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RESEARCH ARTICLE

Color Modification of Andong Bamboo (*Gigantochloa pseudoarundinacea*) through Oil Heat Treatment: Aesthetic Enhancement and Consumer Preferences

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ABSTRACT

Bamboo is a sustainable alternative to wood and is classified as a non-timber forest product. The primary raw material for this research is andong bamboo (*Gigantochloa pseudoarundinacea*). which exhibits vivid physical coloration that may reduce its aesthetic appeal. Additionally, it is susceptible to fungal and insect infestations. Heat treatment has been identified as an effective method for modifying the color properties of bamboo, with oil heat treatment offering potential advantages. This study investigated the impact of oil heat treatment on the color properties of andong bamboo and evaluates consumer preferences regarding its modified appearance. Andong bamboo specimens were subjected to oil bath at temperatures of 180°C, 200°C, 220°C, and 240°C for three hours. Colorimetric analysis was conducted using the CIE-*Lab* system, measuring parameters such as lightness (L^*), red-green chromaticity (a^*), yellow-blue chromaticity (b^*), and overall color change (ΔE^*). The results indicate a significant reduction in L^* values with increasing treatment temperature, leading to a darker appearance. Similarly, a^* and b^* values decreased, indicating a shift in chromatic characteristics. A value of ΔE^* above 12 suggests a total color change. Consumer preference analysis revealed that respondents favored andong bamboo heat-treated at 180°C and 200°C, perceiving these treatments as producing a more exotic and visually appealing. These findings suggest that oil heat treatment not only enhances the aesthetic value of andong bamboo but also increases its potential for high-value applications in furniture and interior design.

1. Introduction

The demand for roundwood supply in Indonesia is increasing, impacting the quality and quantity of harvested timber. The Ministry of Environment and Forestry (2023) reported that the total production of logs in Indonesia has increased yearly, totaling 68.22 million m³. The demand for wood raw materials mostly comes from industrial forest plantations, community forest plantations, and community forests. However, among the three types of forests, there are limitations in the quality of the wood produced (Abdillah et al., 2020). Given these conditions, another raw material source with a similar chemical composition is needed as an alternative. Bamboo is another lignocellulosic material that can be used besides wood (Febrianto et al., 2015). Bamboo is a non-timber forest product species classified as a fast-growing plant and found in almost all regions of Indonesia. There are many different bamboo species in Indonesia. According to Widjaja (2019), there are 160 bamboo species in Indonesia, consisting of 122 species native to Indonesia and 38 non-native (introduced) species. Bamboo has strong and flexible stems, can be cultivated in lowland and highland areas, and has added value for the community. However, bamboo also has weaknesses, including its hydrophilic properties (Sharma et al., 2014), and bamboo is susceptible to fungi and insects (Febrianto et al., 2015). These disadvantages make bamboo less durable for furniture and building material applications, limiting its potential for long-term use (Fahim et al., 2022). Suri et al. (2019) reported that steam-treated bamboo-mixed particleboard showed improved durability and better dimensional stability than heat-soaked. These low properties can be improved through modification (Hidayat et al., 2017).

Modification is generally carried out to change the properties of raw materials (Won et al., 2015). Modification to enhance the color and durability of bamboo includes impregnation and heat treatment. Bamboo impregnation can change the color of bamboo by introducing pigments or chemicals into its pores, resulting in a more attractive and durable color (Zheng et al., 2023). However, this impregnation method has environmental issues. It must be used very carefully (Fahim et al., 2022). Heat treatment aims to alter the chemical composition (lignin, cellulose, hemicellulose, etc) of wood macromolecules, impacting its biological and physical characteristics, thereby enhancing the quality of the finished product and providing wood durability (Hong et al., 2020). These changes occur due to degradation of the chemical composition. Tang et al. (2019a) asserted that heat treatment is an option for improving the eco-friendly bamboo's physical, mechanical, and chemical qualities. This study employed the oil heat treatment approach. The oil heat treatment technique involves thermally processing by cooking with vegetable oil at designated temperatures and durations (Tang et al., 2019a). Vegetable oil is easy to find in the market and economically efficient. This method is more environmentally friendly because it does not use harmful chemicals that can pollute the environment (Azadeh and Ghavami, 2018).

