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The effect of oil heat treatment on color changes and preference of sengon (*Falcataria moluccana*) and African tulip (*Spathodea campanulata*) woods

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ABSTRACT

Indonesia faces increasing pressure on its natural forest resources due to deforestation and rising demand for wood, encouraging the utilization of fast-growing species such as sengon (*Falcataria moluccana*) and underutilized invasive species such as African tulip (*Spathodea campanulata*). However, both species are characterized by naturally light surface colors, which are often perceived as less attractive for decorative and interior applications. Oil heat treatment (OHT) has been used to modify wood color and enhance visual appearance. This study evaluated the effects of OHT at 160°C, 180°C, 200°C, and 220°C for 2 hours on color changes and public color preferences of sengon and African tulip woods. Color changes were visually observed and quantitatively analyzed using the CIE-LAB color system, while preference data were collected through an online survey involving male and female respondents. The results showed that OHT caused significant darkening of wood surfaces, with African tulipwood exhibiting greater color changes than sengon. Preference analysis indicated that female respondents tended to favor wood colors heat-treated at moderate temperatures (180°C), whereas male respondents preferred darker colors produced at higher temperatures (200–220°C). For African tulip wood, treatment at 200°C was the most preferred overall by both genders. These findings demonstrate that oil heat treatment effectively modifies wood color and that consumer color preferences vary by gender, which may be considered in visually oriented wood applications.

Keyword: Color Change, Color Preference, Oil Heat Treatment

1. Introduction

Indonesia's natural forests play an important role in providing wood for industrial and construction needs [1]. However, high population growth rates drive land conversion and deforestation, which negatively affect the area and the production of natural forests [2]. Indonesia lost approximately 258.800 ha of primary forest in the past year [3]. In response, the development of plantation forests has become the primary strategy for meeting the demand for wood, particularly with fast-growing tree species such as sengon (*Falcataria moluccana*) [4]. Sengon is known to have a short growth cycle and high economic value [5].

Wood is widely used in furniture, interior, and decorative applications, where visual appearance—particularly surface color—plays an important role in determining consumer preference and perceived product value. Fast-growing species such as sengon (*Falcataria moluccana*) and underutilized invasive species such as African tulip (*Spathodea campanulata*) are increasingly considered as alternative raw materials to meet wood demand. In addition, invasive alien species such as *Spathodea campanulata* (African tulip) also have potential as alternative raw materials derived from eradication waste [8]. This species, originating from Tropical West Africa, is known for its rapid growth and aggressive spread [9]. The wood of *Spathodea campanulata* has been utilized for light construction and carving applications [10]. Both sengon and African tulip wood naturally exhibit light-colored surfaces—pale yellowish-white in sengon and slightly yellow to light brown in African tulip—as commonly reported in previous studies [6,7,9,10]. These bright color tones are often considered less attractive for decorative or aesthetic purposes.

Modifying their appearance through thermal treatment, such as oil heat treatment (OHT), becomes essential to enhance their visual appeal and potential industrial utilization. One method to improve the quality and aesthetics of fast-growing, invasive wood is oil heat treatment (OHT). OHT is a heat-modification technique that uses oil as a heat conductor to enhance the physical and mechanical properties of wood [11]. This process is also known to alter visual properties, such as color, which is an important aspect of assessing wood aesthetics [12].

Previous studies on sengon and mindi wood have shown that OHT causes significant color changes [13]-[15]. Other studies have reported that color alterations can influence consumer preferences for heat-treated wood surfaces [14]. However, comparative studies on heat-treated sengon (*Falcataria moluccana*) and African tulip (*Spathodea campanulata*) woods remain limited. Therefore, this study aimed to evaluate the effects of oil heat treatment at different temperatures on the color changes of sengon and African tulip woods using the CIE-LAB color system, and to analyze public color preferences. The findings are expected to provide insights into the visual modification of wood and its acceptance by consumers, which are important considerations for the development of aesthetically oriented wood products.

2. Method

2.1. Time and place

This study was conducted from February to April 2025. Sample preparation and oil heat treatment were carried out at the Forest Products Technology Workshop, Faculty of Agriculture, Universitas Lampung. Color measurements and visual evaluations were performed at the Forest Products Technology Laboratory, Department of Forestry, Faculty of Agriculture, Universitas Lampung, Bandar Lampung, Indonesia.

