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OIL HEAT TREATMENT EFFECTS ON COLOR CHANGES IN JABON AND SENGON WOODS

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ABSTRACT

The increasing demand for wood resources has encouraged the utilization of fast-growing species such as jabon (Neolamarckia cadamba) and sengon (Falcataria moluccana), although their relatively low-quality limits their application in high-value products. This study evaluated the effect of oil heat treatment (OHT) on the color characteristics of both species and examined consumer preferences toward the resulting wood appearance. Wood samples were treated in palm oil at temperatures of 170°C, 190°C, and 210°C for 2 h. Color changes were assessed using the CIE-Lab system, and a preference survey with 100 respondents was conducted to evaluate visual acceptance. The results showed that increasing treatment temperature progressively reduced the lightness (L) values of both species, producing darker wood surfaces. Sengon exhibited a greater degree of darkening than jabon, indicating different responses to thermal modification. Changes in the a* and b* parameters also varied between species, reflecting differences in their chemical and anatomical characteristics. The darker, more uniform colors achieved after treatment enhanced the visual appearance of both woods. Consumer responses indicated that moderately dark colors were generally preferred, with jabon treated at 190°C and sengon treated at 210°C receiving the highest appreciation. These findings suggest that oil heat treatment is a promising, environmentally friendly approach to improving the aesthetic value and market potential of fast-growing wood species. Future studies should investigate the effects of OHT on the physical, mechanical, and durability properties of modified wood.*

Keywords: *CIE-Lab System; Consumer Preference; Fast-Growing Wood; Surface Appearance Thermal Modification*

INTRODUCTION

The use of fast-growing wood species has received increasing attention in recent years as demand for wood industry raw materials rises, while the supply of wood from natural forests continues to decline due to logging restrictions and growing demands for sustainable forest management. Fast-growing wood species such as jabon (*Neolamarckia cadamba*) and sengon (*Falcataria moluccana*) are widely cultivated due to their relatively short harvest cycle, ease of cultivation, and faster economic returns compared to wood from natural forests (Mustofa *et al*., 2020). Furthermore, these two species have become important raw materials for the panel, light construction, and furniture industries in Southeast Asia (Krisnawati *et al*., 2022). However, fast-growing wood species generally have low density, poor dimensional stability, and less uniform color, limiting their use in higher-value products (Candelier *et al*., 2016; Yao *et al*., 2023). These characteristics mean that Jabon and Sengon wood are still primarily used for products that do not require high strength and durability.

Various efforts have been made to improve the quality of fast-growing wood through wood modification technologies, one of which is Oil Heat Treatment (OHT). This method combines heat treatment with oil as a heat conductor, thereby affecting the chemical and anatomical structure of wood and resulting in changes in its physical and aesthetic properties (Mandraveli *et al*., 2024). According to Candelier *et al*. (2018), oil-based heat treatment can increase dimensional stability, reduce hygroscopicity, and improve the appearance of wood color through hemicellulose degradation and modification of extractive components. Recent research by Bekhta *et al*. (2022) and Sandak *et al*. (2021) also shows that thermal modification can produce darker, more uniform colors, lower equilibrium moisture content, and weight changes due to the loss of volatile compounds and the penetration of oil into the wood structure. However, the resulting response is strongly influenced by the anatomical characteristics and chemical composition of each wood species (Yang *et al*., 2023).

To date, research comparing color and weight changes in jabon and sengon wood after OHT treatment remains relatively limited. Most previous studies have focused on a single species, thereby lacking sufficient information on the effectiveness of the same treatment across both types of wood. Differences in pore structure, fiber proportion, and cellulose, hemicellulose, and lignin content among species can lead to different responses during heat treatment (Rahayu *et al*., 2019; Sandberg *et al*., 2021). According to Esteves and Pereira (2023), variations in chemical composition and anatomical structure are the main factors determining color changes, mass loss, and hygroscopic properties of wood after thermal modification. This limited information underscores the need for research that directly compares the two species under identical treatment conditions to gain a more comprehensive understanding of the color and weight changes resulting from OHT treatment.

