Baghdad Science Journal

Volume 23 | Issue 1 Article 7

1-1-2026

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How to Cite this Article

Yunianti, Andi Detti; SSuhasman, S; Pangestu, Kidung Tirtayasa Putra; Muthmainnah, Muthmainnah; Hapid, Abdul; Pari, Gustan; and Efiyanti, Lisna (2026) "Sappan and Tingi Wood as a Dye for Gmelina (*Gmelina arborea* Roxb.) and Lento-Lento Wood (*Arthrophillum diversifollium*) at Different Coloring Duration," *Baghdad Science Journal*: Vol. 23: Iss. 1, Article 7.
DOI: https://doi.org/10.21123/2411-7986.5148

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BAGHDAD SCIENCE JOURNAL 2026;23(1):84–94

SPECIAL ISSUE ARTICLE

Sappan and Tingi Wood as a Dye for Gmelina (*Gmelina arborea* Roxb.) and Lento-Lento Wood (*Arthrophillum diversifollium*) at Different Coloring Duration

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ABSTRACT

This study investigates the effects of dyeing duration and soaking pre-treatment on the coloring performance of Sappan (*Caesalpinia sappan*) and Tingi (*Ceriops candolleana*) dyes applied to Gmelina (*Gmelina arborea* Roxb.) and Lento-lento (*Arthrophyllum diversifolium*) woods. Test samples were prepared, pre-treated by soaking at 80°C for 24 hours to remove extractives of the wood, and then colored using Sappan and Tingi dyes at 80°C for 6 and 12 hours. The depth of dye penetration was measured using a stereo microscope, and color variations were assessed using the CIELab color space. Gas chromatography-mass spectrometry (GCMS) was employed to analyze the constituents of the wood, dye material, and colored wood. The results indicated that Sappan dye exhibited greater penetration compared to Tingi dye in both wood types, with deeper penetration in Gmelina than Lento-lento wood. Interestingly, both dyes penetrated more effectively during a 6-hour dyeing period than a 12-hour one. Pre-treatment did not significantly influence dye penetration depth. Color analysis revealed that both dyes imparted a strong red color to the wood, with Sappan producing a more intense red and Tingi exhibiting a yellowish tint. GCMS analysis confirmed the presence of flavonoids, polyphenols, and phenolic compounds in the colored wood samples. These findings contribute to the optimization of natural dyeing techniques for sustainable woodcraft applications.

Keywords: Coloring, Duration, Gmelina, Lento-lento, Sappan

Introduction

The growing interest in sustainable and eco-friendly materials has led to a resurgence in the use of natural dyes for wood coloring, particularly in artisanal and decorative applications. Among the promising candidates for such treatments are gmelina (*Gmelina arborea* Roxb.) and lento-lento (*Arthrophyllum diversifolium*) wood, both of which are native to Southeast Asia and valued for their workability.

Gmelina is a fast-growing deciduous tree widely cultivated in tropical regions. It is appreciated for its light-colored heartwood, ranging from pale yellow to golden brown, and its straight grain, which makes it ideal for carving. Despite its ease of processing, Gmelina wood suffers from low natural durability and susceptibility to decay, limiting its use in high-end applications. However, its porous structure and low density make it an excellent candidate for dye impregnation, especially when pre-treated to

Received 13 March 2025; revised 29 June 2025; accepted 5 July 2025.
Available online 1 January 2026

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International Conference on Discoveries in Applied Sciences and Applied Technology (DASAT2025)
https://doi.org/10.21123/2411-7986.5148

enhance permeability. On the other hand, Lento-lento wood, though less documented in international literature, is locally recognized in parts of Indonesia for its moderate density. Its compatibility with natural dyes and potential for aesthetic enhancement through coloring treatments warrant further scientific exploration.

Generally, there are two types of dyes: natural dyes and synthetic dyes. Coloring using natural materials has been widely developed in textiles, batik, and wood. Natural dyes have better biodegradability properties and generally have high compatibility with the environment. In addition, natural dyes are non-toxic, non-allergenic to the skin, non-carcinogenic, readily available, renewable, and environmentally friendly.[1–3]

Natural coloring commonly used in making batik on mori cloth uses sappan and jambal (*Pelthoporum pterocarpum*) extracts,[4] and producing eco prints uses sappan, tingi, tegeran, and mangosteen skin.[5] The use of natural dyes on wood has been carried out in a previous study on tanned bark extract on red jabon wood; the color change occurs from light grey to reddish-orange.[6] Meanwhile, another study used acacia bark, mangosteen bark, and mangrove bark extracts on Sengon wood; the color change occurred from white (8/1) and then changed successively to reddish yellow (7/8), pale red (7/2), and light red (7/6).[7] Previous research using sappan and tegeran wood natural dyes on gmelina, pine, and jabon wood showed that the depth of distribution of sappan wood dye (179.70 μm to 897.94 μm) was better than tegeran wood dye (67.82 μm to 475.37 μm).[8–10] Coloring fabrics was reported using natural dyes from kesumba keling (*Bixa orellana*) seed and sappan (*Caesalpinia sappan* Linn) wood.[11] The results indicated that the depth of dye from Kesumba keling seeds was greater than that of dye from Indigofera leaves. Other research shows that the best soaking duration using synthetic dyes (Dylon) is 6 hours at 100°C on pine and gmelina wood,[12] while the distribution of dye material is only on the surface of the wood because the dye particle size is larger than the micro pores and cavities of wood cells, so that the dye material cannot absorb deeper.[13] Natural dyes derived from Sappan wood (*Caesalpinia sappan*) and Tingi wood (*Cudrania javanensis*) have long been used in traditional Indonesian crafts. Sappan wood yields a rich red dye known for its antioxidant and antimicrobial properties, while Tingi wood produces a yellowish-brown hue.[6] These dyes are biodegradable, non-toxic, and environmentally friendly, aligning with the principles of green chemistry.