2.2. Materials

Sengon wood (*Falcataria moluccana*) used in this study was obtained from five-year-old trees with an average height of approximately ± 5 m, sourced from a local sawmill in Bandar Lampung, Lampung Province, Indonesia. A five-year-old African tulip wood (Spathodea campanulata) was obtained from logging activities in the Universitas Lampung area. To ensure sample homogeneity, specimens from both species were collected from the sapwood and heartwood. Commercial palm oil (FILMA, PT. SMART Tbk., Tangerang, Indonesia) was used as the heating medium during the oil heat treatment process. As a heating medium in the treatment process, commercial palm oil was used. The equipment used in this study included an oven (BJPX - Summer, PT. Innotech System, Jakarta, Indonesia), oil bath (C-WHT-S2; Chang Shin Science, Seoul, Korea), sanding machine, caliper, ruler, tally sheet, digital camera (Canon EOS 100D), general colorimeter scanner, IBM SPSS Statistics 24 application for data analysis, and a laptop device to support the processing and documentation of research results.

2.3. Sample preparation

Both types of wood were sawn into boards measuring 10 cm (length) × 5 cm (width) × 2 cm (thickness). To ensure sample homogeneity, wood specimens from both species were collected from the mid-stem and the inner wood region. Samples were selected based on the criteria of straight fibers and the absence of natural defects to maintain the homogeneity of the test material. This study used three untreated (control) samples and three replicates at each treatment temperature. All treatments were conducted using the oil-heat method, with a heating time of 2 hours. The specimens were first dried in an oven and subsequently equilibrated at room temperature (28–30 ± 5°C) and 65% relative humidity until a stable moisture content of approximately 10% was achieved.

2.4. Research procedure

The oil heat treatment was conducted in an oil bath using 4 liters of cooking oil as the heating medium. The wood samples were treated at four temperatures (160°C, 180°C, 200°C, and 220°C) for 2 hours, with each temperature treatment replicated three times. The selected temperature range was based on previous studies that reported progressive and distinct wood color changes and their relevance to evaluating consumer color preferences [14,15]. In total, 30 samples were prepared: 15 sengon (*Falcataria moluccana*) and 15 African tulip (*Spathodea campanulata*), including 3 untreated (control) and 12 heat-treated samples for each species. Following the oil heat treatment, all samples were oven-dried at 100°C for 24 hours to ensure consistent moisture conditions before color measurement.

2.5. Color change analysis

Color change testing was conducted to evaluate the effects of high temperature in the oil heat treatment (OHT) process on sengon and African tulip wood using a General Scanner Colorimeter (AMT507, China). Measurements were made at four points on both sides of the sample surface using a general colorimeter scanner, before and after treatment. Color changes were analyzed based on the CIE-LAB system [14-16]. The overall color change (ΔE*) is calculated using the following equation.

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

$$\Delta L^{*} = L_{2^{*}} - L_{1^{*}} \quad (2)$$

$$\Delta a^{*} = a_{2^{*}} - a_{1^{*}} \quad (3)$$

$$\Delta b^{*} = b_{2^{*}} - b_{1^{*}} \quad (4)$$

Measurement in wood was conducted using the CIE-LAB system, which quantifies color components through the parameters L*, a*, and b*. The values of L1* and L2* represent lightness (from black to white) before and after treatment, respectively; a1* and a2* represent chromaticity on the red-green axis, while b1* and b2* reflect chromaticity on the yellow-blue axis. The differences between pre- and post-treatment values are calculated as ΔL*, Δa*, and Δb*, and these are then used to determine the overall color change (ΔE*). The ΔE* value serves as a basis for classifying the degree of visual color difference. The classification of color change is presented in Table 1 [17,18].

Table 1. Classification of color changes

Classification Value	Description
$0.0 < \Delta E^* \leq 0.5$	Negligible
$0.5 < \Delta E^* \leq 1.5$	Slightly Perceivable
$1.5 < \Delta E^* \leq 3$	Noticeable
$3 < \Delta E^* \leq 6$	Appreciable
$6 < \Delta E^* \leq 12$	Very Appreciable
$\Delta E > 12$	Totally Changed

2.6. Collecting community preferences

A public preference survey was conducted to evaluate consumer responses toward the color of heat-treated wood. An accidental sampling method was used, involving respondents who were available and willing to participate in the survey, rather than random selection [14]. The survey was conducted at the University of Lampung and included 100 respondents, 50 male and 50 female. Gender was included as a variable to examine differences in visual perception and aesthetic preference. Previous studies have reported that color perception and preference may differ between genders due to variations in visual sensitivity and evaluative responses [19,20].

