

# Chemical Properties of “Jati Unggul Nusantara” Teak Wood from Gunungkidul

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## Abstract

Jati Unggul Nusantara (JUN) trees show a fast-growing characteristic and a possibility to be harvested in short rotation. This study aims to determine the chemical properties of 8-year-old JUN tree parts. Three individual trees were felled from Paliyan, Gunungkidul, Yogyakarta, Indonesia. The tree parts were observed vertically (i.e., the bottom, center, top, branches, and twigs) and radially (i.e., sapwood and heartwood of the trunk). The result showed that the average content of cell wall components of extractive-free wood, i.e., hemicellulose,  $\alpha$ -cellulose, and lignin, were 20.38–25.71%, 41.88–49.10%, and 26.46–29.85%, respectively. Furthermore, successive extractive measurements showed that ethanol-toluene and hot-water soluble extracts (based on dry wood) were at the levels of 3.01–7.58% and 1.85–3.09%, respectively. The ash content, silica content, and pH values were 0.48–0.82%, 0.13–0.37%, and 5.89–7.51%, respectively. By an analysis of variance, significant differences between the sapwood and the heartwood were observed in ethanol-toluene extractive, lignin, holocellulose, and cellulose contents. The differences among tree parts did not show any significant effect on the hot-water soluble content. Significant differences between the main stem and branches or between the main stem and twigs were observed in most chemical properties.

**Keywords:** Ash, cell wall component, extractive, fast-growing, juvenile

## Introduction

Teak (*Tectona grandis* L.f.) wood is known as a fancy wood due to its wood strength, physical appearance, and high natural durability. The increasing demand for teak timber has caused an imbalance of supply and demand in the wood market (Thulasidas and Bailleres 2017). Consequently, the price of teak wood from long-rotation harvesting is increasing. Therefore, teak stands with fast-growing or superior trees have been developed by breeding to produce short-rotation teak trees.

Jati Unggul Nusantara (JUN) trees have been cultivated by shoot cuttings from Jati Plus Perhutani (JPP) clones (Efansyah *et al.* 2012). JUN trees have various advantages, such as faster growth with harvest periods of less than 10 years and deep-rooted physical characteristics (Anonymous 2011). Although it is harvested at a young age, the heartwood appearance indicates that the teak wood is considered to be durable enough to be used as the main raw material for construction and furniture.

In the logging practice, the main stems of young teak trees are mostly used for construction, while the branches and twigs are generally used as firewood. Therefore, it is important to assess the chemical properties of the wood as it can affect the woodworking process, colour, and natural durability. Studies on the chemical components of JUN and other fast-growing teak trees in general are still limited when compared to studies on their physical properties. Research using 5-year-old JUN trees from a coppiced stand was carried out for chemical properties of their wood by Maulida *et al.* (2020). Recently, the extractive contents of JUN wood (8

years) have been studied by Rahman *et al.* (2022). As a follow-up, this study aims to determine the chemical properties of the main stem, branches, and twigs of JUN trees. Better utilization of JUN wood is expected after evaluation of the chemical properties.

## Materials and Methods

### Samples Preparation

The materials used in this study were three individual JUN trees (8 years) from RPH Kepek, BDH Playen, BKPH Yogyakarta. Wood blocks of the main trunk (dbh = 14–18 cm, heartwood proportion = 33–49%) were cut from the bottom (1 m above the ground), center (2 m from the bottom), and top (2 m from the center) parts. The blocks from branches and twigs were taken from near the top part (Fig. 1). The wood from the main stem was divided into heartwood and sapwood. After removing the bark, each part of the tree was then converted into wood powder (40–60 mesh) by grinding for chemical evaluation.

### Cell Wall Components and Extractives Determination

The determination of extractive contents was carried out by extracting wood powder (2 g equiv. dry weight) with ethanol-toluene solvent (2:1, v/v) (ASTM D1107 – 96 2002) and with hot water (ASTM D 1110 – 80 2002) in succession. The extractive-free wood powder from ethanol-toluene extraction was then determined for holocellulose content using the modified chlorite acid method (Browning 1967), as well as for  $\alpha$ -cellulose (Rowell *et al.* 2005) and Klason lignin

contents (TAPPI T222 – os 78 1992). The hemicellulose content was determined by subtracting the holocellulose content by the  $\alpha$  –cellulose content. The ash content (ASTM D 1102 – 84 2002) as well as the silica content (SNI 14-1031-1989, Dewan Standarisasi Nasional 1989) were measured.