A series of studies that have been conducted show the need for development in coloring methods as an effort to make the distribution of dyes broader and more profound. Recent studies have demonstrated the effectiveness of soaking pre-treatment in improving dye uptake in wood substrates. For instance, it showed that pretreated Gmelina wood by soaking at 80°C for 24 hours exhibited significantly enhanced dye penetration when immersed in Sappan and Tingi dye solutions for extended durations.[6] The anatomical features of Gmelina, such as vessel lumen diameter and fibre structure, were found to influence dye absorption, with amorphous dye structures like those from Sappan penetrating more deeply. Hot soaking is done to remove extractive substances contained in the cell cavities in the wood so that the permeability of the wood increases, facilitating the absorption of dyes into the wood.

Despite these promising findings, comparative studies involving multiple wood types and dyeing parameters remain limited. This study aims to fill that gap by investigating the effects of dyeing duration and soaking pre-treatment on the coloring performance of Sappan and Tingi dyes applied to Gmelina and Lento-lento woods. By evaluating color intensity, uniformity, and dye retention, this research seeks to optimize natural dyeing techniques for broader application in sustainable woodcraft.

Materials and methods

Preparation of research materials

The materials utilized in this study comprised Gmelina and Lento-Lento wood boards, sourced from the sawmill industry, with dimensions of 3 cm (T) x 20 cm (L) x 100 cm (P). Test samples were prepared by cutting the boards into dimensions of 2 cm x 5 cm x 20 cm for each wood type, with four replicates. The samples were initially weighed and subsequently dried in an oven at 103°C for a duration of 24 hours. Following this, the samples were conditioned in a desiccator for approximately 15 minutes and then reweighed to determine the water content. This procedure was implemented to ensure uniform conditioning of the sample state.

The natural dyes utilized in this study were derived from sappan wood (*Caesalpinia sappan*) and tingi wood (*Ceriops candolleana*). Initially, these raw materials were reduced to smaller fragments and subsequently pulverized using a hammermill. The resulting powder was then subjected to a multilevel sieving process to achieve a particle size range of 100-230 mesh. Thereafter, the dye powder was dissolved in distilled water at a ratio of 1:7 (300 g : 2100 ml), rendering it suitable for application as a dye.

Research procedure

In this study, a heat-soaking pre-treatment was conducted before wood coloring to eliminate extractive substances present in the cell cavities of the wood, thereby enhancing the wood's permeability and facilitating dye absorption. The soaking process was performed at 80 °C for 24 hours. Subsequently, the samples were drained and permitted to dry naturally until they attained an air-dry moisture content of approximately 12%. Furthermore, the test samples were colored by soaking in a water bath using sappan and tingi at 80°C for 6 and 12 hours. Following the dyeing process, the samples were drained and allowed to dry naturally at room temperature for 24 hours, after which fixation was performed. Fixation is a crucial step in the dyeing process, intended to ensure the retention of dye within the wood fibres, thereby preventing rapid color fading. In this study, alum was employed as the fixation agent, as referenced in a previous study.[14] The fixation process involved immersing the colored wood samples in an alum solution, prepared with a concentration of 30 g of alum per 1 liter of water,[7] at room temperature for 24 hours. Test samples that have been fixed were drained and permitted to dry naturally until they attained an air-dry moisture content of approximately 12%.

Measurement and observation of results

The successful penetration of dye into the wood was assessed through both physical and chemical observations. The physical assessment involved determining the depth of dye penetration and observing any resultant color changes. The depth of dye penetration was measured by sectioning the colored test samples using a table saw, with cuts made at 1 cm intervals from the surface of the sample in the axial, radial, and tangential planes. The depth of dye penetration was then observed and measured using a stereo microscope with a magnification of 5x on each side of the cut, and the results were averaged.

Color variations in the samples were assessed utilizing the CIELab color space. The determination of color values in colored Gmelina and Lento-Lento wood was achieved by identifying three coordinates: L* for lightness, a* for the red-green axis (with negative values indicating green and positive values indicating red), and b* for the yellow-blue axis (with negative values indicating blue and positive values indicating yellow). Additionally, the transformation of color type was examined by converting the L*, a*, and b* values into RGB format both before and after the coloring process using the online tool available at https://products.aspose.app/svg/id/color-converter/lab-to-rgb.com to obtain the color code. The acquired color code was subsequently matched with the color table on page.[11]

Furthermore, gas chromatography-mass spectrometry (GCMS) was employed to analyze the constituents of the wood, dye material, and colored wood. This analysis aims to assess the effectiveness of the coloring process, as indicated by the presence of both wood elements and dyes within the colored wood.

