# Effects of Tree Portion and Radial Position on Wood Properties Variation of Batai *(Paraserianthes falcataria)* Tree

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**Abstract.** Physical and chemical properties of wood are important factors that influence the usability of wood-based products. This study focused on the fast-growing plant species Batai *(Paraserianthes falcataria)*, which has a diameter at breast height ranging from 50 to 70 cm. Tree trunks were cut into three portions (bottom, middle, and top) and partitioned into near pith, intermediate and near bark. Sampling for physical and chemical analysis were performed in accordance with the Pulp and Paper Technical Association Industry USA (TAPPI) T 208 om-94 standards (1996). Statistical analysis of this study revealed that tree portion and radial position have a significant impact on physical properties. The chemical properties of the tree do not differ significantly from the bottom to the top. The bottom has the highest specific gravity, followed by the middle and top. The moisture content increases from the bottom to the top. Cold and hot water, alcohol toluene, ash content, 1% NaOH extract solubility, lignin and holocellulose content were found to differ significantly between the top, middle, and bottom of the tree. Finally, physical and chemical properties of tree portion and parts were found to be significantly affected.

## 1 Introduction

*Paraserianthes falcataria* is locally known as Batai, a light wood species native to Indonesia and is extensively in tropical regions. It is a member of the Leguminosae family and grows extremely quickly. This is among the tree species selected for commercial forestry plantings in Malaysia due to its quick growth, capacity to flourish on a wide range of soil with good silvicultural features and potential for supplying acceptable grade timber for the panel and plywood industries.

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Batai grows openly and forms like a large umbrella-shaped crown with bright foliage is a promising and versatile species for use in forestry development programs in humid tropics due to its rapid growth, strong resilience, ability to compete with wood and utilities in agroforestry and silvopastoral system.

The high demand for wood products and the diminishing supply of common wood resources have led to the timber industry has realized the importance of relying on other wood species such as Batai. This fast-growing tree species has emerged as one of the most significant for the timber sector. Batai can be considered a sustainable raw material considering the characteristics of its acquisition, renewal and the possibility of recyclability or subsequent reusability. In addition, less energy is used in the extraction and manufacture of wood than in the production of other materials. It can also be said that the furniture industry is mostly dependent on rubberwood causing rubberwood to be limited due to the low price of latex. This indicates that Malaysia's ability to compete on a global scale and dominate the rapidly growing wood based furniture market is increasingly feared due to high demand and volatile export values.

Specific gravity and moisture content of wood are its basic characteristics. Regardless, there are still few studies that provide information on the characteristics of Batai wood [1]. Previous research by [2] showed that the basal density and fiber length of this species differed significantly according to the distance from the pith and close to the bark. This is because, many natural materials including wood are hygroscopic which can absorb moisture from the environment. Relative humidity, temperature and the amount of water in the wood affect how much moisture is exchanged between the wood and the water. The properties and performance of wood are significantly affected by this moisture relationship. The specific gravity of wood is the most significant physical property. Generally, knowing a material's chemical makeup can help determine that material's strength. The chemical component of wood is significant because it determines the use of a particular type of wood and to predict its resistance to wood pest attack. [3] stated that the chemical makeup of wood changes based on the type of wood, location, growing conditions, and tree portion, making it impossible to estimate with precision. Because of the many components that adhere to the tree, it also depends on its anatomical structure [4]. The aim of this study is to determine the physical and chemical characteristics of Batai wood based on tree portion and radial position.

# 2 Material & Method

## 2.1 Materials

Two Batai trees with the diameter of breast height 50 to 70 cm were used in this study. The trees were taken and cut down in Tapah Perak, which was the area of Idaman Teguh Resources. In this study, two Batai trees of 50 to 70 cm in diameter at the breast height were employed. The trees were felled and cut in the Idaman Teguh Resources region of Tapah Perak. The height of each tree was measured by dividing the length from the base to the first branch. The top, middle, and bottom portions of the trees were separated. Each portion of Batai yielded two pieces of one-inch-thick discs, which were used to determine the physical and chemical properties.