### pH Value Measurement

The pH value was measured with the OAKTON pH tester. A total of 1 g (equiv. oven-dry wood) was soaked in 20 ml of distilled water for 48 hours. The pH value of the filtrate was then measured after filtering.

### Data Analysis

A one-way analysis of variance (one-way ANOVA) was carried out to determine the effect of tree part factor i.e. bottom-heartwood, bottom-sapwood, center-heartwood, center-sapwood, top-sapwood, top-heartwood, branch, and twig parts. The effects were taken into account when significant at the 95% level (Type III Sums of Squares). A Tukey test (honestly significant difference) was used to show which group means differ. All calculations used SPSS 16 for Windows software.

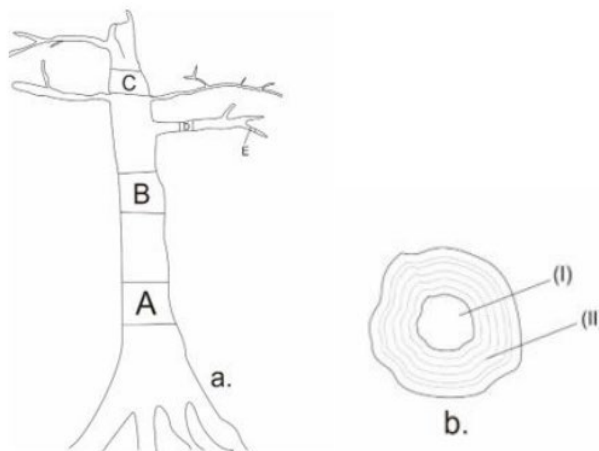


Figure 1. Sampling position on a (a) tree part (A=bottom, B=center, C=top) and cross-section (b) of teak trunk (I=heartwood, II= sapwood)

## Results and Discussion

### Chemical properties from fast-growing teak trees

The 8-year-old JUN wood was assumed to be juvenile wood (Bhat 20001), which was selected to show different properties than those of mature wood (Shmulsky and Jones 2011). A summary of the chemical properties of the 8-year-old JUN wood in this experiment and a comparison with those of fast-growing teak from previous works are presented in Table 1.

The JUN samples from Gunungkidul had higher levels of extractives, holocellulose, and  $\alpha$ -cellulose compared to the 5-year-old JUN main stem samples from a coppiced stand (Maulida *et al.* 2020). They also had higher extractive content but lower lignin content compared to the 10-year-old samples from a community forest (Rizanti *et al.*, 2018). Furthermore, they had lower amounts of soluble ethanol-toluene extractives, holocellulose, hemicellulose, ash, and silica compared to 15-year-old Jati Plus Perhutani (superior teak) wood samples.

In the branch part, they showed holocellulose,  $\alpha$ -cellulose, and lignin contents that were within the range comparable to those of branches of the api wood or *Schizolobium amazonicum* species (Amin *et al.* 2013). Research was also carried out on pohon surga (*Ailanthus altissima*) wood, where the branches and twigs had ash contents of 1.75% and 1.25%, respectively (Samaraha and Kiaei2011).

Wood quality is affected by its extractive content. The higher the extractive content, especially the ethanol-toluene extract, the higher the durability or resistance of the wood to pathogens. Extractives in cell walls are also able to increase density and reduce swelling and shrinkage of wood (Shmulsky and Jones 2011). The low value of the ethanol-toluene extractive content of the 8-year-old JUN wood in this study is thought to reduce the natural durability of the wood when compared to the natural durability of mature teak. However, the relatively low value of hot-water extractive content in the JUN wood is assumed to provide benefits when used in wood gluing products. Previous studies demonstrated that non polar extractives cause change in polarity and wettability to result poor adhesion (Hse and Kuo 1988).

Table 1. Chemical properties of teak wood (Jati Unggul Niusantara) with references of teak wood chemical properties from fast-growing trees.