Data analysis

The findings of the study were analyzed and presented through a randomized complete factorial design, with the results displayed in tables and figures.

Results and discussion

Depth of dye

The data presented in Fig. 1 indicate that sappan dye exhibits a greater propensity for deeper penetration in comparison to tingi dye when applied to gmelina and lento-lento wood. The deeper penetration of sappan dye compared to tingi dye in wood can be attributed to several factors linked to the chemical composition and structural properties of the dyes derived from their respective plants. Sappan contains brazilin, a significant phenolic compound, which exhibits a good affinity for different substrates due to its chemical structure.[15] This compound is known for its versatility and compatibility with various materials, making it a prominent choice for natural dyeing applications. Furthermore, the molecular structure of brazilin from sappan wood allows it to interact more effectively with wood fibers. This interaction is facilitated by the presence of multiple hydroxyl groups in the brazilin molecule, which can form hydrogen bonds with cellulose in the wood, enhancing the penetration and retention of the dye.[16]

In contrast, tingi dyes, which are likely composed of different phenolic structures, may not possess the same affinity or ability to form such stable interactions with wood fibers, resulting in less dye penetration. The environmental conditions, such as pH and temperature, also play a role in dye stability and penetration. Studies have shown that the stability of phenolic compounds like brazilin can be sensitive to pH, which might affect their ability to penetrate substrates under different conditions.[16]

Fig. 1 illustrates that sappan dye penetrates more deeply into gmelina wood than into lento-lento wood. In contrast, tingi dye shows greater penetration in

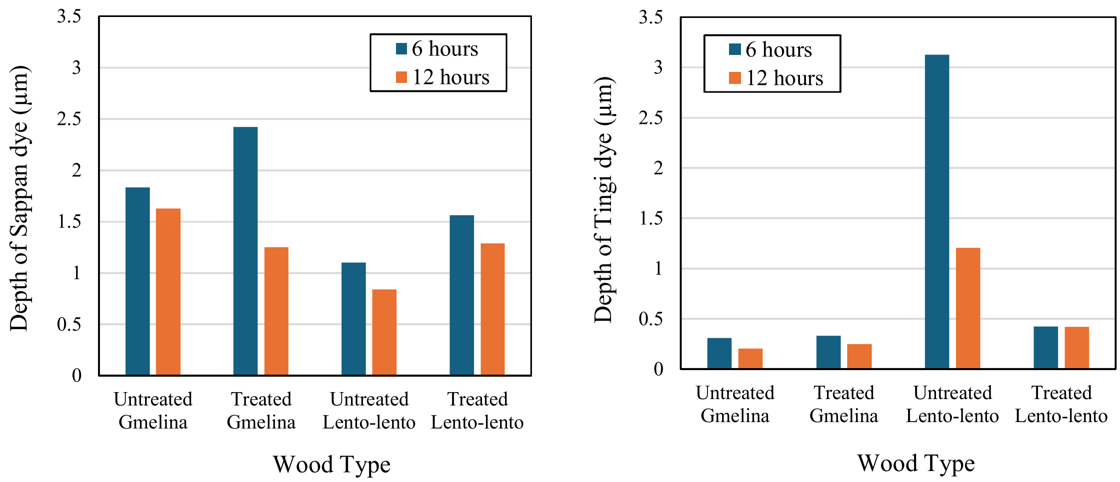

Fig. 1. Depth of sappan (left) and tingi (right) dyes on gmelina and lento-lento wood.

Table 1. Statistical test results of the depth of sappan dye on gmelina wood.

Source of Diversity	Total Sum of Squares	Free Degree	Center Square	F Count	Sig.
Initial Treatment	0.034	1	0.034	0.093	0.768
Length of Coloring	0.697	1	0.697	1.917	0.204
Interaction of pre-treatment and duration of Coloring	1.419	1	1.419	3.902	0.084
Error	2.909	8	0.364		
Total	5.058	11			

Notes: R-squared = 0.425 (adjusted R-squared = 0.209); the depth of sappan dye is the dependent variable.

lento-lento wood compared to gmelina wood. This unique phenomenon indicates that the penetration of a substance into wood is influenced not only by the wood's inherent characteristics[17] and the properties of the substance itself,[18] but also by the interaction between the wood and the dye, which determines their binding strength and retention of the dye.

Fig. 1 highlights a notable trend where both sappan and tingi dyes penetrate more effectively during a 6-hour dyeing period than a 12-hour one. This unique pattern was consistent across all wood samples in the study. The likely reason for this is that during the 6-hour process, the dye quickly infiltrates the wood through pores and microscopic channels. In contrast, during the 12-hour immersion, the wood may absorb water, initially allowing for easier dye entry. However, over time, water evaporation might occur, affecting penetration. If water evaporates during prolonged soaking, the dye on the wood's surface may become more concentrated, but the reduced water volume limits the dye's ability to penetrate deeper into the wood fibers. Dye absorption follows the principle of diffusion, where the dye moves from an area of high concentration (in the dye liquor) to an area of low concentration (in the wood). This process is faster at the start of soaking, but as it continues, the concentration gradient between the dye outside and inside the wood decreases, slowing diffusion. During the first 6 hours, the concentration gradient remains significant, speeding up diffusion. After 12 hours, this gradient lessens, resulting in slower diffusion and, consequently, less dye entering the wood.