## 2.1 Methods

### *2.1.1 Sampling for physical properties*

Two discs measuring two centimeters by two centimeters by thickness were removed from each portion of Batai wood in order to assess its physical characteristics. Samples from indicated samples representing near pith (NP), intermediate (I), and near bark (NB) were used to determine the specific gravity (SG) and moisture content (MC). Three replications of every sample were used to determine these physical parameters. The chemical parameters of all the leftover samples that were not used were determined. Wood analysis testing, preparation, and sample were carried out in compliance with the [5].

#### *2.1.2 Sampling for chemical properties*

For chemical analysis, air-dried Batai sawdust was utilized. In compliance with [6], Batai wood was sampled and ready for chemical analysis. The Batai samples used for this analysis were taken from samples that were not used for physical property examination. Three groups of samples were created: bottom, middle, and top. After the samples were fed into a woodchipper, they were flaked into tiny particles using a flaker. Subsequently, the samples underwent a fine grinding process in a wood grinder and were sieved to yield sawdust with a mesh size of 60. The sawdust was then air-dried for at least one day prior to the chemical analysis to make sure the wood had completely reacted with the reagents used. For each component, three duplicates were performed. The following standard procedures were followed in order to conduct the analyses: TAPPI standard T207 cm-99 (1999) for cold and hot water soluble content; TAPPI standard T204 cm-97 (1997) for alcohol toluene soluble content; TAPPI standard T211 om-02 (2002) for ash content; TAPPI standard T212 om-02 (2002) for alkali (1% sodium hydroxide) soluble content; TAPPI standard T222 om-02 (2002) for lignin content; and TAPPI standard T222 om-02 (2002) for holocellulose content.

## 3 Results and Discussion

### 3.1 Physical Properties

Table 1 displays the differences in specific gravity and moisture content based on tree portion and radial position. The moisture content of the portion comprising the bottom, middle, and top portions ranges from 34.58% to 109.27%. According to Table 1, the average moisture content of the bottom, middle, and top portions is 70.75%, 70.99%, and 86.27%, respectively. All portions were observed to have a decreasing moisture content at the radial position, from those closest to the pith to those closest to the bark. The range of specific gravity is 0.76 - 0.60. The bottom portion has the highest average specific gravity (0.76) while the top has the lowest (0.60). The region closest to the bark has the highest specific gravity as measured in radial position; the middle and bottom portions of the sample also showed similar pattern. Two of the most important factors influencing wood's appropriateness as a raw material are its specific gravity and moisture content. Moisture has a major impact on the weight of every product, and the specific gravity of each piece of wood is used to determine its strength.

**Table 1.** Average Tree Portion and Radial Position Moisture Content and Specific Gravity Values for Batai Wood.

| Distance | Portion | Moisture Content (%) | Specific Gravity |
|---|---|---|---|
| Near pith | | 91.56 | 0.31 |
| Intermediate | Bottom | 86.11 | 0.93 |
| Near bark | | 34.58 | 1.03 |
| **Average** | | **70.75** | **0.76** |
| Near pith | | 85.61 | 0.54 |
| Intermediate | Middle | 80.90 | 0.62 |
| Near bark | | 46.46 | 0.69 |
| **Average** | | **70.99** | **0.62** |
| Near pith | | 109.27 | 0.50 |
| Intermediate | Top | 97.20 | 0.76 |
| Near bark | | 52.39 | 0.55 |
| **Average** | | **86.27** | **0.60** |

### *3.1.1 Statistical Significance*

The results of the analysis of variance (ANOVA) for comparing tree portion, radial position, moisture content (MC), and specific gravity (SG), along with their effects on these variables, are presented in Table 2. Neither the main factors of radial position nor tree portion caused significant changes in moisture content or specific gravity at the 95% confidence level. Additionally, the interaction between tree portion and radial position showed no effect on moisture content and specific gravity.