This study aims to provide a scientific overview of the differences in the responses of jabon and sengon wood to OHT. The scope of the research includes observing color changes before and after treatment, measuring changes in wood weight, and analyzing the characteristics that emerge after the modification process. The research results are expected to provide a basis for the wood processing industry to select the most suitable fast-growing wood species for modification, while also supporting the development of more efficient, environmentally friendly, and sustainable wood utilization technologies. In line with the concept of bioeconomy and the utilization of renewable resources, wood modification technology is considered capable of increasing the added value of fast-growing wood without the use of hazardous chemicals, thus supporting the principles of sustainability in the modern forestry industry (Sandberg *et al*., 2021; Jones *et al*., 2024).

METHODS

Time and Place

This research was conducted over 15 days, from November 17, 2025, to December 1, 2025, at the Forest Products Engineering and Technology Laboratory, Department of Forestry, Faculty of Agriculture, University of Lampung, and at the Integrated Field Laboratory, Faculty of Agriculture, University of Lampung, in a workshop.

Materials and Equipment

The main materials used were sengon and jabon wood, obtained from two different woodlots: the Sumber Jaya Plantation on Jalan Ridwan Rais, Kedamaian, and the CV. Cekatan Plantation on Jalan Tanjung Raya, Tanjungkarang Timur District, Bandar Lampung City, Lampung, Indonesia. The materials were prepared to the dimensions of 16 cm (length) × 4 cm (width) × 1.5 cm (thickness). Other materials used were commercial palm oil (SANIA, PT. Wilmar Cahaya Indonesia Tbk., Indonesia). The equipment used included an oven (BJPX - Summer, PT. Innotech System, Jakarta, Indonesia), an oil bath (C-WHT-S2; Chang Shin Science, Seoul, Korea), a caliper, a ruler, a tally sheet, a mobile phone camera, a general-purpose colorimeter scanner, and a laptop to support the processing and documentation of the research results.

Oil Heat Treatment Process

The oil heat treatment was performed in an oil bath (C-WHT-S2; Chang Shin Science, Seoul, Korea). A total of four liters of commercial palm oil (SANIA, PT. Wilmar Cahaya Indonesia Tbk., Indonesia) was used as the heating medium. The wood samples were stacked using metal stickers, and the top stack was held in place with a metal bracket to prevent floating during the treatment. The wood samples were treated at three temperatures (170°C, 190°C, and 210°C) for 2 hours. After the oil heat treatment process was completed, the wood samples were cooled and dried to remove the oil. All samples were then oven-dried at 100°C for 24 hours to ensure consistent moisture levels.

Dimensional and Color Change Analysis

Dimensional and color change testing was conducted to evaluate the effect of high temperatures during the oil heat treatment process on sengon and jabon wood using a General Scanning Colorimeter (AMT507, China). Measurements were taken at four points on both sides of the sample surface using a general scanning colorimeter before and after treatment. Color changes were analyzed using the CIE-LAB system. The overall color change (ΔE*) was calculated using the following equation.

$\Delta E^* = (\Delta L^*2 + \Delta a^*2 + \Delta b^*2\ )1/2$ ....(1)

$\Delta L^* = L2^* - L1^*$ ....(2)

$\Delta a^* = a2^* - a1^*$ ....(3)

$\Delta b^* = b2^* - b1^*$ ....(4)

Wood measurements were performed using the CIE-LAB system, which measures color components through the parameters L*, a*, and b*. The L1* and L2* values represent the brightness levels (from black to white) before and after treatment, respectively; a1* and a2* represent the chromaticity along the red-green axis, while b1* and b2* represent the chromaticity along the yellow-blue axis. The differences between the pre- and post-treatment values were calculated as ΔL*, Δa*, and Δb*, and then used to determine the overall color change (ΔE*). The ΔE* value serves as the basis for classifying the degree of visual color difference. The classification of color changes is presented in Table 1.

