3%. In this study, the average value of adMC was found to be 13.08%. Compared to Hidayati et al. (2020), the 5 years old red jabon wood had a 102-115% gMC. Analysis of variance in this moisture content test showed that tree parts significantly affected gMCg and adMC. Further, Duncan's test showed that the gMC of jabon was significantly different at the top and middle of the tree base.

*Density (ρ)*

Density values were obtained in green (gρ), air dried (adρ), and oven dried (odρ) conditions on three parts of tree (B, M, T). The highest ρ value of 0.89 $g/cm^3$ was obtained at the middle and the lowest was at the base, which was 0.85 $g/cm^3$. Furthermore, the highest adρ value of 0.51 $g/cm^3$ was obtained at the top and the lowest at the base, namely 0.43 $g/cm^3$. The highest odρ value of 0.47 $g/cm^3$ was obtained at the top and the lowest of 0.38 $g/cm^3$ at the base. Figure 5 shows that the highest wood density value at gρ was obtained in the middle, while adρ and odρ are obtained at the top. In comparison, the lowest value was equally obtained at the base. Indahsuary et al. (2014) reported the variation in density was influenced by moisture content and the composition of wood substance, including several pores, cell cavities, and extractive substances. The results varied significantly from the reports by Nurrachmania and Rozalina (2021) who obtained adρ of 0.39 $g/cm^3$ type of boiling treatment, while this study achieved an average adρ of 0.48 $g/cm^3$.

The highest gρ of 0.95 $g/cm^3$ was obtained in segment 2 at the top and the lowest value was 0.80 $g/cm^3$ As shown in Figure 5, the highest adρ of 0.57 $g/cm^3$ was obtained in the middle segment 4 and the lowest value of 0.38 $g/cm^3$ in segment 1 at the base, with an average value of 0.48 $g/cm^3$. The highest odρ of 0.52 $g/cm^3$ was in segment 4 in the middle and the lowest in segment 1 at the base was 0.34 $g/cm^3$. These results differ from the study by Lempang (2014), who observed the same species with an average odρ of 0.45 $g/cm^{3,}$ and Supriadi et al. (2017) with an average adρ of 0.34 $g/cm^3$ for jabon of 5 years old. According to Anoop and Pasha (2017), the classification of adρ is grouped into 3 classes, namely low/light wood (ρ<0.55 $g/cm^3$), medium (ρ=0.55-0.75 $g/cm^3$), and high/ heavy wood (ρ>0.75 $g/cm^3$). Therefore, the white jabon wood density in this study is classified as light to medium wood. Specifically, the value of the wood density gρ ranged from 0.74-1.06 $g/cm^3$, adρ was 0.34-0.62 $g/cm^3$, and odρ was 0.30-0.58 $g/cm^3$. Analysis of variance in this density test showed that tree parts had a significant effect on adρ and od-ρ but had no influence on fresh density (gρ).

*Specific gravity (G)*

Specific gravity of the wood tested was green (gG), air dried (adG), and oven dried (odG) conditions, on three parts of tree (B, M, T). The highest g-G of 0.44 was obtained at the top, while the lowest value of 0.36 was shown in the base. Furthermore, the highest adG of 0.46 was at the top, and the lowest at the base, namely 0.37. The highest odG was achieved at the top and the lowest value of 0.38 was at the base. Figure 6 shows that the specific gravity is greatest at the top and lowest at the base. This result differed from Lessy et al. (2018), who found that the average specific gravity of 14 years old sengon (*Albizia chinensis*) wood planted under agroforestry system was obtained in the middle section. The odG value is higher in each condition than the gG and adG values. Similarly, Widiyanto and Siarudin (2016) stated that the specific gravity determined based on the oven dry volume had a relatively more significant value than the fresh and dry air. The volume value for the oven dry weight divider is smaller compared to others due to the reduced moisture content in the cell walls, leading to higher results.

