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Colour changes of teak wood from three different seed sources to solvent extraction

Abstract

Teak is a highly-sought timber, especially for furniture, due the outstanding quality of the wood. Superior teak has been developed from clonal propagation. Therefore, this study aims to determine the total phenolic content (TPC) and color properties of three seed sources: conventional, superior seed, and superior clone (Jati Plus Perhutani). The materials used in this research were teak trees (15 years) from KPH Ciamis, West Java, and teak trees (65 years) from KPH Madiun for comparison purposes. The wood was successively extracted with n-hexane, methanol, and hot water. Total phenolic content was measured in the extracts soluble in n-hexane and methanol. Using the CIELab system, the color properties before extraction was L* (brightness) = 45.21-67.50; a* (redness) = 8.15-12.75; b* (yellowness) = 23.88-28.54, while after extraction they were L* = 52.53-66.05; a* = 6.62-9.16; b* = 19.77-22.76. Seed sources did not affect the colour properties before and after extraction. The L* and a* values before and after extraction were significantly affected by radial direction. After extraction, in the heartwood region, brightness change (ΔL*) increased, whereas redness (Δa*) and yellowness (Δb*) changes decreased. The total color difference (ΔE*) ranged from 5 to 11. The superior clone had comparatively low ΔL* values in the outer heartwood. Color changes in mature heartwood (control) were higher in ΔL* and lower in a* and b*. The TPC from *n*-hexane and methanol extracts, also its combination, ranged from 61.07-80.21, 118-131.72, and 180.73-211.65 mg GAE/g samples, respectively. Seed sources significantly affected TPC values, with samples from superior seed and superior clone exhibiting higher amounts than those from conventional teak. No systematic pattern was observed between color properties and TPC values.

Keywords: tree breeding, clonal forest, JPP, quinone, radial direction

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Introduction

Teak (*Tectona grandis* L.f.) is a highly utilized timber, particularly for furniture, due to its superior properties. Its outstanding wood quality places its products in a high-priced, luxury category. Rising domestic and export demand for teak products has created an imbalance between supply and demand. This insufficient supply leads to high prices due to long rotations, with a minimum harvest age of 45 years. To overcome these problems, Perum Perhutani, the largest teak wood supplier in Indonesia has developed a fast-growing variety called 'Jati Plus Perhutani' (JPP, superior teak wood) to increase productivity. Conventional teak is propagated generatively from seeds, while JPP is developed through tree breeding by selecting over 600 parent trees, conducting clone trials, and implementing the results at several locations (Cepu, Ciamis, Ngawi, etc.). Several clones with superior growth characteristics were subsequently obtained.[1] JPP, a product of 20 years of breeding, is expected to be an alternative source of teak for industrial raw materials.[2]

Teak wood is valued for its natural durability and high weather resistance but also for its surface appearance, including color and grain. Durability and color properties are primary considerations for consumers in assessing teak wood quality. Beyond its aesthetic value, color properties are important as they can be used to predict teak wood durability[3–6] and extractive content.[7–10] Wood color is influenced by extractive substances, especially phenolic compounds.[11] Wood color stability can be evaluated by solubility pigments through neutral organic solvents. Previous studies on the relationship between color and successive extraction have been conducted on the heartwood of black-streaked teak,[12] *Robinia pseudoacacia,*[13] and pine.[14] Differences in growth rates between clonal and seed regeneration teak might generate various color properties and extractive content. This study aims to compare the color properties and total phenolic content of three seed sources in the radial direction. This study is a continuation of research on the basic properties of JPP wood.[15,16] Its purpose is to optimize wood products by leveraging color properties, either through genetic selection or by reducing defects due to color changes in wood products.