**Table 2.** Summary of ANOVA on the Moisture Content and Specific Gravity of Batai influenced by Tree Portion and Radial Position.

| SOV | Df | Moisture Content (%) | Specific Gravity |
|---|---|---|---|
| Tree portion | 2 | 0.991ns | 0.408ns |
| Radial position | 2 | 0.205ns | 0.818ns |
| Tree portion x radial position | 4 | 0.142ns | 1.568ns |

Note: SOV = Source of variance, Df = Degree of freedom, ns = Not significant at $p > 0.05$

### *3.1.2 Effects of Tree Portions*

Figure 1 illustrates the effects of tree portion from top to bottom, revealing a downward trend in moisture content, further supporting this observation. Figure 2 demonstrates that as tree height increases, specific gravity decreases from the base to the top of the tree. The specific gravity in the middle and top sections is significantly lower than at the base, although there is no substantial difference between the specific gravity values of the bottom and middle sections. Wood can expand or contract depending on changes in air humidity and the moisture it absorbs or loses. As moisture content increases with rising humidity, wood expands. Conversely, wood can contract as moisture content decreases in response to lower humidity. Wood with lower moisture content tends to have thicker cell walls and smaller lumens, leaving less internal space for water to be absorbed [7]. As a result, the specific gravity decreases from the base to the top portion of the tree. According to [8], this decrease in specific gravity with tree height is due to a higher proportion of heartwood at the base and a greater proportion of juvenile wood near the top.

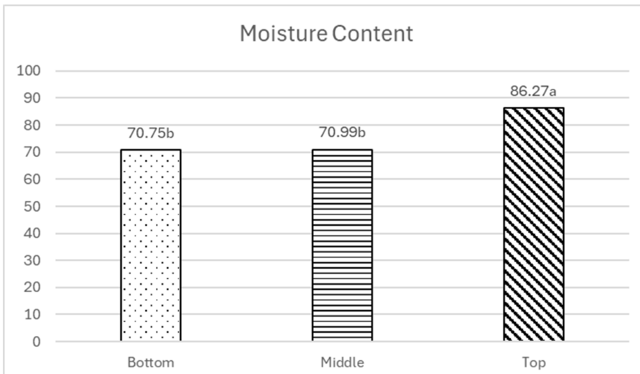


**Fig. 1.** Effects of Tree Portion on Moisture Content (MC).

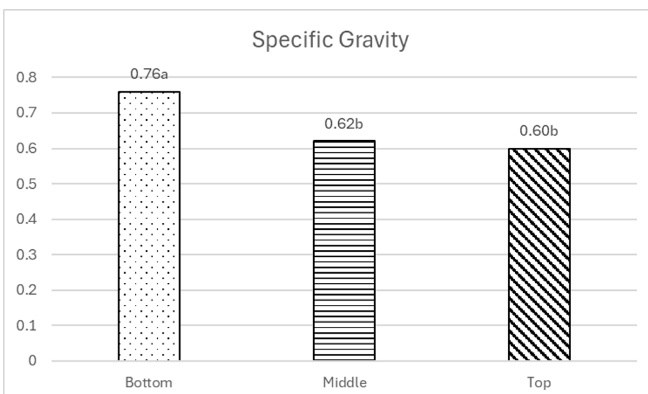


**Fig. 2.** Effects of Tree Portion on Specific Gravity (SG).

### *3.1.3 Effects of Radial Position*

Figure 3 illustrates the effect of radial position on moisture content, showing that the moisture content is highest near the pith (95.48a) compared to the intermediate part (88.07a) and the area near the bark (44.48b). However, the intermediate section exhibits the highest specific gravity (0.77a) compared to near the pith (0.45b) and near the bark (0.76a). A consistent distribution of moisture content was observed from the inner to the outer wood across the radial positions. The results suggest a significant increase in moisture content from the bark towards the pith. Specific gravity increases slightly from the bark to the intermediate section and then decreases from the intermediate to the pith. A previous study found that age and genetic factors contribute to the variation in specific gravity both between species and within individual trees [9].