The highest gG of 0.49 was obtained in segment 4 at the middle and the lowest value of 0.31 was obtained in segment 1 at the base. Moreover, the highest adG of 0.51 was obtained it segment 4 at the middle and the lowest value of 0.33 was in segment 1 at the base. The highest odG of 0.52 was obtained in segment 4 at the middle and the lowest value of 0.34 was achieved in segment 1 at the base, as shown in Figure 6. Haygreen et al. (2003) reported that the variation in density values was influenced by several variables, including where the plant grows, geographic location, climate, and species. These variables can all alter the size and thickness of the cell wall, thereby influencing density.

*Wood shrinkage*

The average shrinkage of jabon wood in this study was observed on the base (B), middle (M), and top (T) of the tree as presented in Figure 7. The highest value of longitudinal (L) shrinkage was produced by the top at 0.28% and the lowest value of 0.09% was obtained in the middle. Meanwhile, the highest radial (R) shrinkage was produced by the middle at 1.27%, and the lowest value of 1.10% was at the base of the tree. The highest tangential (T) shrinkage value was obtained from the middle of the tree at 2.71%, and the lowest value of 2.55% was at the base. The L shrinkage is lowest in the middle of the tree, while R and T shrinkage show the highest value. Rahmayanti et al. (2016) examined jabon wood originating from Alindau Village, Donggala District, Central Sulawesi, and showed that the base obtained the lowest R and T shrinkage. A study by Hidayati et al. (2016) examined 11-year-old superior teak wood originating from the Wanagama Education Forest, Gunungkidul, Yogyakarta. The results showed that the average shrinkage value was 1.00% (L), 4.60% (R), and 7.9% (T) compared to the values obtained in this study, namely 0.17% (L), 1.17% (R), and 2.64% (T).

The average shrinkage of jabon wood from each segment (pith to bark) in the tree section is shown in Figure 7. In this study, the shrinkage value of jabon wood is measured in longitudinal (L), radial (R), and tangential (T) directions based on the segments of the tree (B, M, T). The highest value of L shrinkage for jabon wood was produced by segment 4 of the top, namely 0.43%, and the lowest value was produced by segment 2 of the base and segments

2 and 4 of the middle at 0.00%. The highest R shrinkage of 1.54% was produced by segment 4 at the top and the lowest value of 0.77% was obtained by segment 5 at the base. Meanwhile, the highest T shrinkage value of 3.41% was shown in the middle 3 segments, and the lowest value of 2.25% was produced by the top 4 segments. Figure 7 shows irregular and inconsistent L, R, and T shrinkage values, which vary in magnitude. In comparison, Marsoem et al. (2014) examined teak wood with a diameter of 30 cm, taken from the community forest of Gunungkidul District, Yogyakarta. The results showed an average shrinkage of 0.54% (L), 2.97% (R), and 5.34% (T), which was different from 0.17% (L), 1.17% (R), and 2.64% (T) obtained in this study.