Material and methods

Sample preparation

The materials used in this study were teak wood from three seed sources (15 years) collected from Ciamis KPH, West Java: conventional teak (three trees), superior seed (three trees), and superior clone (four trees). Conventional teak is propagated generatively from common seed, superior seed is propagated generatively from superior teak, while superior clone refers to the JPP variety developed through vegetative propagation (cloning). The average breast height diameter of the superior clone, superior seed, and conventional teak were 31.90, 22.01, and 20.85 cm, respectively. For comparison (control), three teak trees (65 years) were felled from KPH Madiun, East Java. The felled trees were cut into logs, and the bottom part was sampled at 30 cm above the ground. The logs were then processed into 5 cm thick disks. Each disk cross-section, along the radial direction, was divided into three parts: sapwood (±0.5 cm from near the bark), outer heartwood (±1 cm from the sapwood-heartwood border), and inner heartwood (±1 cm from the pith). Drilling was performed in opposite directions to avoid radial variations. Each part was converted into wood powder (40-60 mesh) for analysis of color properties and total phenolic content.

Wood extraction

The wood powder (5 g, oven-dry equivalent) was extracted sequentially with *n*-hexane and methanol using a Soxhlet apparatus for 6 hours, followed by hot water extraction in a water bath for 3 hours at 100°C. Filtrates from *n*-hexane and methanol extraction were evaporated to obtain the dry extract.

Colour properties

Wood color properties were measured using the CIELab system[17] with an NF333 Spectrocolorimeter (Nippon Denshoku). Measurement conditions included a 6 mm aperture diameter, D56 lighting representing sunlight, and a tungsten halogen light source with 10 mm interval. Color measurements were performed on air-dried wood powder before and after extraction. Each sample was measured three times, and the average was recorded. Automatically, three color parameters were obtained: L * (brightness level), a * (redness level), and b * (yellowness level). L * with a scale of 0 (black) - 100 (white), a * with a scale of + (red) and (-) for green, and b * with a scale of (+) yellow and (-) blue. The total color difference (ΔE*) was calculated using formula $(\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2})^{½}$, where ΔL*, Δa* and Δb* are the differences before and after extraction, respectively.

Total phenolic content

Total phenolic content (TPC) was determined in the *n*-hexane and methanol-soluble extracts of inner and outer heartwood using the Folin-Ciocalteu method.[18] The extract was dissolved in methanol (0.5 ml) at a concentration of 50 ppm and mixed with Folin-Ciocalteu reagent (2.5 ml) diluted 10 times, then left for 2 minutes at room temperature. Next, 2 ml of sodium bicarbonate solution (7.5%) was added, and then left for 30 minutes. A blank with a solvent was prepared for comparison. Then, the absorbance was measured at 765 nm using an Optima Nano 3000SP Nano UV-Vis Spectrophotometer. Gallic acid solution (0.5 ml, 0.1-100 mg/ml) was used to construct the calibration curve. Each measurement was performed in triplicate, and the results were averaged. TPC was expressed as milligrams of gallic acid equivalents (mg GAE/g dry extract). The combined TPC was determined by adding the TPC values of the n-hexane extract and methanol extract.

Data analysis

The effects of seed source and radial position were calculated by analysis of variance (ANOVA) GLM procedures followed by Tukey's test ($p = 0.05$). The relationships between the independent variables were studied with a Pearson's correlation analysis. All statistical calculations were conducted using SPSS-Win 16.0

Results and discussion

Colour properties

Colour measurements were conducted before and after extraction with several solvents (Table 1). Before extraction, brightness values (L*) ranged from 60.32–67.50 in sapwood, 45.21–51.91 in outer heartwood, and 47.33–54.34 in inner heartwood. Redness value (a*) in sapwood, outer heartwood, and inner heartwood were 8.15 – 10.28, 12.11 – 12.75, and 11.63 – 12.24, respectively. Yellowness (b*) values in sapwood, outer heartwood, and inner heartwood were 24.19 – 28.32, 24.93 – 25.45, and 23.88 – 28.54 respectively. The L*a*b* values in this study varied greatly from previous reports on superior teakwood grown in Perhutani plantation.[9,10] After sequential extraction, brightness (L*) values ranged from 62.84–66.05 in sapwood, 53.01–57.70 in outer heartwood, and 52.16–57.53 in inner heartwood. Redness (a*) values in sapwood, outer heartwood, and inner heartwood were 6.62 – 8.15, 8.21 – 9.16, and 7.73 – 8.87, respectively. Yellowness (b*) values in sapwood, outer heartwood, and inner heartwood were 20.37 – 22.76, 20.01 – 20.86, and 19.77 – 20.58, respectively.