	References			Jati Unggul Niusantara (8 years)			Content (%)
	15 years <sup>3</sup>	10 years <sup>2</sup>	5 years <sup>1</sup>	Twig	Branch	Wood	
	7.91~9.74	1.6(0.05) <sup>5</sup>	1.2(0.06) <sup>4</sup>	5.85	3.53	3.01~7.58	Ethanol-toluene Extractive <sup>b</sup>
	2.02~2.42	2.5(0.48)	2.5(0.48)	2.08	1.85	2.16~2.74	Hot-water solubility <sup>b</sup>
	75.93~77.47	67.50(1.53)	63.11~64.08	66.70	63.12	66.49~71.27	Holocellulose <sup>a</sup>
	47.07~47.64	48.80(1.19)	33.68~41.16	41.88	47.74	43.57~49.10	$\alpha$ -cellulose <sup>a</sup>
	26.87~29.86	18.70 (1.72)	-	24.48	20.38	21.62~25.71	Hemicellulose
	28.12~32.45	35.53(0.78)	24.33~30.54	27.36	27.56	26.46~29.85	Lignin <sup>a</sup>
	0.86-1.18	-	-	0.77	0.80	0.48~0.82	Ash <sup>b</sup>
	0.36~0.55	-	-	0.22	0.32	0.18~0.37	Silica <sup>b</sup>
	7.08~7.38	-	-	5.89	5.92	6.9~7.51	pH value

Remarks: Average of three replications (with the standard deviation parentheses) a = percentage of free-extractive meal; b = percentage of oven-dry weight meal

Sources: <sup>1</sup>Maulida *et al.*, (2020): coppiced superior teak (Jati Unggul Niusantara),

<sup>2</sup>Rizanti *et al.* (2018): from fast-growing clonal seeds grown in a community forest;

<sup>3</sup>Lukmandaru *et al.* 2016: Jati Plus Perhutani (superior teak) from Perhutani plantation

<sup>4</sup>ethanol-benzene (1/2,v/v) extraction,

<sup>5</sup>successive extraction with dichloromethane, acetone, and ethanol/toluene(1/2, v/v)

The pH values observed here were relatively high and close to neutral pH, while the ash and silica content values were relatively low. In an earlier study, pH value range of teak wood from community forests in Gunungkidul were 5.23~6.98 (Lukmandaru *et al.* 2017). It is thought that the site influenced the pH values. High levels of ash content can be the main inhibitor in the hardening process of urea resin adhesive in teak wood (Kanazawa *et al.* 1978). The low ash content of the JUN wood in this study is an advantage in wood bonding. Similar to the ash content, lower levels of silica content would reduce the negative effect on sawmill equipment (Shmulsky and Jones 2011) because most samples showed silica levels below 0.3% and only one sample showed values above 0.3% (the bottom of the sapwood part, 0.37%). Technically, a low pH value will accelerate the hardening of UF adhesive in the wood bonding process during hot pressing for particleboard (Maloney 1993). In contrast to wood-cement compatibility, a lower pH value will tend to inhibit the crystallization process compared to a high pH value (Hachmi and Moslemi 1990). In this study, the JUN wood had a relatively high percentage of sapwood (51~78%) and a pH value in the range of 6.90~7.51. It is thought that this will tend to reduce the speed of the UF adhesive hardening process. Likewise, low pH values tend to reduce the hardening process of UF adhesive on particleboard. However, low pH values will benefit the compatibility of wood with cement.

### Comparison of Tree Parts

The results of the one-way ANOVA on the main stem parts showed a significant effect on all parameters except for solubility in hot-water. Post-hoc Tukey test results are shown in Figure 2~4. Based on the Tukey test results of the main stem parts for the vertical position, significant differences existed in all properties except for pH values. The amounts of ethanol-toluene extractive, holocellulose, hemicellulose, and lignin contents decreased from the bottom to the top in the heartwood parts. A similar pattern was observed in ash and silica contents for the sapwood parts. The cellulose content fluctuated both in sapwood and heartwood. A slightly different pattern was observed in the 5-year-old JUN samples, in which case the levels of holocellulose and lignin tended to be high in the center (Maulida *et al.* 2020) (Table 1). Syahidah *et al.* (2007) observed teak wood < 10 cm in diameter from community forests in South Sulawesi and found the highest cellulose content at the top part. The high content of cellulose and lignin in the middle heartwood might be due to variation on specific gravity and juvenility (Ona *et al.* 1998; Rahman *et al.* 2018). Similar pattern was also observed in raru wood (Iswanto *et al.* 2021).