The survey was conducted online via a questionnaire that included photographs of wood samples from each treatment condition. Respondents were asked to select the wood color they preferred based solely on visual appearance. The collected preference data were then analyzed to identify trends in color selection associated with treatment temperature, wood species, and respondent gender.

3. Results and Discussion

3.1. Color change visual

Oil heat treatment (OHT) on sengon and African tulip wood results in significant color changes, characterized by decreases in lightness (L*) values as temperature increases from 160°C to 220°C (Figures 1 and 2). This change is closely related to the thermal degradation of hemicellulose, the most heat-sensitive wood component, in which chain cleavage and the release of acetyl groups produce derivatives such as sugars and low-molecular-weight compounds, which then polymerize into dark-colored products [19]. A similar phenomenon was observed in jabon wood, which showed an ΔE* value greater than 12 after treatment at 170°C-210°C, indicating a total color change [20]. Another study reported that increasing the treatment temperature of Korean white pine and royal paulownia wood to 220°C resulted in a significant decrease in L* value and an increase in ΔE*, with dark colors preferred by consumers [16]. In addition, the effectiveness of

OHT is greatly influenced by the type of wood, the temperature and duration of treatment, and the type of oil, with oil acting as an efficient heat transfer medium and a protector against oxidation during heating [21].

Figure 1. The appearance of untreated sengon wood (control) and woods heat-treated at 160°C, 180°C, 200°C, and 220°C.

Figure 2. The appearance of untreated African tulip wood (control) and wood heat-treated at 160°C, 180°C, 200°C, and 220°C.

3.2. Changes in lightness values (L) in sengon wood and African tulip wood*

The surface brightness value of wood (L*) decreased with increasing OHT treatment temperature for both sengon and African tulip wood. In control conditions, the L* value of sengon was 79.75, decreasing to 54.90 at 220°C. This decrease indicates that the wood surface color is becoming darker as a result of heat treatment. The same pattern was observed for African tulip wood, which initially had a higher L* value (82.78) and decreased to 52.70 at the highest temperature. The decrease in L* in African tulip was more drastic than in sengon, especially in the temperature range of 160°C to 180°C, indicating a higher thermal sensitivity to color changes. Based on the data obtained, the L* value of the control sample decreased as the treatment temperature increased to 220°C. The decreasing trend in L* value for heat-treated wood indicates that surface brightness decreases with increasing treatment temperature. The darkening of wood color during heat treatment is influenced by hemicellulose degradation products and oxidation of phenolic compounds [22]-[24].