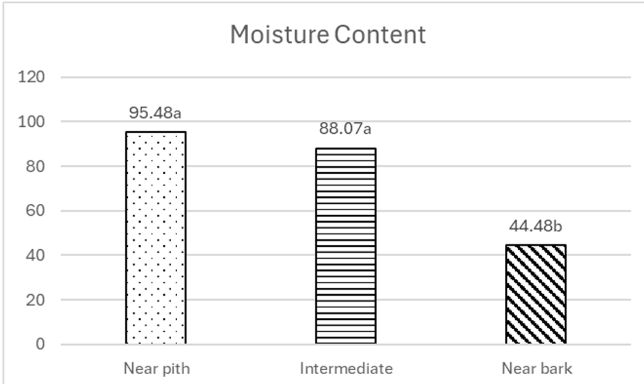


**Fig. 3.** Effects of Radial Position on Moisture Content (MC).

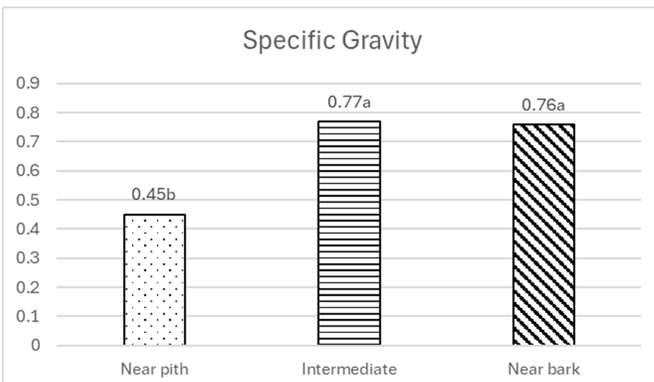


**Fig. 4.** Effects of Radial Position on Specific Gravity (SG).

### 3.2 Chemical Properties

The chemical analysis of wood was conducted to gain insights into the structural composition of the material. The chemical composition plays a crucial role in determining the suitability of wood for different applications. The properties of wood products are directly influenced by the key components of wood, such as cellulose, hemicellulose, lignin, and extractives. These functional groups, which form the structural basis of wood, interact with other chemical compounds and physical factors like heat and light, driving the wood's chemical behavior. Cellulose, hemicellulose, and lignin are the three main compounds that make up the cell walls of woody plants, while extractives represent another category of wood components. Extractives are often species or genus-specific, generally soluble, and vary in abundance, structure, and quantity. Table 3 presents the experimental results detailing the chemical composition of Batai wood across different sections of the tree. The portion of the tree has a significant effect on the wood's chemical composition, and due to the natural variability in wood, a wide range of values is observed.

According to Table 3, the top portion of Batai wood had the highest cold water-soluble content at 5.88%, while the middle portion had the lowest at 4.44%. The hot water-soluble content followed a similar pattern, with the top portion having the highest percentage at

5.44% and the middle portion the lowest at 4.70%. The concentration of alkali solubles in Batai wood varied, with 15.83% in the top portion, 17.57% in the middle, and 16.32% in the bottom, indicating an uneven distribution. The bottom portion had the highest alcohol toluene extract content at 3.08%, while the top portion had the lowest at 2.30%. The ash content of Batai wood ranged from 1.00% to 1.26%, with the top portion having the highest ash content, the middle portion the lowest at 1.00%, and the bottom portion recording 1.03%. Lignin content also varied, with the top portion showing the highest value at 37.00%, the bottom portion at 33.98%, and the middle portion being lower than the bottom at 32.00%. The top portion of the Batai tree had the highest holocellulose content, with an average value of 70.44%.