Table 1 Brightness (L*) of teak wood (15 y) before and after solvent extraction with the standard deviation in parentheses. The same letters are not significantly different at $p < 5\%$ by Tukey's test

Sources	Before extraction			After extraction		
	Sapwood	Outer heartwood	Inner heartwood	Sapwood	Outer heartwood	Inner heartwood
Conventional	67.14 (8.48)	45.21 (6.87)	47.33 (3.70)	66.05 (0.97)	53.01 (6.58)	52.16 (4.62)
Superior seed	67.50 (1.17)	48.29 (6.47)	51.51 (3.92)	63.49 (8.25)	56.36 (5.72)	55.74 (5.31)
Superior clone	60.31 (8.05)	51.91 (3.98)	52.21 (6.84)	62.84 (7.43)	57.70 (3.48)	57.53 (5.16)
Average	64.52 (7.14) b	48.81 (5.81) a	50.35 (4.92) a	64.13 (5.98) c	55.89 (5.02) d	55.15 (4.97) d
Control (65 y)	58.01 (1.27)	43.75 (4.36)	44.54 (3.25)	58.79 (0.15)	53.43 (2.78)	51.86 (2.51)

Two-way ANOVA showed no significant interaction between seed source and radial direction. A significant effect was observed only in the radial direction, with L* and a* values differing significantly between sapwood and heartwood, both before and after extraction. Observations on the same samples showed a similar pattern, with no significant effect of seed source.[16] Tukey's test showed no significant difference between outer and inner heartwood parts. Similar patterns have been reported in previous teak wood studies.[5,9] These findings indicate that pigments responsible for dark and red coloration were largely unaffected by extraction. In contrast, different patterns have been observed in teak grown at various locations.[4,10,19]

ANOVA results indicated that both factors had no significant effect on b* values. This trend was similar to that observed in teak grown in Kulonprogo community forests[5] but differed from trends in other studies.[6,19] The b* color index is primarily influenced by climate and soil properties,[20] which explains the similar b* values observed for teak from the three seed sources planted at the same site. No significant effect of seed source was observed, in contrast to previous studies on teak clones in Costa Rica.[21,22] In addition, other studies[21,23–25] have reported that fast-growing teak exhibits brighter color than conventional teak. These results suggest that teak color is not highly sensitive to the type of regeneration.

The L*a*b values of teak from conventional, superior seed, and superior clone, when compared with control samples (65 years), showed that control teak tended to be darker but had lower red and yellow elements (Table 1–3). This pattern was also observed along the radial direction, likely due to age-related differences between young and mature trees.[8,26] Furthermore, previous research by Moya and Berrocal[27] also indicated that color properties were influenced by environmental conditions or silvicultural treatment.

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Table 2 Redness (a*) of teak wood (15 y) before and after solvent extraction with the standard deviation in parentheses. The same letters are not significantly different at $p < 5\%$ by Tukey's test

Sources	Before extraction			After extraction		
	Sapwood	Outer heartwood	Inner heartwood	Sapwood	Outer heartwood	Inner heartwood
Conventional	8.15 (1.26)	12.19 (0.61)	12.02 (1.29)	6.66 (0.08)	9.16 (0.30)	8.87 (0.67)
Superior seed	9.20 (1.73)	12.75 (1.18)	12.24 (0.46)	6.62 (0.61)	8.52 (0.73)	8.81 (0.44)
Superior clone	10.28 (1.94)	12.11 (0.61)	11.63 (0.88)	8.15 (1.58)	8.21 (0.85)	7.73 (1.19)
Average	9.31 (1.77) a	12.32 (0.72) b	11.96 (0.86) b	7.24 (1.23) c	8.58 (0.74) d	8.39 (0.97) d
Control (65 y)	8.27 (0.20)	10.22 (0.51)	10.89 (0.43)	7.56 (0.49)	8.58 (0.47)	8.93 (0.39)