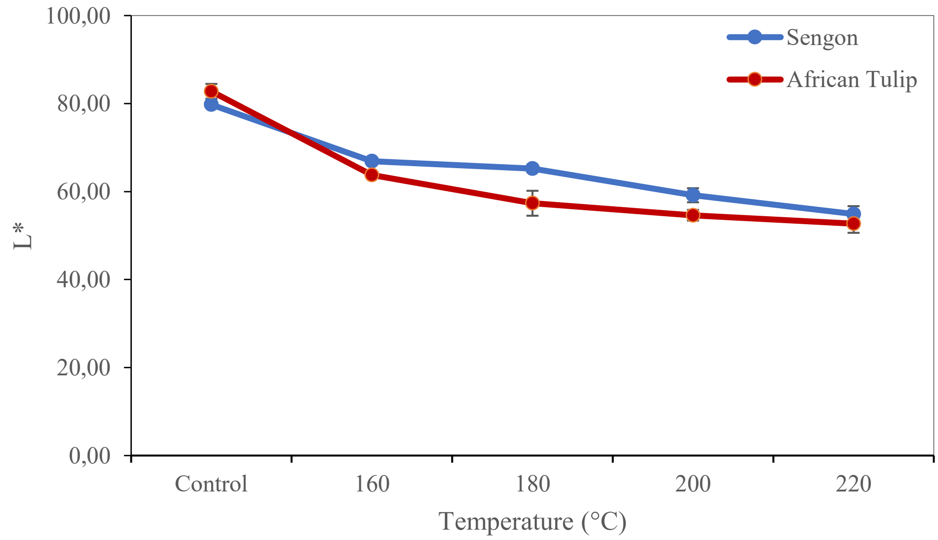

Figure 3. Changes in lightness value (L*) of sengon and African tulip woods

3.3. Changes in red/green chromaticity values (a) in sengon wood and African tulip wood*

The red-to-green chromaticity (a*) value increased with increasing OHT treatment temperature in sengon and African tulip wood. Under control conditions, the a* value of sengon wood was 5.91, increasing to 6.84 at 220°C. This increase indicates a tendency for wood color to become redder following heat treatment. The same pattern was observed for African tulip wood, which initially had an a* value of 4.69 and increased to 6.26 at the highest temperature. In sengon wood, the a* value decreased slightly from the control condition to 180°C, then increased significantly at 200°C and stabilized at 220°C. This is in accordance with the research of Korean white pine and royal paulownia wood [14], where there was an increase in the a* value at a temperature of 180-220°C.

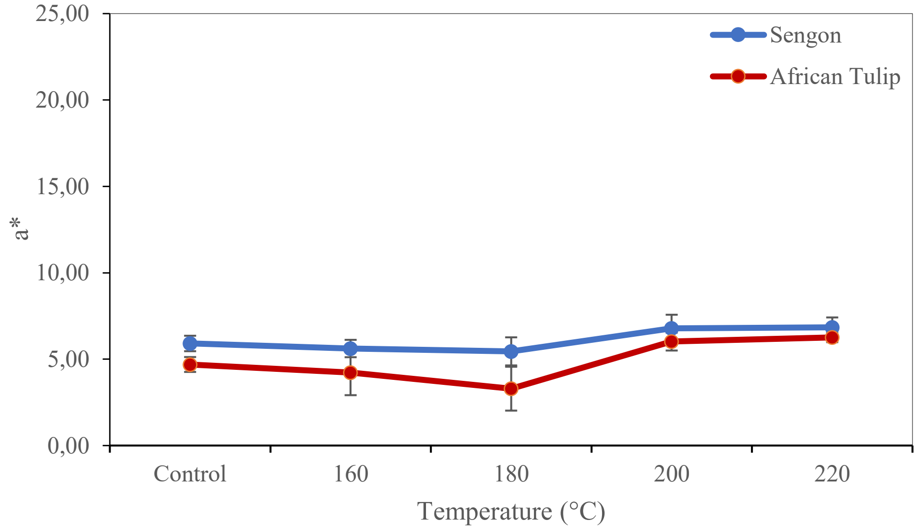

Figure 4. Changes in red/green chromaticity value (a*) of sengon wood and African tulip wood

3.4. Changes in yellow/blue chromaticity values (b) in sengon wood and African tulip wood*

The yellow-to-blue chromaticity value of the wood surface (b*) showed varying changes with increasing OHT treatment temperature in sengon and African tulip wood. Under control conditions, the b* value of Sengon wood was 17.60, which decreased at 160°C and 180°C to 16.58 and 16.81, respectively. Furthermore, the b* value increased to 17.84 at 200°C, then decreased slightly to 17.03 at 220°C. The same pattern was observed in African tulip wood. The initial b* value under control conditions of 18.84 decreased sharply to 15.38 at a temperature of 160°C, then increased gradually to reach 17.28 at a temperature of 220°C. The decrease in b-value following heat treatment indicates degradation of chemical compounds, such as hemicellulose and extractives, that contribute to wood's natural yellow hue. This is consistent with reports that the blue color shift occurs due to changes in chemical composition during the OHT process [24].

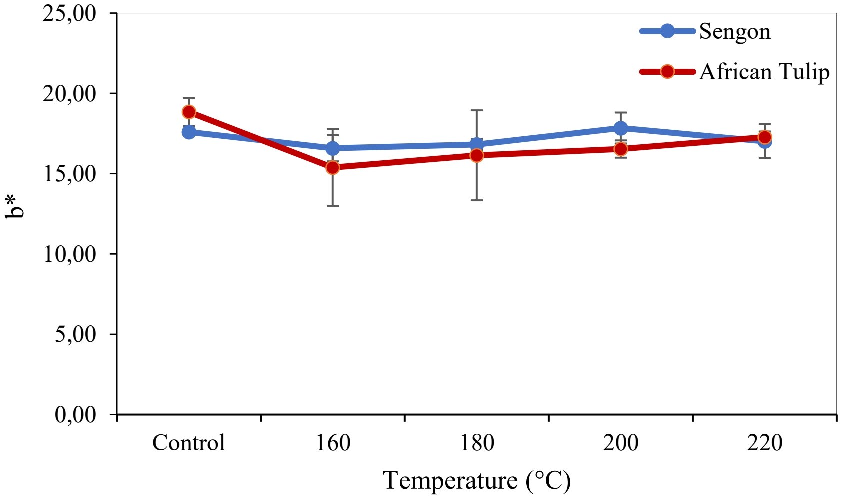

Figure 5. Changes in yellow/blue chromaticity value (a*) of sengon wood and African tulip wood