Table 1. Classification of Color Changes

Classification Value	Description
$0.0 < \Delta E^* \le 0,5$	Negligible
$0,5 < \Delta E^* \le 1.5$	Slightly Visible
$1.5 < \Delta E^* \le 3$	Noticeable
$3 < \Delta E^* \le 6$	Quite Large
$6 < \Delta E^* \le 12$	Highly Appreciated
$\Delta E > 12$	Really Changed

Weight change

Weight changes were evaluated to determine the effect of heat treatment on wood mass. The weight of each treatment was measured before heat treatment as the initial weight (m_0), then remeasured after treatment and drying as the final weight (m_1). The percentage weight change was calculated based on the difference between the initial weight and the final weight against the initial weight of the sample using the equation:

$WC\ (\%) = \frac{m1-m0}{m0} \times 100$ ....(1)

Description:

m_0 : The weight before treatment

m_1 : The weight after treatment

Community Preferences

A public preference survey was conducted to evaluate consumer preferences for wood colors resulting from oil heat treatments. The method used was accidental sampling, involving respondents who agreed to participate in the survey without being randomly selected. The survey was conducted at the University of Lampung with a total of 100 respondents. Two types of wood were used in this study: jabon and sengon. Each type of wood was heat-treated at 170°C, 190°C, and 210°C. The survey was conducted online by distributing a questionnaire link containing photos of wood samples from each oil heat treatment for each type. Respondents were asked to select their preferred wood color from the photos displayed in the questionnaire. The obtained preference data were then analyzed to determine color preferences based on treatment results.

RESULTS AND DISCUSSIONS

Color Change

Figure 1 shows that the lightness value (L*) of both jabon and sengon wood decreased progressively as the heat treatment temperature increased. This trend indicates that the wood surface became darker following thermal modification. Under untreated conditions, sengon wood exhibited a higher L* value than jabon wood, suggesting that sengon possesses a naturally lighter color. As the treatment temperature increased from 170°C to 210°C, both species experienced a gradual reduction in lightness, with the most pronounced decrease observed at 210°C. At this temperature, sengon wood exhibited a greater decline in L* than jabon wood, indicating a more severe darkening effect.

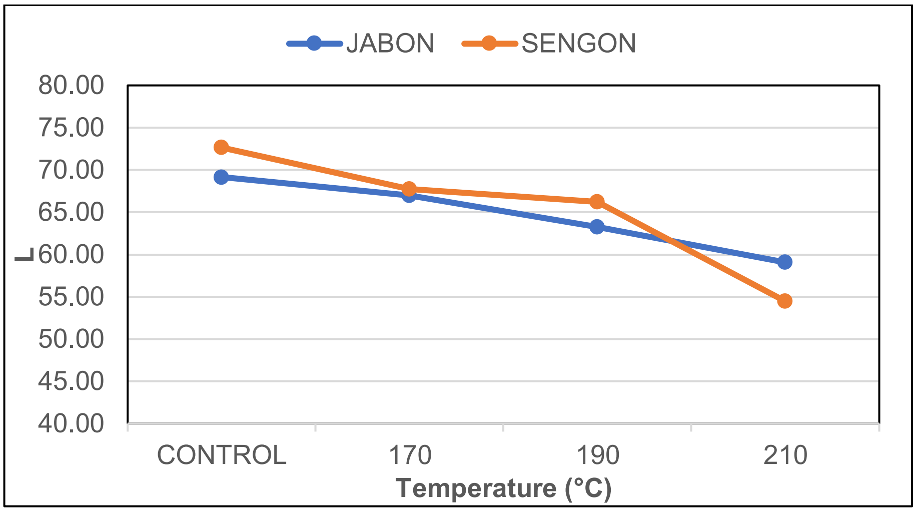

Figure 1. The Lightness (L) Of Sengon and Jabon Wood After Oil Heat Treatment.*

The reduction in lightness can be attributed to a series of chemical transformations occurring within the wood structure during heat treatment. According to Hill *et al*. (2021), thermal modification promotes the degradation of hemicelluloses and induces oxidation and condensation reactions in lignin, resulting in the formation of chromophoric compounds that contribute to the darker appearance of wood. In addition, extractives may undergo chemical changes and participate in non-enzymatic browning reactions, further contributing to color development. Yao *et al*. (2023) reported that thermal degradation and Maillard-type reactions are among the major mechanisms governing color changes during heat treatment.

The present results are consistent with previous studies demonstrating that increasing treatment temperature substantially reduces L* values. Sikora *et al*. (2018) found that thermal modification at 160-210°C significantly darkened spruce and oak wood, primarily due to chemical alterations in hemicellulose and lignin. Similarly, Zhou *et al*. (2021) observed that the severity of heat treatment had a pronounced effect on wood color, with higher temperatures producing lower lightness values and more homogeneous coloration.