Table 3 Yellowness (b*) of teak wood (15 y) before and after solvent extraction with the standard deviation in parentheses. The same letters are not significantly different at $p < 5\%$ by Tukey's test

Sources	Before extraction			After extraction		
	Sapwood	Outer heartwood	Inner heartwood	Sapwood	Outer heartwood	Inner heartwood
Conventional	28.32 (3.50)	24.93 (4.25)	23.88 (4.26)	22.76 (2.08)	20.72 (2.39)	19.77 (2.60)
Superior seed	27.89 (0.40)	25.52 (0.75)	24.76 (0.75)	22.07 (1.56)	20.01 (1.91)	20.58 (1.05)
Superior clone	24.19 (2.51)	25.45 (1.66)	26.02 (1.53)	20.37 (1.78)	20.86 (1.45)	20.73 (2.28)
Average	26.53 (2.99)	25.30 (2.26)	24.88 (2.61)	21.59 (1.95)	20.56 (1.71)	20.36 (1.86)
Control (65 y)	24.89 (0.91)	22.80 (2.20)	23.58 (1.15)	23.29 (0.20)	21.26 (1.84)	21.30 (1.61)

Colour changes after extraction

Based on the measured color changes in three parameters (Figure 1–3), the change in each part (ΔL*, Δa*, Δb*) was calculated, and total color change (ΔE*) was obtained as the combined sum. ANOVA results showed a significant interaction of seed source and radial direction for ΔL*. Tukey's test revealed a different pattern in sapwood: brightness increased after extraction in superior clone samples but decreased in conventional and superior seed samples (Figure 1), with the decrease in superior seed samples being greater than in conventional samples. In the heartwood, a significant difference was observed in outer heartwood, where superior clone samples had the lowest increase value (ΔL*=5.79).

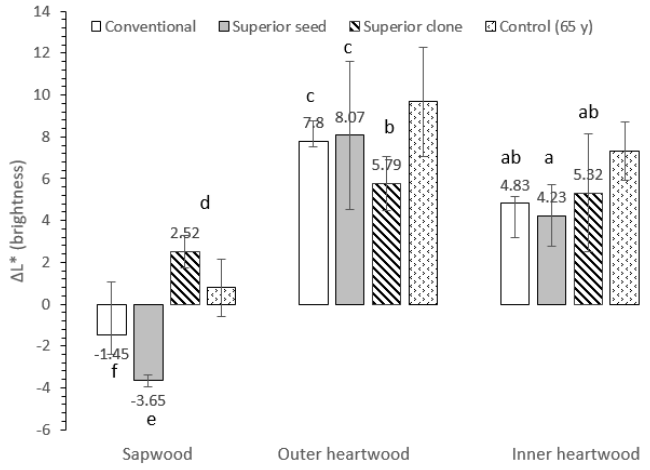

Figure 1 Changes in brightness (ΔL*) of teak wood after extraction with the standard deviation error bar. The same letters are not significantly different at $p < 5\%$ by Tukey's test.

Wood color is heavily affected by phenolic components.[11] The different pattern is probably due to differences in phenolic composition in the sapwood and among seed source samples. However, compared to sapwood, heartwood remains darker even after extraction with organic solvents. Theoretically, this is because of the polymerization of low-molecular-weight substances in the heartwood into higher-molecular-weight colored substances, which are resistant to removal by organic solvents.[17] The highest color change occurred in the outer heartwood from superior seed samples after extraction, with ΔL* increasing by 7.80, resulting in brighter wood. These results align with Pandey's,[28] who reported increased surface brightness after extraction.