It appears that the pre-treatment of gmelina and lento-lento wood through high-temperature soaking does not significantly influence the penetration depth of sappan and tingi dyes into the wood. The dye penetration results, showing no discernible pattern, support this conclusion. These findings further elucidate that the efficacy of dye penetration into wood is contingent not only upon the extent of dye infiltration but also on the strength of the bond between the dye and the wood's chemical constituents.

Tables 1 to 4 present the results of statistical tests on the depth of Sappan and Tingi dyes on Gmelina and Lento-Lento wood.

The test results showed that neither the pre-treatment nor the duration of the coloring process significantly affected the depth of sappan dye on Gmelina wood. The interaction between pre-treatment and duration of the coloring process showed a significant value of 0.084, close to 0.05, but not strong enough to be considered significant at the 5% level.

The test results showed that pre-treatment and the interaction between pre-treatment and the length of the coloring duration did not significantly affect the

Table 2. Statistical test results of the depth of the tingi dye in Gmelina wood.

Source of Diversity	Total Sum of Squares	Free Degree	Center Square	F Count	Sig.
Pre-treatment	0.004	1	0.004	2.951	0.124
Duration of Coloring	0.027	1	0.027	20.911	0.002*
Interaction of pre-treatment and duration of Coloring	0.000	1	0.000	0.328	0.583
Error	0.010	8	0.001		
Total	0.041	11			

Notes: R-squared = 0.751 (adjusted R-squared = 0.658); the depth of the tingi dye is the dependent variable.

Table 3. Statistical test results of the depth of sappan dye on lento-lento wood.

Source of Diversity	Total Sum of Squares	Free Degree	Center Square	F Count	Sig.
Pre-treatment	0.620	1	0.620	1.958	0.199
Duration of Coloring	0.215	1	0.215	0.679	0.434
Interaction of pre-treatment and duration of Coloring	0.000	1	0.000	0.000	0.983
Error	2.533	8	0.317		
Total	3.369	11			

Notes: R-squared = 0.248 (adjusted R-squared = 0.034); the depth of sappan dye is the dependent variable.

depth of the high dye on Gmelina wood. However, the soaking length significantly affects the depth of Tingi dye (p-value < 0.05). The test results showed that, before treatment, the length of the coloring and the interaction between the two did not significantly affect the depth of the sappan dye on Lento-lento wood.

The test results indicate that pre-treatment and the length of the dyeing process significantly affect the depth of Tingi dye in Lento-lento wood. A p-value smaller than 0.05 indicates that the interaction between conditioning and soaking duration significantly affects the depth of Tingi dyes. This means that the immersion duration influences the conditioning effect on the depth of Tingi dye and vice versa.

Color change

The color changes of untreated and treated Gmelina and Lento-Lento wood were presented in Figs. 2 and 3. Visual observation in Fig. 2 indicated no perceptible color changes in gmelina and lento-lento wood following pretreatment. Furthermore, variations in the duration of coloring did not appear to result in any observable color changes. The most notable observation is the color transformation before and after the coloring process in both gmelina and lento-lento woods. Post-coloring with sappan and tingi, the wood exhibited a distinct shift to a reddish hue. The reddish coloration resulting from coloring with sappan is more pronounced, whereas coloring with tingi imparts a slightly more yellowish tone.

The findings depicted in Fig. 3 reveal that the pretreatments did not show any significant differences in the L*, a*, and b* values. The most notable color changes occurred before and after the dyeing process. Before dyeing, the high L* values in both gmelina and lento-lento wood indicated a light wood color, while the low positive a* and b* values suggested that the color of gmelina and lento-lento wood fell within a warm and soft spectrum. After the dyeing process, the lightness (L*) of both wood types decreased significantly. In contrast, the positive a* value, which indicates a red hue, increased sharply. The positive b* value, representing yellow, also rose, though not as dramatically as the a* value. This pattern was consistent across all wood types and dyes examined in this study, demonstrating that both sappan and tingi dyes imparted a strong red color effect on the dyed wood.

The changes in a* values for gmelina wood dyed with sappan and tingi are almost similar. However, the a* value for lento-lento wood dyed with sappan

Table 4. Statistical test results of tingi dye depth on lento-lento wood.

Source of Diversity	Total Sum of Squares	Free Degree	Center Square	F Count	Sig.
Pre-treatment	9.118	1	9.118	55.487	0.000*
Duration of Coloring	2.771	1	2.771	16.861	0.003*
Interaction of pre-treatment and duration of Coloring	2.755	1	2.755	16.767	0.003*
Error	1.315	8	0.164		
Total	15.958	11			

Notes: R-squared = 0.918 (adjusted R-squared = 0.887); the depth of tingi dye is the dependent variable.