Interestingly, sengon wood exhibited a more pronounced decrease in L* than jabon wood, particularly at 210°C. This finding suggests that the two species differ in their susceptibility to thermal degradation. Such differences are likely associated with variations in chemical composition, especially the contents of hemicellulose, lignin, and extractives. Hill *et al*. (2021) emphasized that the response of wood to heat treatment is strongly species-dependent because degradation pathways and reaction rates vary with the chemical constituents present in the cell wall. Consequently, even under identical treatment conditions, different species may exhibit different extents of color modification.

The considerable reduction in L* observed at 210°C suggests that this temperature accelerates the formation of colored degradation products. Preklet *et al*. (2023) demonstrated that while extractives play an important role in color development at lower temperatures, degradation products originating from hemicellulose become increasingly dominant as treatment temperatures approach 200°C. Likewise, Zhang *et al*. (2023) reported that darker colors in thermally modified Populus tomentosa were associated with changes in the wood's internal structure and improved dimensional stability. Therefore, color changes may serve as an indirect indicator of chemical and structural modifications occurring during heat treatment.

As shown in Figure 2, the a* values of jabon and sengon wood change with increasing heat treatment temperature. *Under control conditions, the a* value of jabon wood was around 9.2, while that of sengon wood was 5.3. After treatment at 170°C, the a* values of both wood types increased, with a more pronounced increase in sengon wood, reaching approximately 7.3. This increase in a* value indicates that heat treatment at medium temperatures can increase the color tendency towards red. Bekhta and Niemz (2003) reported that heat treatment can increase the a* value due to color changes triggered by thermal reactions in the wood's constituent components.

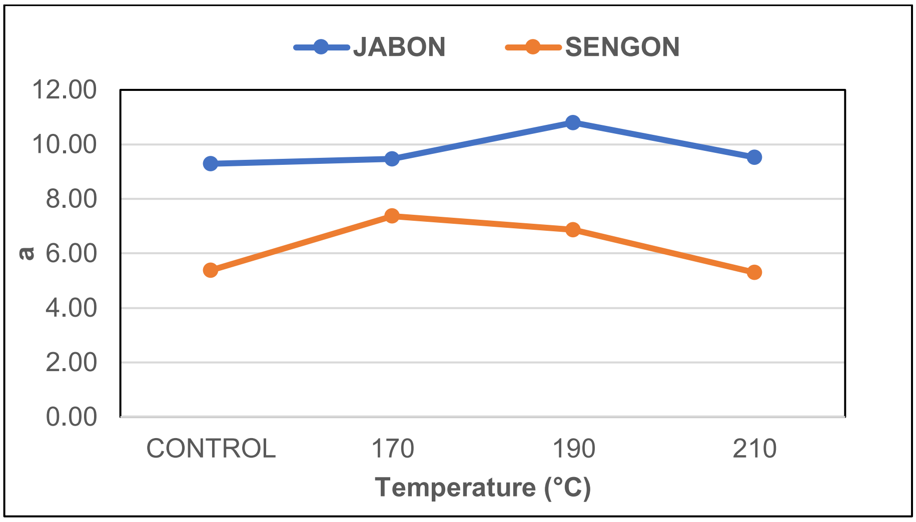

Figure 2. The Red and Green Chromaticity (a) of Sengon and Jabon Wood after Oil Heat Treatment.*

At 190°C, the a* value of jabon wood continued to increase to a maximum of approximately 10.8, while the a* value of sengon wood decreased slightly to approximately 6.9. These results indicate that the two wood types respond differently to increasing temperatures. Jabon wood continued to experience an increase in red color intensity up to 190°C, while sengon wood experienced a maximum increase at 170°C. According to Matsuo *et al*. (2014), changes in color parameters during heat treatment are strongly influenced by wood species and treatment temperature, allowing each species to exhibit distinct color-change patterns.

When the treatment temperature was increased to 210°C, the a* values of both wood species decreased. The a* value of jabon wood dropped to around 9.5, while sengon wood returned to the control value of around 5.2. This decrease indicates that raising the temperature above 200°C no longer increases red color intensity but instead decreases the a* value. Bekhta and Niemz (2003) stated that higher treatment temperatures result in more intense color changes, whereas at higher temperatures the wood color tends to darken, decreasing the a* value.