**Table 3.** Chemical Properties of Batai Wood.

| | **Tree Portion** | **Batai** | **Rubberwood [10]** |
|---|---|---|---|
| Cold Water Soluble Content (%) | Top | 5.88 | |
| | Middle | 4.44 | |
| | Bottom | 5.15 | |
| | **Average** | **5.16** | |
| Hot Water Soluble Content (%) | Top | 5.44 | |
| | Middle | 4.70 | 6.55 |
| | Bottom | 5.22 | |
| | **Average** | **5.12** | |
| 1% NaOH Soluble Content | Top | 15.83 | |
| | Middle | 17.57 | |
| | Bottom | 16.32 | |
| | **Average** | **16.57** | |
| Alcohol Toluene Soluble Content (%) | Top | 2.30 | |
| | Middle | 2.67 | 3.34 |
| | Bottom | 3.08 | |
| | **Average** | **2.68** | |
| Ash Content (%) | Top | 1.26 | |
| | Middle | 1.00 | 0.60 |
| | Bottom | 1.03 | |
| | **Average** | **1.10** | |
| Lignin Content (%) | Top | 37.00 | |

| | | | |
|---|---|---|---|
| | Middle | 32.00 | 23.00 |
| | Bottom | 33.98 | |
| | **Average** | **34.33** | |
| Holocellulose Content (%) | Top | 70.33 | |
| | Middle | 72.50 | 66.86 |
| | Bottom | 68.50 | |
| | **Average** | **70.44** | |

*3.2.1 Statistical Significance*

Table 4 presents the ANOVA results on the effect of tree portion on the chemical properties of the wood. At the 95% confidence level, it was found that tree portion had a significant influence on the content of cold water solubles, alcohol toluene solubles, and holocellulose. However, there was no significant effect on the hot water solubles, 1% NaOH solubles, ash, or lignin content.

**Table 4.** Summary of the ANOVA on Chemical Properties influenced by Tree Portion.

| SOV | CW | HW | NaOH | AT | Ash | Lignin | Holo |
|---|---|---|---|---|---|---|---|
| Tree Portion | 17.55* | 2.86ns | 1.12ns | 59.84* | 4.53ns | 3.33ns | 8.88* |

Note: SOV = Source of variance, CW = Cold water, HW = Hot water, NaOH = 1% Sodium hydroxide, AT = Alcohol toluene, Holo = Holocellulose

*3.2.2 Cold and Hot Water Soluble Content*

Table 3 presents the hot water solubility results for Batai wood, compared to a prior study on rubberwood, showing that Batai wood is comparable to rubberwood. Cold and hot water soluble contents are crucial for evaluating water-soluble substances like starch, sugars, tannins, and phenolic compounds in lignocellulosic materials [11]. Figure 5 highlights the highest hot water solubility result for Batai wood in the top portion at 5.435a, followed by 5.22a in the bottom portion, and 4.695b in the middle portion. The portion of the tree significantly impacted cold water soluble content. According to [12], portions with higher cold water solubility contain more active cells. Cold water extractives vary across wood species due to differences in wood type, compression, geography, climate, and soil conditions. Species with higher extractive content tend to have better dimensional stability, plasticizing ability, and durability. The cold water soluble content of wood is primarily composed of salts, sugars, gums, and tannins. Hot water solubility, on the other hand, measures the amount of extraneous substances like tannins, gums, sugars, and coloring agents in wood. Hot water extraction typically removes more material, including parts of the cell structure and some inorganic compounds. In general, wood portions with higher cold and hot water solubility contain more cells, while parts with lower solubility often have higher lignin content. The average hot water soluble content of Batai wood in this study is higher than that reported for rubberwood in [10].