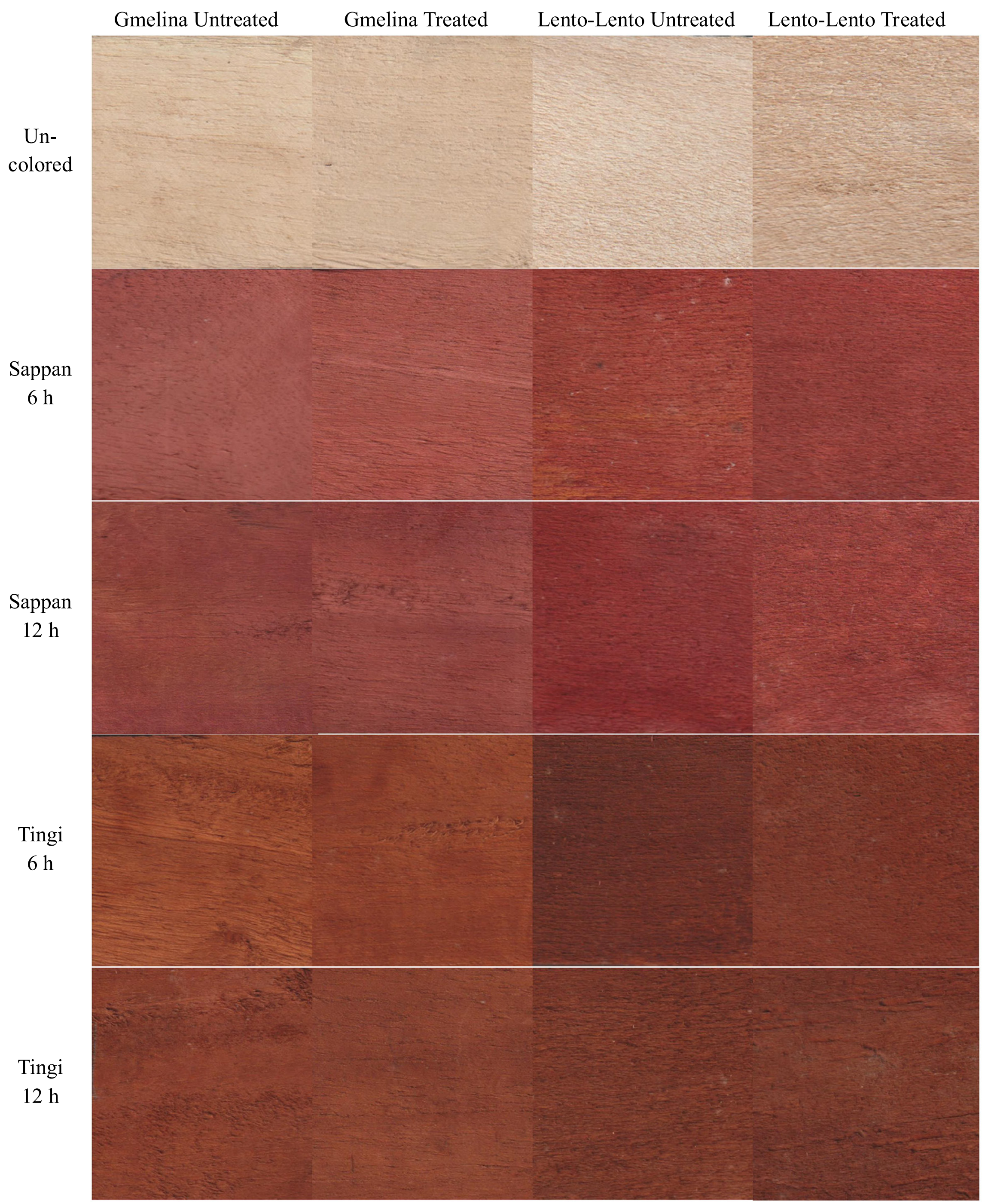

Fig. 2. The color appearance of Gmelina and Lento-lento wood changes after coloring.

is higher than that for tingi. In contrast, the b* values for lento-lento wood dyed with sappan and tingi are similar, while in gmelina wood, the b* value for tingi dye surpasses that for sappan. The findings suggest two primary observations. Firstly, both sappan and tingi dyes impart a red hue to gmelina and lento-lento wood. Notably, sappan produces a more intense red, whereas the red from tingi exhibits a yellowish tint. Secondly, the two wood types, gmelina and lento-lento, demonstrate distinct responses in color change when exposed to these dyes.