The pattern in Δa* values were similar, with a decrease ranging from -0.44 to -5.46. The largest color change occurred in the outer heartwood from superior seed samples, where the reddish color decreased (Δa*=-4.23). ANOVA showed that only radial factor had a significant effect, with heartwood showing a greater decrease than sapwood (Figure 2). Extraction also decreased b* values in all samples, with Δb* ranging from -0.42 to -8.45. The largest average color change occurred in sapwood from superior seed samples, where the yellowish color decreased (Δb*=-5.82). However, ANOVA showed no significant effect of either factor, indicating uniformity of yellow pigments in the samples. Previous studies have shown similar trends: extraction of *Robinia pseudoacacia* wood with polar solvents such as water, ethanol, and dioxane caused a drastic decrease in yellowness but little effect on redness, while extraction with ethanol and dioxane increased brightness.[13] In addition, research on pine sawdust found that ethanol/toluene effectively reduced yellow color, while acetone/water solvents removed most red color.[14]

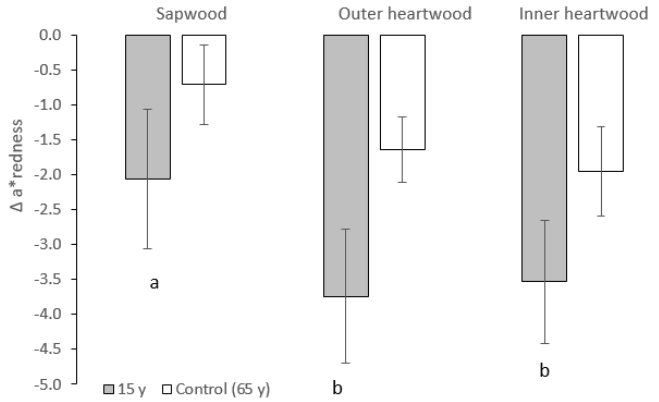

Figure 2 Changes in redness (ΔL*) of teak wood after extraction with the standard deviation error bar. The same letters are not significantly different at $p < 5\%$ by Tukey's test.

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The largest magnitude of color change caused by extraction were ΔL* (2 – 8), then Δb* (3 – 6), and Δa* (2 – 4) respectively. Overall, total color change (ΔE*) ranged from 5 – 11, with values above 3 indicating visually visible color change.[11] The largest ΔE* values were occurred in the outer heartwood of superior seed samples, reflecting the largest ΔL* changes. This aligns with previous observations that ΔL* contributes most color change in normal teak wood.[12] These values also align with ranges reported in earlier studies on normal teak heartwood.

ANOVA indicated that only radial direction significantly affected ΔE*, with outer heartwood exhibiting higher color change than sapwood (Figure 3), indicating higher pigment in the extracted heartwood. Previous studies have shown that color changes in black-streaked teak heartwood are greater than in normal teak wood due to significantly different extractive contents between the two groups.[7] These findings suggest that varying extractive compounds will contribute to various color changes.

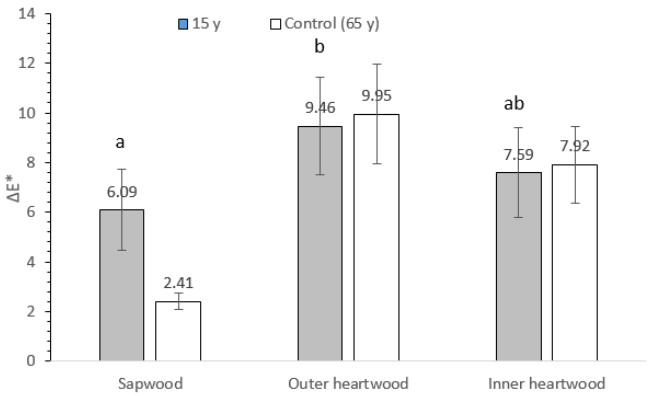

Figure 3 Colour differences (ΔL*) of teak wood after extraction with the standard deviation error bar. The same letters are not significantly different at $p < 5\%$ by Tukey's test.