3.5. Overall color changes of sengon wood and African tulip wood

The overall color change (ΔE*) values increased with increasing OHT treatment temperature in sengon and African tulip wood. In sengon wood, the ΔE* values were 11.39 (160°C), 13.03 (180°C), 22.58 (200°C), and 26.05 (220°C), respectively. Meanwhile, in African tulip wood, the ΔE* values were 17.73 (160°C), 21.52 (180°C), 26.30 (200°C), and 28.93 (220°C), respectively. The overall color change value (ΔE) is used to determine the degree of color difference on the wood surface [16,17]. According to the classification of Hidayat et al. [13], only sengon wood heat-treated at 160°C exhibited a very appreciable color change (6 < ΔE ≤ 12). In contrast, higher treatment temperatures resulted in a total color change (ΔE > 12).

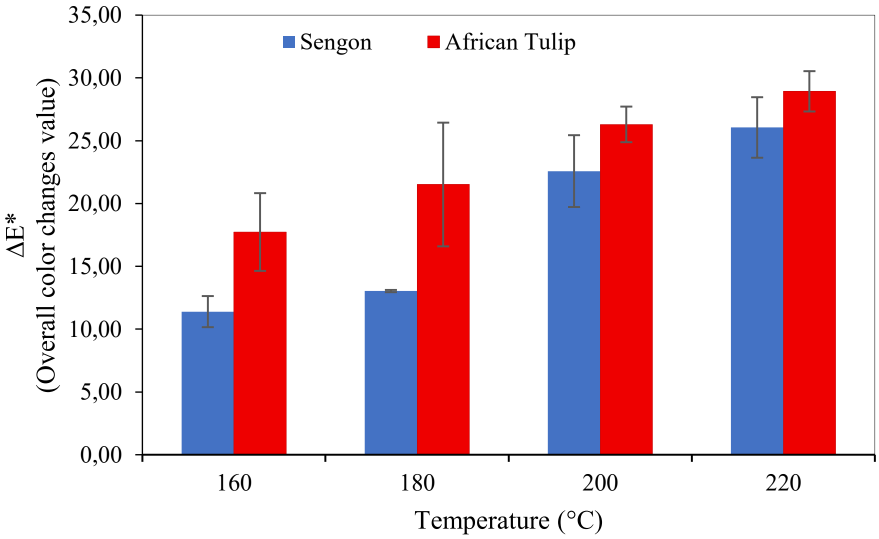

Figure 6. Overall color changes of sengon wood and African tulip wood

3.6. Community color preference

Wood color preference data following oil heat treatment (OHT) varied by wood type, treatment temperature, and respondent gender. The total dataset comprised 100 respondents, 50 men and 50 women. Among sengon wood, the highest color preference among female respondents was at 180°C (23 respondents), whereas male respondents preferred heat-treated wood at 220°C (19 respondents). A temperature of 180°C also showed a relatively strong preference among men, with 15 participants. Meanwhile, the 200°C temperature received 10 votes from men and 5 from women. Only 3 men and 6 women selected 160°C; 3 people in each group preferred the control temperature (without treatment). In African tulip wood, 200°C was the most preferred temperature among men (24 participants) and women (17 participants). The temperature of 180°C received 10 votes from each group, and the temperature of 220°C received 10 votes from men and 7 from women. Meanwhile, the 160°C temperature was chosen by only 3 men and 13 women, and the control condition was preferred by the fewest participants in both groups, 3 each. In general, temperatures of 180°C and 200°C elicited the highest preference, with male respondents tending to prefer the treatment color at higher temperatures than female respondents.