Overall, the a* value of jabon wood was higher than that of sengon wood at all treatment levels. Furthermore, a temperature of 190°C produced the highest a* value in jabon wood, while the highest value was obtained in sengon wood at 170°C. These differences in patterns indicate that the color-change response to heat treatment is influenced by the characteristics of each wood species. These results are consistent with the findings of Bekhta and Niemz (2003), who stated that the combination of wood species and treatment temperature is the primary factor determining changes in wood color parameters.

The b* (yellowness) values of sengon and jabon wood before and after oil heat treatment (OHT) are shown in Figure 3. In general, the two wood species showed different responses to increasing treatment temperatures. The b* value in jabon wood tended to decrease with increasing OHT temperature, whereas in sengon wood it increased up to 190°C and then decreased slightly at 210°C.

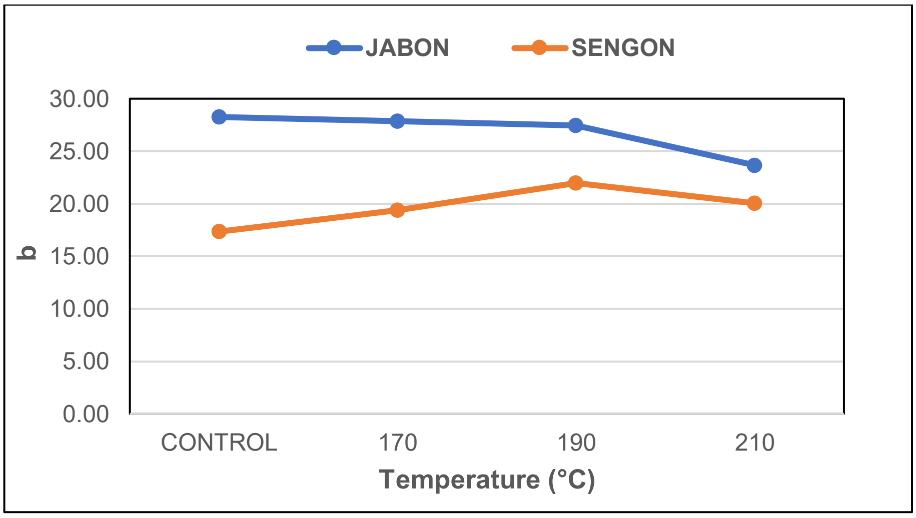

Figure 3. The Blue and Yellow Chromaticity (b) of Sengon and Jabon Wood after Oil Heat Treatment.*

Under control conditions, jabon wood had a b* value of around 28.3, then gradually decreased to 27.8 at 170°C, 27.5 at 190°C, and then dropped more significantly to around 23.8 at 210°C. This decrease in the b* value indicates a reduction in the yellow color component on the wood surface due to the heat treatment. This phenomenon is related to the degradation of hemicellulose and to changes in the chemical structure of extractives that occur during heating. According to Barcík *et al*. (2015), increasing the thermal treatment temperature generally causes a decrease in the b* value in several wood species due to the decomposition of compounds that contribute to the wood's yellow color. This finding aligns with research by Suri *et al*. (2021), which reported that in heat treatments using oil, the b* value tends to decrease at high temperatures due to changes in chemical components and the formation of degradation products that affect the wood's color appearance.

In contrast to jabon wood, the b* value in sengon wood increased from around 17.3 under control conditions to 19.3 at 170°C and reached a peak of 21.9 at 190°C. This increase indicates that during the initial stages of the OHT treatment, the yellow color on the wood surface intensifies. This is thought to be caused by the formation of compounds resulting from oxidation and condensation reactions of extractives, as well as lignin, which still dominates at medium temperatures. However, when the temperature is increased to 210°C, the b* value decreases to around 20.0. This decrease indicates that at higher temperatures, the degradation of wood components begins to occur more intensively, reducing the intensity of the previously formed yellow color. Similar results were reported by Suri *et al*. (2021), who found that the b* value of wood heat-treated in oil media increased at relatively low temperatures, but then decreased as the temperature and treatment intensity increased.