The L*a*b* change values in the tested samples showed greater color change in sapwood compared with control samples (Figure 1–3), indicating that older trees exhibit smaller sapwood color changes due to extraction. The ΔL* value in the heartwood is higher, while Δa* and Δb* values in control samples are lower. ΔL* remained the largest contributor to color change in both control teak and teak from the three seed sources. ΔE* in heartwood was similar between control and three seed sources samples. In addition, the color trends before and after extraction indicate that control samples remain darker but less red and yellow (Table 1–3). This indicates that some color-causing substances are strongly bound to cell walls or exist as polymeric compounds, depending on seed source and tree age.

For exterior application, it is necessary to pay attention to wood prone to color changes upon water exposure, such as the outer heartwood of superior seed samples (ΔE*=10.81), assuming that ΔE* values above 3 indicate perceptible color change. In addition, wood can also experience color change during processing, such as drying. The advantage of superior clone is its comparatively low ΔL* value in the outer heartwood (Figure 1).

Total phenolic content

Technically, wood color is determined by the presence of phenolic compounds.[17,29] TPC measurements were only performed on heartwood, as phenolic concentration is higher than in sapwood. Measurements were performed on *n*-hexane and methanol soluble extracts, and their combined values were calculated (Table 4). The obtained values were within the range reported for juvenile teak wood extracts[30] but lower when compared to control samples, presumably due to age differences.

Table 4 Total phenolic content (mg GAE/g) of teak wood (15 y) from n-hexane and methanol soluble extracts with the standard deviation in parentheses. The same letters are not significantly different at $p < 5\%$ by Tukey's test

Radial position	*n*-hexane soluble extract			
	Conventional	**Superior seed**	**Superior clone**	**Control (65 y)**
Outer heartwood	66.85 (2.27)	79.94 (2.62)	80.21 (3.78)	98.48 (0.92)
Inner heartwood	61.07 (4.66)	79.37 (4.31)	76.17 (1.58)	94.08 (2.16)
Average	63.96 (4.56) a	79.65 (3.20) b	78.19 (3.44) b	96.28 (2.83)
	methanol soluble extract			
Outer heartwood	118.97 (4.05)	131.72 (8.83)	124.50 (18.52)	173.63 (1.54)
Inner heartwood	119.66 (1.44)	125.32 (8.37)	124.78 (14.69)	169.49 (2.71)
Average	119.32 (2.75)	128.52 (8.45)	124.64 (15.47)	171.56 (3.00)
	n-hexane+ methanol soluble extract			
Outer heartwood	185.83 (2.73)	211.65 (10.21)	204.71 (21.70)	272.11 ()
Inner heartwood	180.73 (6.00)	204.69 (11.21)	200.95 (15.38)	263.57 (1.75)
Average	183.28 (5.01) a	208.17 (10.32) b	202.83 (17.53) b	267.84 (4.99)

Remarks: GAE = gallic acid equivalent

ANOVA showed that seed source significantly affected TPC values in n-hexane and combined extracts. Superior seed and clone samples were not significantly different but had higher TPC values than conventional samples. Radial direction also significantly affected *n*-hexane TPC, with the outer heartwood yielding higher values than inner heartwood (76.12 vs. 72.60 mg GAE/g). High TPC values are beneficial for wood durability due to the toxic quinone compounds in teak extract.[31–33]

Pearson's correlation calculations (data not shown) revealed no significant correlation between TPC and color properties. This contrasts with a study on 11-year-old superior teak, which found a significant correlation between TPC and a* values.[10] A strong correlation between a* and phenolic compound levels have also been observed in *Larix* sp. heartwood.[34] This suggests that, in addition to total extractive contents, wood color is quantitatively affected by certain compounds. Several extractive components, particularly

phenolic compounds from the quinone group, have been detected in teak wood.[35–37] However, this study did not examine individual component level, highlighting the need for further research on the components that influence teak heartwood color.

Conclusion

Seed source did not significantly affect wood color properties before or after extraction. Superior clone wood (JPP) exhibited lower brightness change values (ΔL*) in the outer heartwood. Furthermore, superior clones had significantly higher TPC levels than conventional teak. However, no significant correlation was observed between TPC and color properties, indicating that the contribution of phenolic components to teak color warrants further investigation.

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Conflicts of interest

The authors declare that there are no conflicts of interest.

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