The variations in lignin, cellulose, hemicellulose, and extractives among wood types influence their interaction with dyes. For instance, thermal modifications can alter the chemical composition, leading to changes in a* and b* values. Specifically, in

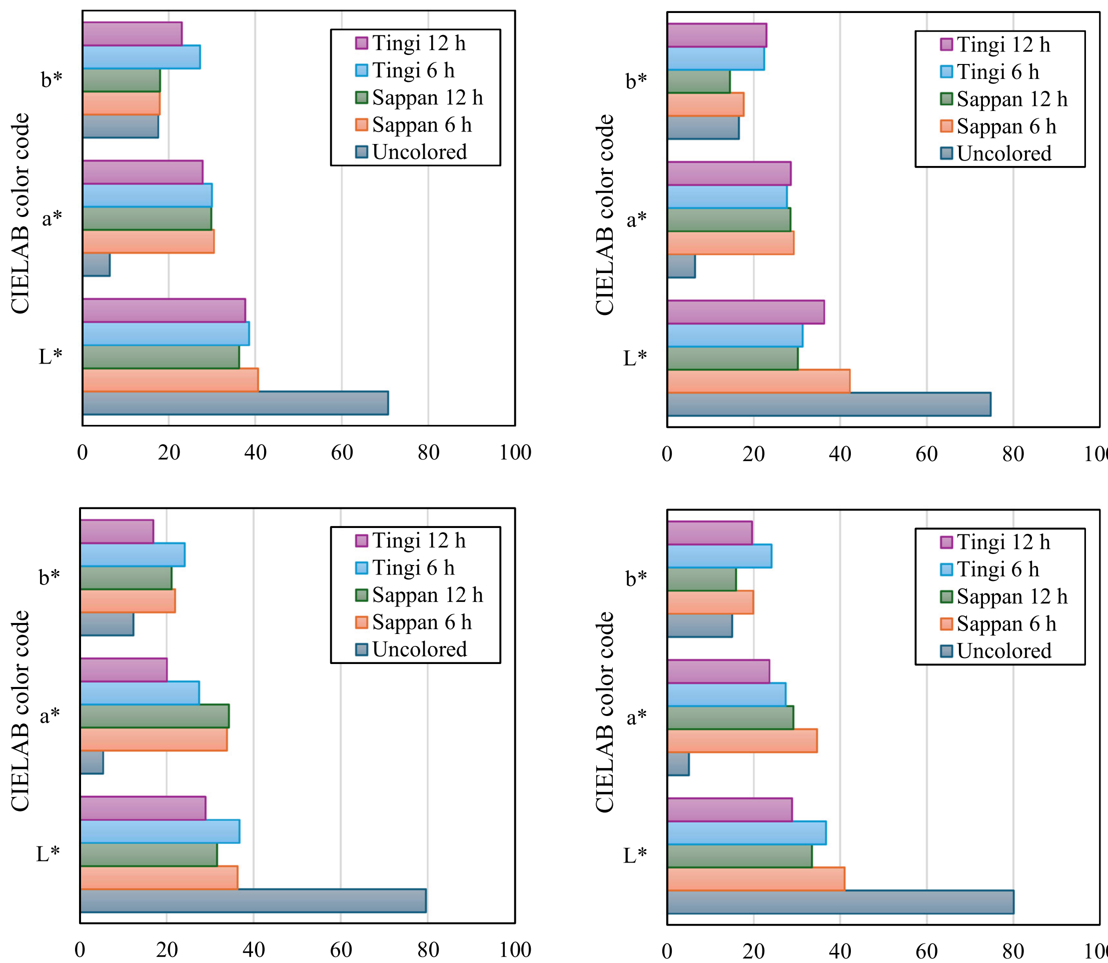

Fig. 3. The L*, a*, b* changes of untreated (left) and treated (right) Gmelina (up) and Lento-Lento (down) wood.

spruce and oak woods, thermal treatment modifies the composition of lignin and cellulose, affecting their interaction with stains and resulting in varied color outcomes.[19] Additionally, the physical structure of the wood, including porosity and grain patterns, affects dye penetration and absorption. Studies on furfurylated and acetylated treatments have shown that wood porosity significantly impacts coloring outcomes, as more porous woods may allow deeper penetration and more uniform color distribution compared to less porous ones.[20]

The results depicted in Fig. 3 indicate that the L*, a*, and b* values for gmelina and lento-lento wood dyed for 6 hours are generally higher than those for wood dyed for 12 hours. This phenomenon is similar to the results shown in Fig. 1, where sappan and tingi dyes penetrate gmelina and lento-lento wood more effectively with a coloring duration of 6 hours rather than 12 hours. It can be inferred that greater dye penetration leads to more vivid and intense coloration.

The phenomenon discussed above can be attributed to several factors. Initially, during the dyeing process, the dye predominantly affects the wood's surface layer, resulting in elevated L* values and more vivid a* and b* chromaticity values. However, as the soaking time extends beyond a certain threshold, the dye begins to penetrate deeper into the wood fibers. This deeper penetration may reduce the overall dye concentration at the surface, leading to a shift in the color values.[21,22] Additionally, prolonged soaking times might lead to over-saturation, where the wood fibers reach their maximum dye uptake capacity. Beyond this saturation point, further soaking does not increase dye uptake but may slightly dilute the surface concentration of the dye. This could affect the apparent color intensity, resulting in lower L*, a*, and b* values after 12 hours of soaking.[22] Furthermore, the interaction between the dye and wood could become more complex with longer soaking times, potentially resulting in chemical changes or rearrangements that affect color perception. Certain dyes might exhibit

Table 5. Results of GCMS analysis of gmelina wood with sappan dye.