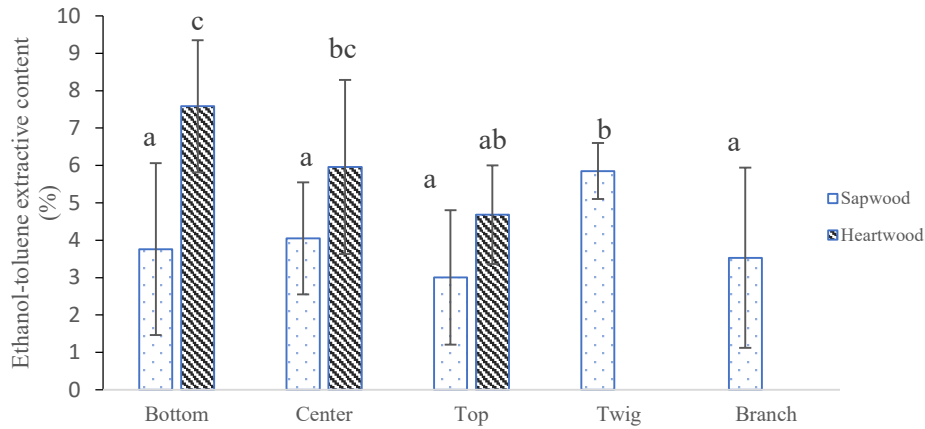


Figure 2. Ethanol-toluene extractive content (% oven dried wood) of Jati Unggul Nusantara (Superior teak) wood by tree part. Average of 3 trees, with the standard deviation error bar. The same letters on the same graphic are not statistically different at  $p < 0.05$  by Tukey's test.