*3.2.2 Alkali Soluble Content*

Low molecular weight carbohydrates, such as cellulose and hemicellulose, are extracted from wood using 1% NaOH. According to [13], this extraction process reveals degradation caused by factors like fungi, heat, light, and oxidation. The hot alkaline solution breaks down the cellulose in the wood, extracting primarily hemicellulose and other low molecular weight carbohydrates. For Batai wood, the alkalinity ranged from 15.83% to 17.57% (Table 3). As shown in Figure 5, the dissolved alkali content in the top portion (15.83a), middle portion (17.58a), and bottom portion (16.32a) does not exhibit a significant difference, with the highest value in the middle portion. The data indicates that the tree portion has an insignificant effect on alkali solubility across the tree, although the middle portion shows a slightly higher alkali-soluble content compared to the top and bottom. According to [11], higher alkali solubility is associated with increased cellulose degradation and lower polyphenol content. The primary components of the wood, as revealed by the high extractive materials in the 1% NaOH solution, include inorganic minerals, carbohydrates, fats, oils, dyes, and aromatic compounds.

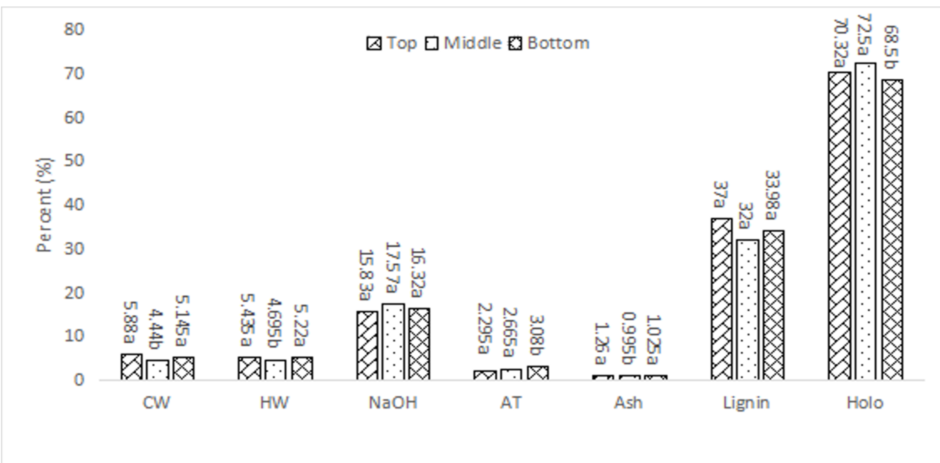


**Fig. 5.** Effects of Tree Portion on Chemical Analysis.
Note: CW = Cold Water, HW = Hot Water, NaOH = 1% Sodium hydroxide, AT = Alcohol Toluene, Holo = Holocellulose

*3.2.3 Alcohol Toluene Soluble Content*

The alcohol-toluene (1:2) soluble content is an important indicator of waxes, fats, resins, gums, and other extractives, as well as ether-insoluble components. As shown in Figure 5, the alcohol-toluene soluble content in Batai wood ranges from 3.08b in the bottom portion, 2.665a in the middle portion, to 2.295a in the top portion. The figure indicates that the bottom portion of the tree has the highest soluble content, followed by a decrease from the middle to the top of the tree. Extractives play a key role in providing fungal resistance, particularly in heartwood, and contribute to the wood's structural integrity. This suggests that the bottom portion may contain higher levels of resins, waxes, fats, and gums compared to other portions. However, previous studies have indicated that the upper portion of trees often contains more alcohol-toluene extractives than the lower portion [14], with extractive content increasing as the number of cambial cells or living tissues increases. In contrast, this study found that Batai wood tends to have lower extractive content compared to more commonly used tropical hardwood species, such as rubberwood [10].