Peak#	R.Time	Area	Area%	Name
1	14.184	6712966	0.12	3-Methyl Hydantoin
2	14.834	50728903	0.90	Phenol, 2-Methoxy- (CAS) Guaiacol
3	14.975	25642321	0.46	Phenol, 4-Methoxy- (CAS) Hqmme
4	15.817	13004020	0.23	2-Methoxy-4-Methylphenoi
5	15.948	113064018	2.01	2-Methoxy-4-Methyiphenoi
6	19.054	40576871	0.72	Benzaldehyde, 4-Hydroxy-3-Methoxy- (CAS) Vanillin
7	19.651	42512722	0.76	Ethanone, 1-(4-Hydroxy-3-Methoxyphenyl)- (CAS) Acetovanillone

Table 6. Results of GCMS analysis of gmelina wood with tingi dye.

Peak#	R.Time	Area	Area%	Name
1	15.919	113506399	1.78	2-Methoxy-4-Methyiphenoi
2	18.499	128991184	2.02	Benzene, 1,2,3-Trimethoxy- (CAS) 1,2,3-Trimethoxybenzene (CAS) Methylsyringol
3	19.075	3294665	0.05	Benzaldehyde, 4-Hydroxy-3-Methoxy- (CAS) Vanillin
4	19.775	162643369	2.54	2-Propanone, 1-(4-Hydroxy-3-Methoxyphenyi)- (CAS) 1-(4-Hydroxy-3-Methoxy-F
5	20.333	180325859	2.82	Benzaldehyde, 4-(Acetyloxy)-3-Methoxy- (CAS) Vanillin Acetate

altered binding characteristics over extended periods, which could translate into lower or altered color metric values.[23]

Sappan wood is a plant that contains active compounds such as flavonoids, alkaloids, brazilin, tannin, saponins, phenylpropane, and terpenoids that can be used for natural coloring.[24] Parts of sappan wood that produce bright red, brown, and mauve colors and can be used as a natural dye are the stems, bark, and pods, while the roots can produce a yellow color. The natural red pigment in sappan wood is produced by brazilin, which acts as an active compound. According to a previous study,[15] Brazilin ($C_{16}H_{14}O_5$) is a yellow crystal, a color pigment in sappan. Brazilin is a class of flavonoids, such as isoflavonoids, which produce reddish-brown and dark red when dissolved in hot water. Brazilin can produce a pale yellow when mixed with ether and alcohol. Oxidized brazilin will quickly form a brownish-red color,[25] and the formation of brazilin causes the red color. Apart from brazilin, there are anthocyanins, which are natural dyes belonging to the flavonoid group and produce a red color. Anthocyanins are amphoteric compounds that can react under acidic or alkaline conditions. The proper solvent and concentration influence the color produced by anthocyanins to produce colors of better quality during extraction.

Apart from that, the brown color comes from the tannin content of sappan wood, around 44%. Colored wood with sappan tends to be reddish, while colored wood with tingi tends to be reddish brown. According to a previous study,[26] Tingi is an Indonesian plant that has the potential to be used as a natural textile dye. The tannin content of tingi bark varies from 13% to 40%. Tannins from soga tingi bark belong to the procyanidin-type condensed tannin group, so tingi is reddish brown.[27]

GCMS analysis results

Table 5 shows that gmelina wood colored with sappan contains flavonoids, polyphenols, and phenolic compounds, for example, brazilin, flavonoids, tannins, saponins, alkaloids, and steroids. Brazilin gives a red color to wood if it is oxidized to Brazilein.

Table 6 shows that Gmelina wood colored with Tingi generally contains anthocyanins, flavonoids, which are phenolic compounds; tannins, which are polyphenolic compounds; citric acid and malic acid; saponins, which are glycoside compounds; essential oils and carbohydrates (starch and sugar).

Table 7 shows that the same as Gmelina wood colored with Sappan, Lento-lento wood colored

Table 7. Results of GCMS analysis of lento-lento wood with sappan dye.

Peak#	R.Time	Area	Area%	Name
1	15.310	168106950	3.88	2-Furanmethanol (CAS) Furfuryl Alcohol
2	17.901	121503186	2.81	Phenol, 2,6-Dimethoxy- (CAS) 2,6-Dimethoxyphenol
3	19.261	67000256	1.55	Benzeneacetic Acid, 4-Hydroxy-3-Methoxy- (CAS) Homovanillic Acid
4	19.908	46896283	1.08	Phenol, 2,6-Dimethoxy-4-(2-Propenyi)- (CAS) 4-Aiiyi-2,6-Dimethoxyphenoi
5	22.177	17846985	0.41	Ethanone, 1-(4-Hydroxy-3,5-Dimethoxyphenyl)- (CAS) Acetosyringone

Table 8. Results of GCMS analysis of lento-lento wood with tingi dye.