The differences in the b* value changes between jabon and sengon wood indicate that the wood's color response to OHT is strongly influenced by the anatomical characteristics and chemical composition of each wood species. A comprehensive review by Sandak *et al*. (2021) stated that changes in color parameters in the CIE-Lab* system are significantly influenced by temperature and treatment duration, with hemicellulose degradation reactions, extractive oxidation, and lignin structural modification being the main factors determining wood color change after OHT. Therefore, the results of this study indicate that a temperature of 190°C can still increase the yellow color components in sengon wood, whereas in jabon wood, increasing OHT temperatures tend to cause a gradual decrease in the b* value.

Oil heat treatment of sengon and jabon wood causes significant overall color changes (ΔE), marked by a decrease in brightness as the temperature increases from 170°C to 210°C (Figure 4). As the treatment temperature increases, the wood color becomes darker (Figures 5 and 6). The L* value decreases drastically with increasing temperature (Suri *et al*., 2021). Wood color changes are closely related to the thermal degradation of hemicellulose, the most heat-sensitive wood component, which causes the product to darken. In addition, the effectiveness of Oil Heat Treatment (OHT) is greatly influenced by the type of wood, temperature, and treatment duration, as well as the type of oil, which acts as an efficient heating medium and protects against oxidation during heating (Lee *et al*., 2018).

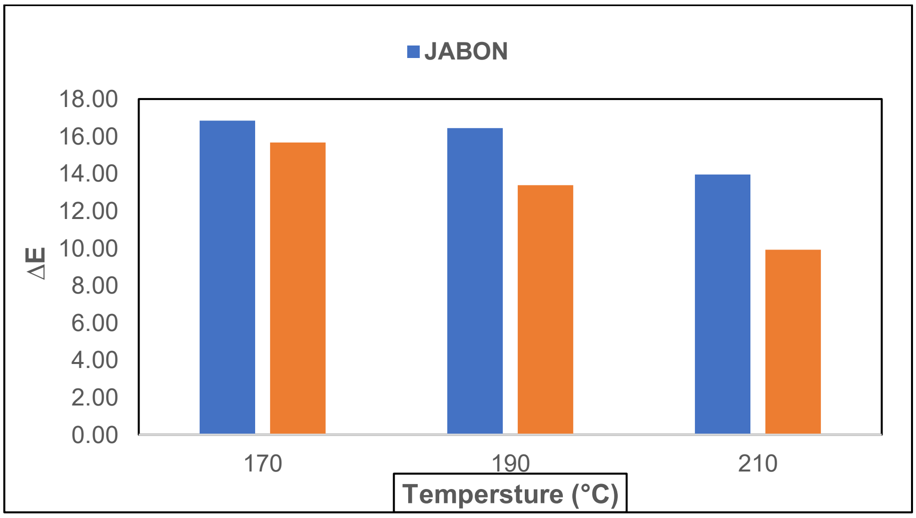

Figure 4. The Overall Color Change (ΔE) of Sengon and Jabon Wood after Oil Heat Treatment.

Figure 5. The Appearance of Sengon Wood Before and after Oil Heat Treatment. The Results, from Left to Right, are Control, 170°C, 190°C, and 210°C.

Figure 6. The Appearance of Jabon Wood before and after Oil Heat Treatment. The Results, from Left to Right, are Control, 170°C, 190°C, and 210°C.

From a practical perspective, the darkening effect of heat treatment may enhance the aesthetic appeal of fast-growing plantation species. As noted by Jančíková and Jablonský (2025), thermally modified wood often exhibits a color similar to that of naturally darker and more expensive hardwood species, making it attractive for furniture and interior applications. Nevertheless, excessively high temperatures should be carefully controlled because severe degradation of cell wall polymers may compromise the mechanical properties of wood. Balancing improved appearance and preservation of strength properties remains one of the major considerations in thermal modification processes (Jančíková and Jablonský, 2025).

Overall, the results demonstrate that increasing heat treatment temperature from 170°C to 210°C significantly reduced the L* values of both jabon and sengon wood. Sengon wood exhibited a greater degree of darkening than jabon wood, suggesting that species-specific chemical characteristics play an important role in determining the response of wood color to thermal modification.