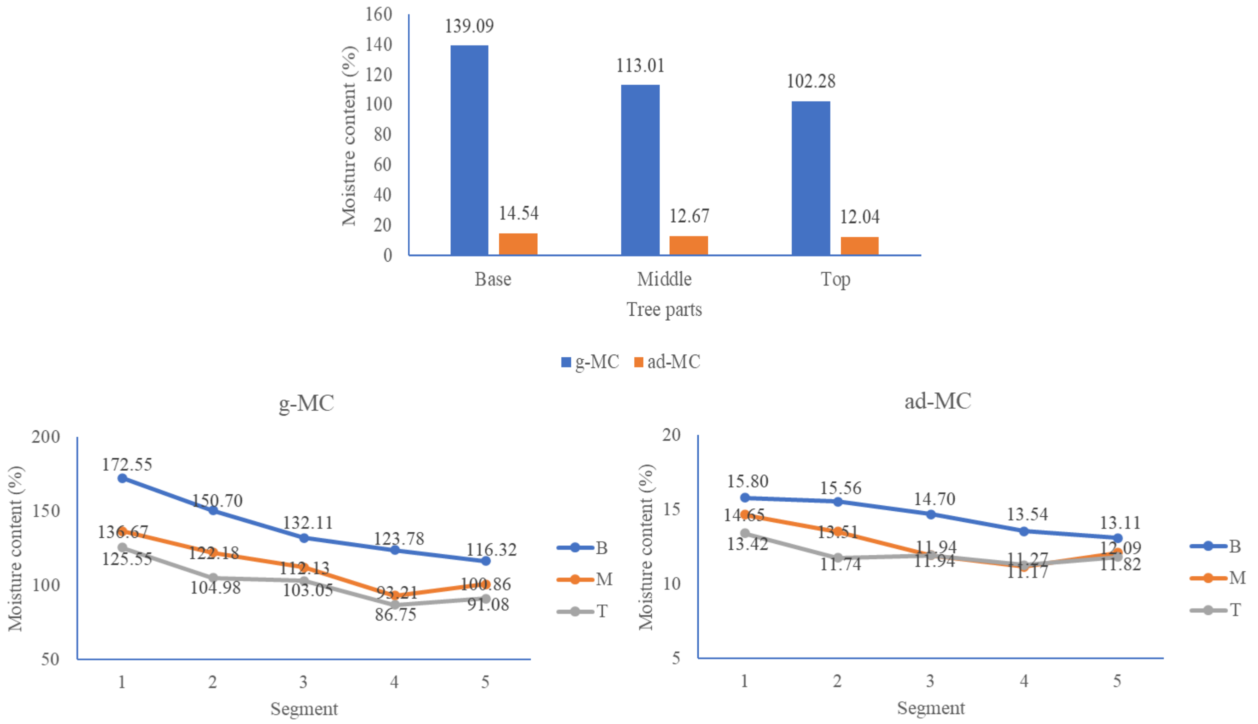


**Figure 4.** The properties of wood moisture content of jabon planted under agroforestry system

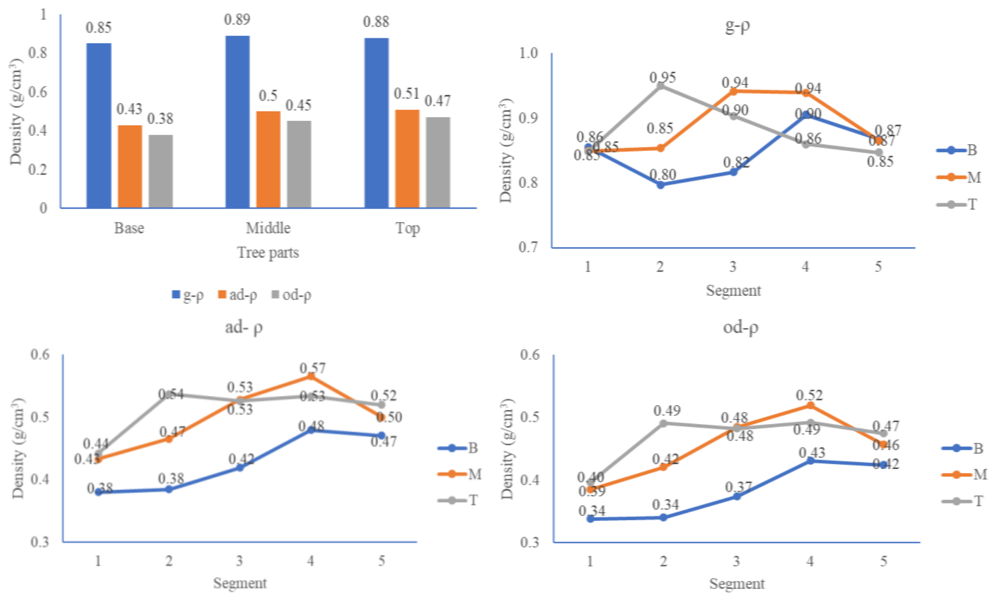


**Figure 5.** The properties of wood density of jabon planted under agroforestry system

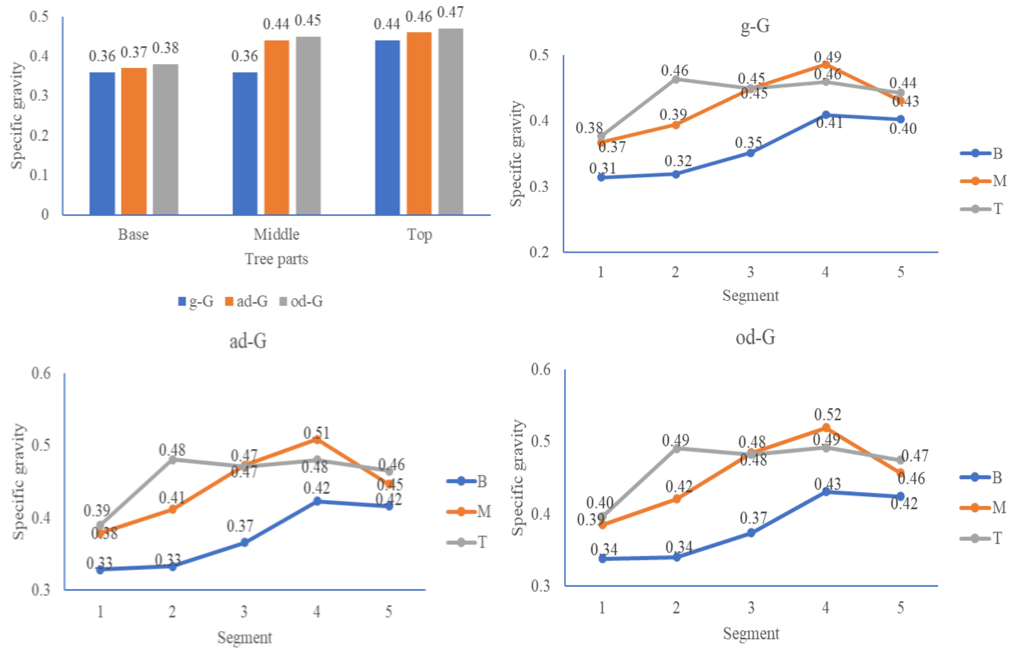


**Figure 6.** The properties of wood specific gravity of jabon planted under agroforestry system

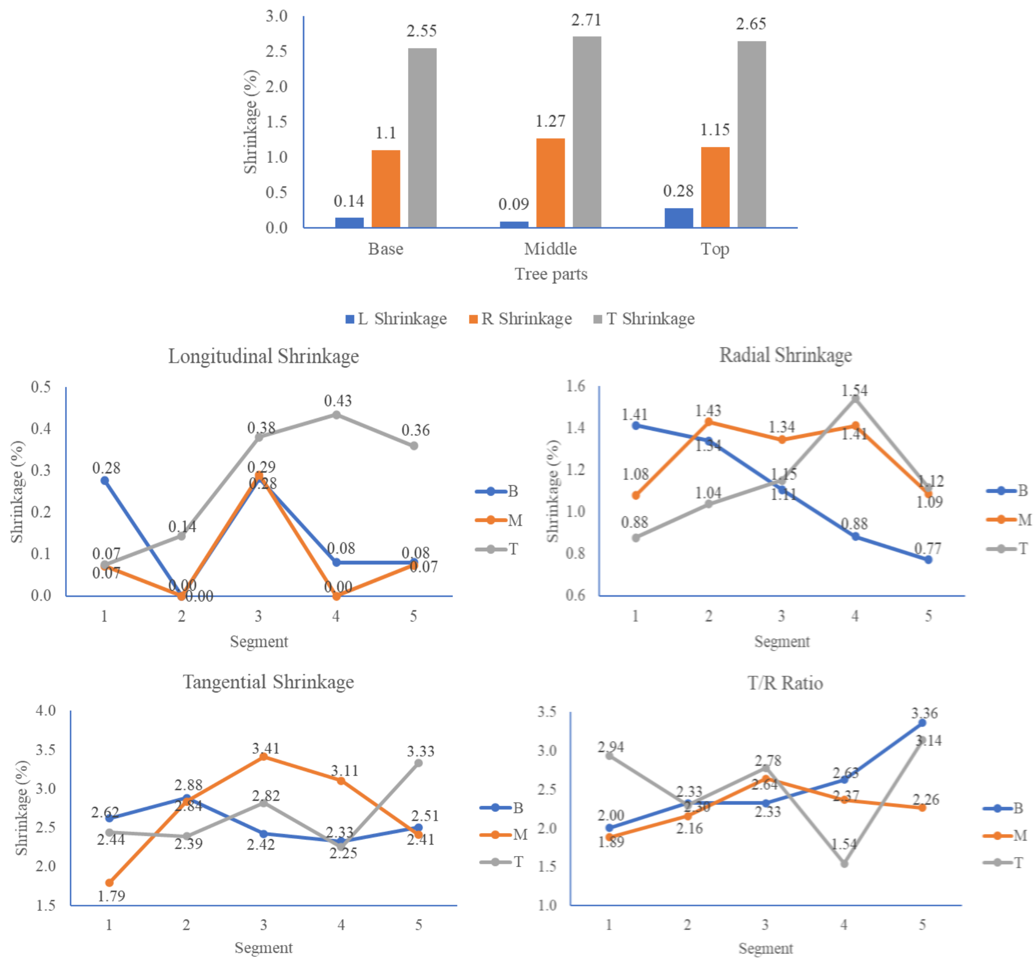


**Figure 7.** The properties of wood shrinkage of jabon planted under agroforestry system

The dimensional stability of wood can be determined by comparing its tangential and radial (T/R ratio) ratio. The average T/R Ratio value for jabon wood from each segment (pith to bark) obtained from each part of the tree is shown in Figure 7. The highest value of 3.36 was produced in segment 5 at the base and the lowest value of 1.54 was obtained in segment 4 at the top. Bowyer et al. (2007) reported that when the T/R ratio value of a type of wood was smaller than 2 or close to 1 (T/R≤2), the wood had good dimensional stability. Mochsin et al. (2014) reported that the T/R shrinkage of approximately 1.0 represented the best, ≤1.5 better, ≤2.0 good, and ≥2.0 denoted poor dimensional stability.