The results showed that OHT significantly influenced wood color preferences for both sengon and African tulip wood, with gender-based differences in responses. For sengon wood, female respondents preferred the color produced by heat treatment at 180°C, whereas male respondents preferred that produced by heat treatment at 220°C. A similar trend was observed for African tulipwood: males showed the highest preference at 200°C, whereas females also showed the highest value at this temperature, albeit at lower levels. In general, male respondents tended to prefer wood colors produced at higher heat treatment temperatures (200°C-220°C), with darker color results. In contrast, female respondents showed a greater preference for colors that appeared at medium temperatures (160°C-180°C) and were brighter. These differences indicate the influence of gender on the aesthetic assessment of wood color after heat treatment. This darker color change was preferred by consumers over the lighter natural wood color, indicating an increase in aesthetic value from the heat treatment [14]. This strong preference for 180°C and 200°C is consistent with research on Andong bamboo, which found that treatments at these temperatures produced an appearance considered more exotic and attractive by consumers [25]. The findings are also consistent with a study on apus and ater bamboo, which found that consumers generally preferred the darker color of bamboo after OHT compared with untreated samples [26]. Differences in preference are based on gender: men tend to prefer the darker color of wood heat-treated at higher temperatures, whereas women prefer the lighter color of wood heat-treated at lower temperatures [19]. This demonstrates the importance of considering consumer preferences in product development, especially regarding color. A deeper understanding of these specific color preferences is crucial for enhancing the aesthetic value and application potential of OHT-treated wood products and for increasing their market value [14,27].

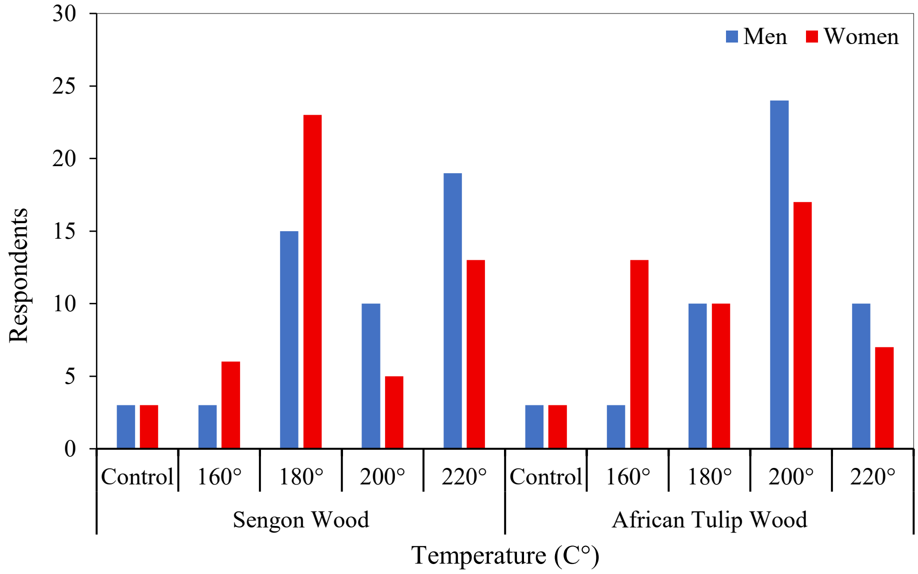

Figure 7. Community preferences for sengon wood and African tulip wood based on gender

4. Conclusion

Oil heat treatment (OHT) effectively alters the visual appearance of sengon wood (Falcataria moluccana) and African tulip wood (Spathodea campanulata), producing significant changes in color parameters (L*, a*, b*) as reflected in the overall color difference (ΔE*). Increasing the treatment temperature from 160°C to 220°C consistently darkens the wood surface due to thermal degradation of wood components, particularly hemicellulose. Based on the ΔE* value, sengon wood experienced a color change of 11.39 at a temperature of 160°C, 13.03 at 180°C, 22.58 at 200°C, and 26.05 at a temperature of 220°C. Meanwhile, African tulip wood showed ΔE* values of 17.73 (160°C), 21.52 (180°C), 26.30 (200°C), and 28.93 (220°C). Based on the classification of color changes, OHT treatment at 160°C on sengon wood is classified as very large color changes. In contrast, all other treatments on both wood types showed total color changes (ΔE* > 12), indicating a strong influence of OHT on wood color appearance. In terms of public preference, both male and female respondents showed the highest interest in wood heated to 180°C and 200°C, with men tending to prefer darker colors (higher temperatures) than women. These findings indicate that OHT not only improves the aesthetics of wood by producing darker, more even colors but also increases its appeal to consumers, especially at medium to high treatment temperatures. Therefore, OHT can be recommended as an effective method to improve the visual quality and market value of wood from both fast-growing and invasive species.

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