Community Color Preferences

A color preference test was conducted to assess the interest of respondents in wood color changes based on the oil heat treatment. The data revealed varied responses across occupation, gender, age, and preferred wood color. Of the 100 respondents, 65 were female, and 35 were male.

As shown in Figure 7, the data indicate that, compared with the descriptive data in the survey table, preferences vary as the wood color becomes darker. In the darker color category, some respondents associated their choice with the aesthetic impression and visual quality of the wood, such as more visible grain, mature color, and an elegant impression. However, the proportion of respondents who chose too dark colors remained smaller, because dark colors are considered to reduce the natural appearance of the wood. Retantoko (2016) explained that color changes resulting from treatment affect not only aesthetics but also the perception of the continuity of the wood's original character.

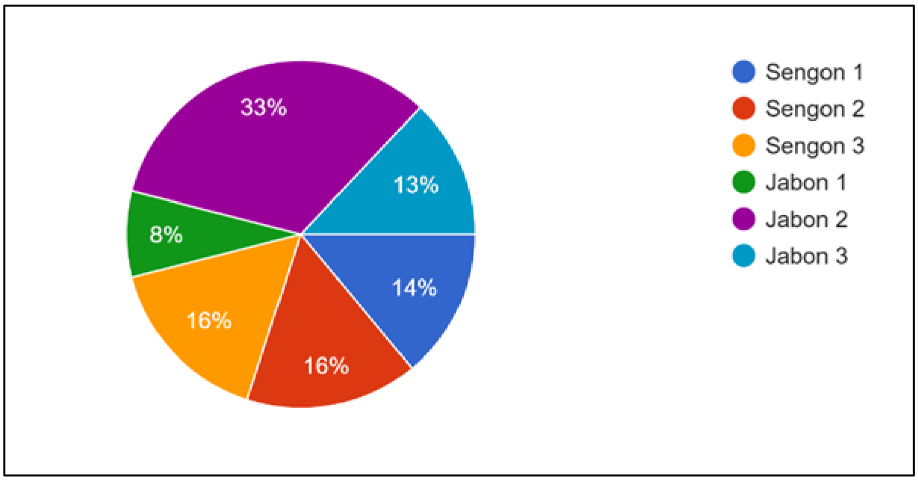

Figure 7. Percentage of Interest in Jabon and Sengon Wood after Heat-Treatment with Oil

Note: Sengon 1: oil heat-treated at 170°C; Sengon 2: oil heat-treated at 190°C; Sengon 3: oil heat-treated at 210°C; Jabon 1: oil heat-treated at 170°C; Jabon 2: oil heat-treated at 190°C; and Jabon 3: oil heat-treated at 210°C.

Jabon, which is naturally lighter in color, remains a favorite among respondents who prefer a clean and fresh look, while sengon is preferred by those who prefer contrasting or dark colors. A simple correlation is evident: respondents who mentioned keywords such as bright, clean, and neat tended to choose jabon after oil heat-treated at 190°C, whereas voters who mentioned keywords such as dark, elegant, natural, and strong motifs were more common among sengon after oil heat-treated at 210 °C. Afkar *et al.* (2022) also reported that the aesthetic perception of wood after heat modification is strongly influenced by the interaction between the wood's base color and the surface effects of thermal reactions, such that people's preferences can be mapped based on the visual characteristics that appear after treatment.

CONCLUSIONS AND RECOMMENDATIONS

Oil heat treatment significantly affected the color characteristics of both jabon and sengon wood. Increasing the treatment temperature from 170°C to 210°C resulted in progressively darker wood surfaces. Sengon wood showed a greater degree of darkening than jabon wood, indicating differences in the response of each species to heat treatment. Changes in the color parameters also demonstrated that wood species strongly influence the final appearance after modification. Overall, OHT produced a more uniform and attractive color that may increase the value of fast-growing wood species. Consumer preference results indicated that moderately dark colors were generally preferred over excessively dark colors. Jabon treated at 190°C and sengon treated at 210°C showed the highest visual appeal among respondents. These findings suggest that oil heat treatment can be used as an environmentally friendly method to improve the aesthetic quality of plantation wood. Therefore, the selection of treatment temperature should be adjusted according to the desired appearance and market preferences. Further studies are recommended to evaluate the effects of OHT on the physical, mechanical, and durability properties of thermally modified wood.

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