Peak#	R.Time	Area	Area%	Name
1	14.979	33198431	0.83	Phenol, 2-methoxy- (CAS) Guaiacol
2	15.669	34126878	0.85	Phenol, 4-methyl- (CAS) p-CresoI
3	16.311	172523101	4.30	Heptanal (CAS) n-Heptanal
4	17,923	52893522	1.32	Phenol, 2,6-dimethoxy- (CAS) 2,6-DimethoxyphenoI
5	19,836	67114603	1.67	2-Propanone, 1-(4-hydroxy-3-methoxyphenyl)- (CAS) 1-(4-Hydroxy-3-Methoxy-F
6	22.125	54171053	1.35	Ethanone, 1-(4-hydroxy-3,5-dimethoxyphenyl)- (CAS) Acetosyringone

with sappan, generally contain flavonoids, namely quercetin, kaempferol, and rutin, tannins, namely polyphenolic compounds, amino acids, and carbohydrates. In addition, some anthocyanin or brazilin ($C_{15}H_{10}O_5$) compounds were also identified.

Table 8 shows that Lento-lento wood colored with Tingi generally contains anthocyanins, flavonoids (namely phenolic compounds), tannins (namely polyphenolic compounds), citric acid and malic acid, saponins (namely glycoside compounds), essential oils and carbohydrates (starch and sugar). In addition, the anthocyanin compounds found consisted of glycosides and flavonoids that gave the colored lento-lento wood its red and purplish.

Conclusion

The study concludes that sappan dye demonstrated greater penetration depth compared to tingi dye in both wood types examined. Specifically, sappan dye penetrated more deeply into gmelina wood than into lento-lento wood, whereas tingi dye exhibited greater penetration in lento-lento wood. The findings provide valuable insights for choosing appropriate dyes for different wood types. The dyes were more effectively absorbed during a 6-hour dyeing period rather than 12 hours, potentially leading to more efficient dyeing processes in wood treatment applications. Pre-treatment involving high-temperature soaking did not significantly affect the depth of dye penetration. Notable color changes were observed before and after the dyeing process, with both wood types displaying a distinct shift towards a reddish hue. Sappan dye resulted in a more intense red coloration, while tingi dye imparted a slightly more yellowish tone. Gas chromatography-mass spectrometry (GCMS) analysis identified the presence of flavonoids, polyphenols, and phenolic compounds in the dyed woods. The results open avenues for further investigation into optimizing wood dyeing processes and exploring the potential of natural dyes in various applications.

Authors' declaration

- Conflicts of Interest: None.
- We hereby confirm that all the figures and tables in the manuscript are ours. Furthermore, any figures and images that are not ours have been included with the necessary permission for republication, which is attached to the manuscript.
- No animal studies are present in the manuscript.
- No human studies are present in the manuscript.
- Ethical Clearance: The project was approved by the local ethical committee at the Ministry of Education, Culture, Research, and Technology of Indonesia.

Authors' contribution statement

A.D.Y. and S.S. designed the study. M. and A.H. performed sample preparation. L.E. performed GCMS analysis. K.T.P.P. and G.P. analyzed the data. A.D.Y. and K.T.P.P. performed the coloring and wrote the paper.

Funding statement

The research was supported by the Ministry of Education, Culture, Research, and Technology of Indonesia under grant 00323/UN4.22/PT.01.03/2023.

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خشب سابان وتينجي كصبغة لخشب جميلينا (Gmelina arborea Roxb.) وخشب لينتو-لينتو (Arthrophillum diversifollium) في أوقات تلوين مختلفة

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الخلاصة

تدرس هذه الدراسة تأثير مدة الصباغة والمعالجة المسبقة بالنقع على أداء صبغتي Sappan (Caesalpinia sappan) وTingi (Ceriops candolleana)المطبقتين على خشبي Gmelina (Gmelina arborea Roxb.) وLento-lento (Arthrophyllum diversifolium). جُهزت عينات الاختبار بعد معالجتها مسبقًا بالنقع عند 80°م لمدة 24 ساعة لإزالة المركبات المستخلصة من الخشب، ثم صُبغت بصبغتي Sappan و Tingiعند 80°م لمدة 6 و12 ساعة. تم قياس عمق اختراق الصبغة باستخدام ميكروسكوب ستيريو، وقيمت تغيرات اللون باستخدام فضاء اللون CIELab. استُخدم الكروماتوغرافيا الغازية-مطياف الكتلة (GCMS) لتحليل مكونات الخشب، ومواد الصبغة، والخشب الملون. أظهرت النتائج أن صبغة Sappan حققت اختراقًا أكبر مقارنة بصبغة Tingi في كلا النوعين من الخشب، مع اختراق أعمق في خشب Gmelina منه في خشب Lento-lento. ومن اللافت أن كلا الصبغتين حققتا اختراقًا أكثر فعالية خلال فترة صبغ 6 ساعات مقارنة بفترة 12 ساعة. لم تؤثر المعالجة المسبقة بشكل كبير على عمق اختراق الصبغة. كشفت تحليلات اللون أن كلا الصبغتين أضافتا لونًا أحمر قويًا للخشب، حيث أنتجت Sappan لونًا أحمر أكثر كثافة بينما أظهرت Tingi لونًا مصفرًا. أكد تحليل GCMS وجود الفلافونويدات والبوليفينولات والمركبات الفينولية في عينات الخشب الملون. تسهم هذه النتائج في تحسين تقنيات الصباغة الطبيعية لتطبيقات الحرف الخشبية المستدامة.

الكلمات المفتاحية: التلوين، المدة، Gmelina، Lento-lento، Sappan.