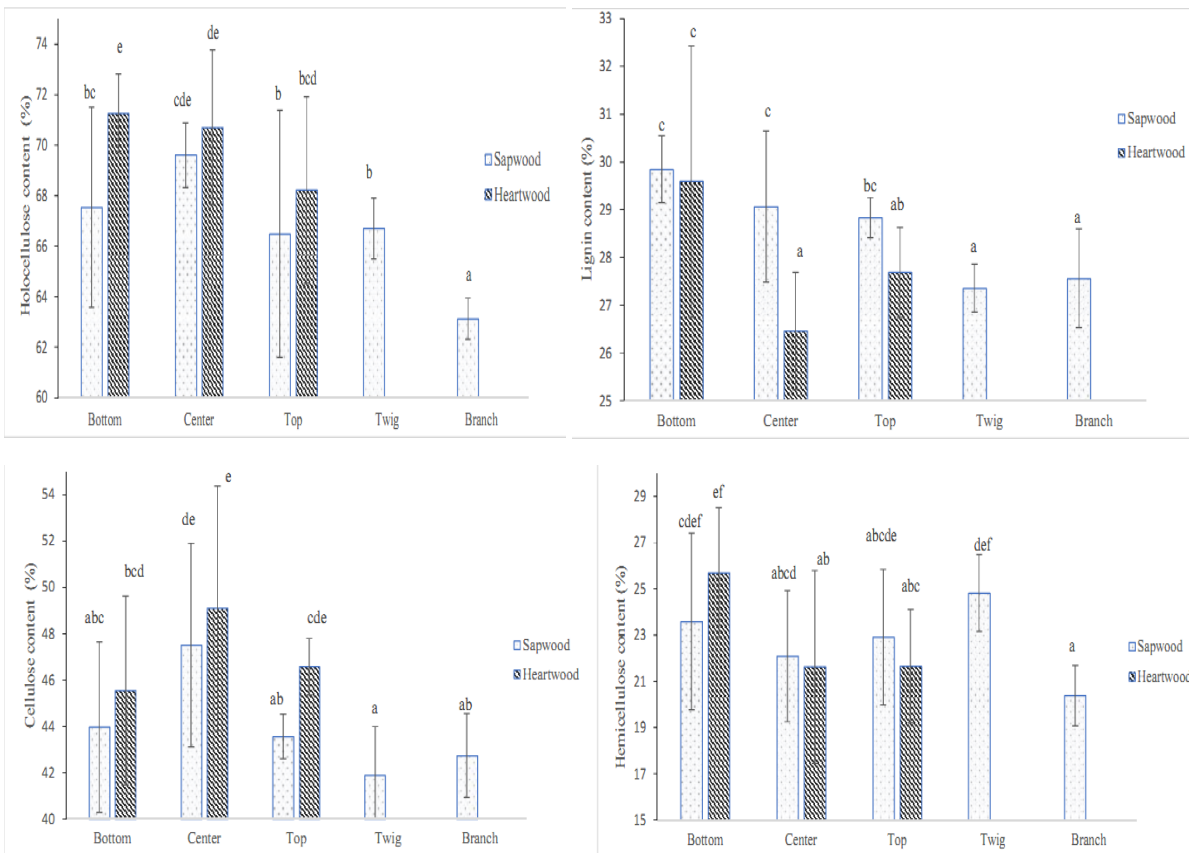


Figure 3. Cell wall component contents (% extractive-free wood) of Jati Unggul Nusantara (Superior teak) wood by tree part. Average of 3 trees, with the standard deviation error bar. The same letters are not statistically different at  $p < 0.05$  by Tukey's test.

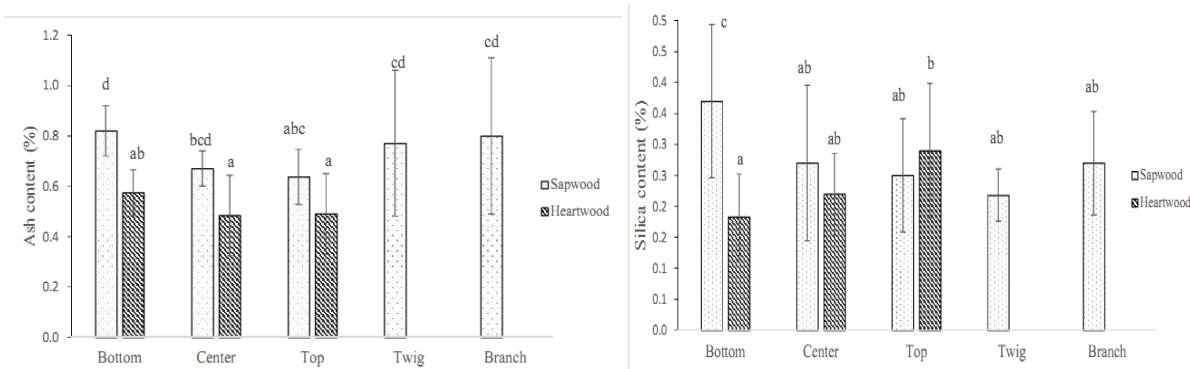


Figure 4. Ash and silica contents (% extractive-free wood) of Jati Unggul Nusantara (Superior teak) wood by tree part. Average of 3 trees, with the standard deviation error bar. The same letters are not statistically different at  $p < 0.05$  by Tukey's test.

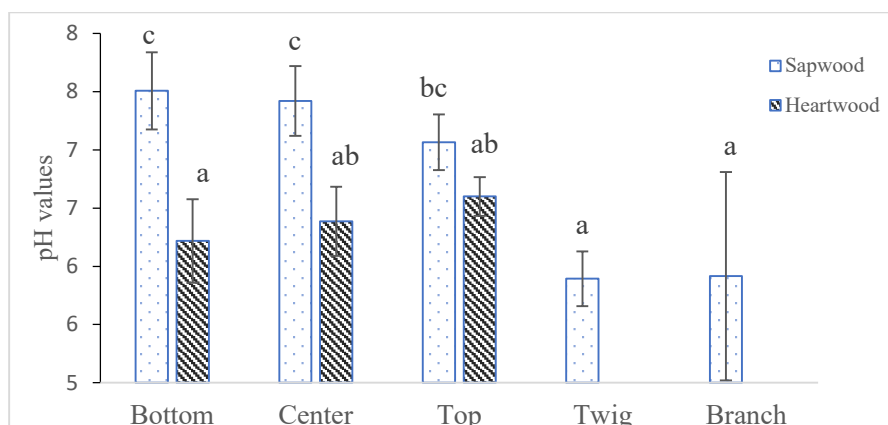


Figure 5. pH values of Jati Unggul Nusantara (Superior teak) wood by tree part. Average of 3 trees, with the standard deviation error bar. The same letters are not statistically different at  $p < 0.05$  by Tukey's test.