#### *3.2.4 Ash Content*

Ash content refers to the residue left after burning wood at 575°C for three hours or longer, depending on the amount of carbon that needs to be burned off. This value indicates the silica and salt content in the wood, with silica accumulation often linked to a higher proportion of heartwood [15]. As shown in Figure 5, Batai wood's ash content ranges from 1.26a in the top portion to 0.995b in the middle and 1.025a in the bottom, with the top portion exhibiting the highest ash content. The overall ash content of Batai wood is 1.10%, which is notably higher than the 0.60% recorded for rubberwood. Ash tends to be produced in larger amounts by the bark and leaves of the tree rather than its inner woody parts. The higher ash content in the bottom portion of the tree is attributed to its greater density and heartwood content, as heartwood generally contains more silica-based material. The findings suggest that the higher ash content in the top portion of Batai is due to the increased density as sapwood transitions into heartwood from the base of the tree to the crown. This study found that Batai had an average ash content of 1.10%, which is slightly higher than rubberwood at 0.60% [10]. In wood and pulp, sulfuric acid hydrolyzes and dissolves the carbohydrates, leaving behind acid-insoluble lignin, which is then filtered, dried, and weighed. Lignin constitutes 20% to 30% of wood, and the primary goal of pulping and bleaching processes is to remove it. Measuring the lignin content in wood and pulps is crucial for evaluating and optimizing these processes. Lignin content also influences pulp properties such as color, hardness, and bleachability, as lignin is found in the middle lamella and cell walls of wood and is removed during pulping and bleaching. As shown in Figure 5, lignin content in Batai wood is unevenly distributed, with the top portion containing 37a, the middle portion 32a, and the bottom portion 33.98a. Higher lignin content contributes to the strength of the wood's cell walls and is associated with supporting the plant's vertical growth. Previous research has indicated that lignin content varies only slightly along the tree stem [16]. Another study [10] found that rubberwood contains 23% lignin by mass, while Batai wood has a higher lignin content, as indicated in Table 3.

#### *3.2.5 Lignin Content*

In wood and pulp, sulfuric acid hydrolyzes and dissolves the carbohydrates, leaving behind acid-insoluble lignin, which is then filtered, dried, and weighed. Lignin constitutes 20% to 30% of wood, and the primary goal of pulping and bleaching processes is to remove it. Measuring the lignin content in wood and pulps is crucial for evaluating and optimizing these processes. Lignin content also influences pulp properties such as color, hardness, and bleachability, as lignin is found in the middle lamella and cell walls of wood and is removed during pulping and bleaching. As shown in Figure 5, lignin content in Batai wood is unevenly distributed, with the top portion containing 37a, the middle portion 32a, and the bottom portion 33.98a. Higher lignin content contributes to the strength of the wood's cell walls and is associated with supporting the plant's vertical growth. Previous research has indicated that lignin content varies only slightly along the tree stem [16]. Another study [10] found that rubberwood contains 23% lignin by mass, while Batai wood has a higher lignin content, as indicated in Table 3.

#### *3.2.6 Holocellulose Content*

Holocellulose, one of the main components of lignocellulosic materials, consists of the extractive-free portion of wood, and lignin must be removed before holocellulose can be obtained. Wood with higher concentrations of cellulose and hemicellulose typically has a higher holocellulose content. As shown in Figure 5, the holocellulose content varied significantly across different portions of the tree. The research results in Figure 5 display a patchy pattern of holocellulose distribution. The lower portion of the tree had a significantly lower holocellulose content (68.5b) compared to the middle (72.5a) and upper portions (70.32a), with the middle portion showing the highest content. This variation might be linked to the fact that fast-growing species, such as Batai, tend to have a higher proportion of juvenile wood [8]. Juvenile wood is known for its rapid growth and higher cellulose content, which could explain the higher holocellulose levels in certain parts of the tree. The findings suggest that as the tree grows, the holocellulose content remains relatively consistent across different portions. In this study, Batai had an average holocellulose content of 70.44%, which is higher than that of rubberwood, as indicated in Table 3.

## 4 Conclusion

This study found that the radial position and tree portion had minimal impact on the physical properties of Batai wood. Moisture content was not significantly influenced by either tree portion or radial position, and specific gravity showed only slight variation across these factors. The average values for the soluble contents were as follows: cold water soluble (5.2%), hot water soluble (5.1%), alkali soluble (16.6%), alcohol toluene soluble (2.7%), and ash (1.1%). Additionally, the average lignin and holocellulose contents were 34.3% and 70.4%, respectively. These findings suggest that Batai wood has physical and chemical properties suitable for use as wood composite feedstock in Malaysia.

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