Shrinkage in L, T, and R direction ranged from 0.00-0.87%, 0.69-2.07%, and 1.18-4.22%, respectively, with T/R ratio between 1.04-4.79. Variations in depreciation values were obtained from the three jabon trees studied. The T/R Ratio value obtained showed that the dimensions of the wood were less stable against shrinkage, suggesting susceptibility to drying defects. Similarly, Ridho and Marsoem (2015) obtained T/R ratio of 1.92-6.59 by examining the same type of wood aged 4 years, originating from Ambarketawang Village, Gramping Sub-district, Sleman District, Indonesia. Widiati et al. (2022) reported that higher T/R ratio values corresponded with lower wood stability. This suggested that wood would easily experience changes in shape due to the surrounding environmental conditions.

The growth, density, and shrinkage variations of jabon wood planted under agroforestry are important factors in determining its suitability for different applications, and these variations could be studied to better understand how the wood could be used in various ways. Beside producing wood products, agroforestry contributes significantly to biodiversity conservation, ecosystem sustainability and land use efficiency. The diversity of vegetation structures and types in this system increases ecosystem complexity which had a positive impact on micro and macro biodiversity. In addition, this system also reduces pressure on natural forests as the need for timber could be met from mixed cultivation land, supporting the principle of sustainability. In terms of land efficiency, agrforestry maximizes ecological and economic functions simultaneously, such as carbon sequestration by jabon trees as well as agricultural products that could be harvested periodically, making the land more productive throughout the year. Therefore, jabon planted in agroforestry system is not only a fast-growing timber producer, but also an important element in biodiversity conservation and sustainable forestry development.

In conclusion, jabon grown in an agroforestry system showed good growth characteristics as indicated by optimal tree diameter and height, suggesting that agroforestry does not inhibit the growth of jabon. Physical properties of wood such as moisture content, density, specific gravity, and shrinkage showed varying values but were still within an acceptable range for the light wood industry such as plywood, and furniture components. Differences in physical properties among stem sections (base, middle, and top) also reflect rapid but relatively stable growth. Overall, 13 years old jabon in agroforestry systems have the potential as a source of industrial wood raw materials due to the fast-growing, productivity and sustainability. Agroforestry system, including integrating jabon, is a solution for the future, as it can utilize limited space, enhance biodiversity and maintain microclimate.

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