Between the main stem and branch parts or the main stem and twig parts, there were significant differences in varied positions for all properties. The values of ethanol-toluene extractive, lignin, holocellulose, cellulose, hemicellulose, silica, and pH in the branches or twigs were generally lower than those in the main stem. The high ash content at the branch and twig parts is caused by the vicinity to the canopy as a place of photosynthesis where metals are necessary during the process. Between the twig and branch parts, statistical differences were observed in ethanol-toluene extractive, holocellulose, and hemicellulose contents, where the twig parts had higher levels in all the aforementioned contents.

Twigs and branches have been utilized for furniture making in the past few years. The different chemical properties between the twig and branch parts and the main stem should be noticed. However, information on twig chemistry is still limited. With regard to main stem and branch parts, these findings were different compared to earlier studies. Hassan *et al.* (2020) found that, in *Pinus halepensis* and *Eucalyptus camaldulensis*, compared to the stem wood, the contents of lignin, extractives, and ash of the branch wood

were higher, but the contents of cellulose and hemicellulose were lower. In *Trema orientalis*, the branch samples consistently had lower cellulose and higher lignin and extractive contents than the stem samples (Jahan *et al.* 2010). A different pattern was observed in plum (*Prunus domestica*), where no significant differences between stem and branch samples in cellulose, lignin, and extractive contents were observed (Kiaei *et al.* 2014). The differences in species, tree age, and site were probably the reasons for the inconsistent patterns.

#### Comparison between Sapwood and Heartwood

By Tukey tests (Fig. 3–5), significant differences between the sapwood and heartwood in the main stem were observed in the contents of ethanol-toluene extractives (bottom and center parts), holocellulose (bottom part), cellulose (top part), lignin (center part), ash (bottom and center parts), and silica (bottom part), as well as in pH values (bottom and center parts). The heartwood part had higher values in ethanol-toluene extractive, holocellulose, and cellulose contents but lower in lignin, ash, silica, and pH

values. Previous research on teak wood showed that there were no significant differences between sapwood and heartwood in holocellulose and  $\alpha$ -cellulose contents (Miranda *et al.* 2011; Lukmandaru *et al.* 2016). Using 50~70-year-old teak from forests in East Timor, Miranda *et al.* (2011) observed no significant difference in lignin content between sapwood and heartwood (32.4% and 32.2%, respectively). It indicates that, in the case of juvenile wood, such as the JUN wood in this study, significant differences exist, but in mature wood, these differences are no longer visible.

The ethanol-toluene extractive content (Fig. 2) showed significant differences between sapwood and heartwood except at the bottom and center parts. A previous work observed that superior teak wood (11 years, JPP) showed significant differences in ethanol soluble extractives in the sapwood and heartwood in all vertical parts of the stem (Zulkahfi *et al.* 2020). The average value of ethanol-toluene extractive content was greater in the heartwood than in the sapwood in Gunungkidul community forest teak (Lukmandaru *et al.* 2016), Indonesian plus teak (Rudman *et al.* 1966), and Panama teak (Windeisen *et al.* 2003). Research related to hot-water solubility found no significant difference between the sapwood and the heartwood. This result is different from the earlier study by Lukmandaru *et al.* (2016), which showed significant differences between the sapwood and the inner and outer heartwood. It is assumed that these differences in value were influenced by the environmental conditions of the stand under observation, the age of the JUN wood, and the extraction method used.

The ash and pH values (Fig. 4 and 5) showed significant differences between the sapwood and the heartwood at the bottom and center parts. These differences might be caused by the age and condition of the stand. Furthermore, there were both similarities and differences between the current patterns and the patterns of plantation teak in ash, silica, and pH values (Lukmandaru and Hidayah 2016; 2018).

### Conclusions

The wood properties of JUN were investigated for the tree parts. Among the main stem parts, significant differences were found in all properties except for hot-water solubility. The values in the branches or twigs were generally lower than those of main stem for ethanol-toluene extractive, lignin, holocellulose, cellulose, hemicellulose, silica, and pH values. Compared to the branch, twig parts had higher levels in ethanol-toluene extractive, holocellulose, and hemicellulose. Compared the sapwood part, the heartwood part had higher values in ethanol-toluene extractive, holocellulose, and cellulose contents but lower in lignin, ash, silica, and pH values. To establish the differences among the tree parts, investigations with more individual samples as well as young teak samples from various locations will be necessary in the next work due to high standard deviation in most parameters in this experiment.

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