The oil heat treatment method has a significant effect on color change. The temperature and duration of heat treatment can produce intended and unintended color changes (Kim, 2016). A study by Hidayat et al. (2016) on high-density wood, specifically okan wood (*Cylicodiscus gabunensis*), showed that the application of heat treatment affects the degree of discoloration. Wood is commonly used for furniture and many other uses, where the choice of color affects personal preference. Prior research conducted by Hidayat et al. (2017) indicated that consumer preferences for alterations in the coloration of *Pinus koraiensis* and *Paulownia tomentosa* wood following heat treatment led to darker wood colors. Most consumers prefer darker wood colors following heat treatment compared to untreated wood. The change in color of wood material that turns darker due to heat treatment is preferred by consumers and can add to the aesthetic value of the product (Hidayat et al., 2017). Consumer preference is important in selecting bamboo products after heat treatment, as it can be considered when selecting furniture and other household products (Lee et al., 2021). Suri et al. (2021) also showed that oil heat treatment with vegetable oil can remarkably darken the color of royal Paulownia and Korean white pine woods. They said that heat treatment of oil causes the wood to absorb the oil during the treatment process, and the high temperature during treatment also causes a shift in the chemical components of the wood.

Several previous studies have reported on heat treatment using bamboo. Hao et al. (2021) reported that oil heat treatment at a temperature range of 160–200°C for 2–6 hours provided increased dimensional stability and decreased the moisture content of moso bamboo (*Phyllostachys edulis*). Baiti et al. (2021) reported changes in the hygroscopic properties of betung bamboo, which became more hydrophobic (water resistant) and darker in color after heat modification using the air heat treatment method at 160°C for three hours. Wahab et al. (2016) conducted oil heat treatment at 180–220°C for 2 hours on suluk bamboo (*Gigantochloa levis*), resulting in significant color changes where the bamboo appeared darker than the bamboo that was not heat-treated. However, few studies have conducted oil heat treatment on andong bamboo (*Gigantochloa pseudoarundinacea*) at 180–240 °C for 3 hours. Therefore, this study uses different bamboo species and various temperatures to determine the effect of oil heat treatment on color changes in several types of bamboo. Andong bamboo (*G. pseudoarundinacea*) was chosen for this study because of its application in manufacturing building materials and furniture (Alamry, 2024). Andong bamboo has specific advantages compared to other bamboo species, such as high strength and durability and the ability to absorb color well through heat treatment (Tang et al., 2019b). Customer preferences were also observed to determine the optimal temperature for bamboo color change. This study was conducted to test the effect of oil heat treatment on color change and to determine customer preferences for the color of andong bamboo, which is very important in increasing the added value of bamboo products.

2. Materials and Methods

2.1. Sample Preparation

Andong bamboo (*G. pseudoarundinacea*) was obtained from the Cilimus Village, Pesawaran Regency, Lampung Province, Indonesia. The bamboo stems that have been obtained were then taken at the base and cut into several parts, with the length of each sample ± 5 cm. Only bamboos without natural defects were selected as samples. Bamboo culms with a length of ± 2 m were cut into smaller pieces with a length of 5 cm, the bamboo diameter ranged from 10–12 cm, and three samples were used for each treatment temperature. Prior to the oil heat treatment test, the bamboo samples were oven-dried at 100°C for 24 hours.

2.2. Oil Heat Treatment

The samples were immersed in an oil bath (C-WHT-S2; Chang Shin Science, Seoul, Korea). The oil heat treatment technique involves thermally processing by cooking with vegetable oil, which was conducted at target temperatures of 180°C, 200°C, 220°C, and 240°C for 3 hours. After the oil heat treatment phase, the samples were maintained at an ambient temperature between 26 to 28°C and 80% relative humidity before the next testing phase.

2.3. Bamboo Color Evaluation

The testing was conducted with four patterns on each bamboo sample. Color data were taken before and after the heat treatment. The bamboo was scanned with a general calorimeter scanner (AMT507, Amtast, Qingdao, China), and then each visible color change was measured using the CIE-Lab* system. The color change calculated using the Equation 1:

$$\begin{aligned} \Delta L^* &= L_2^* - L_1^* \\ \Delta a^* &= a_2^* - a_1^* \\ \Delta b^* &= b_2^* - b_1^* \\ \Delta E^* &= (\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2})^{1/2} \end{aligned} \tag{1}$$

L_1^*, a_1^*, and b_1^* indicate the lightness, red/green, and yellow/blue chromaticity before heat treatment. L_2^*, a_2^*, and b_2^* indicate the lightness, red/green chromaticity, and yellow/blue after heat treatment. The changes in lightness, red/green, yellow/blue, and overall color are indicated by ΔL^*, Δa^*, Δb^*, and ΔE^*. The overall color change (ΔE^*) is then classified based on the ΔE^* values as $0.0 < \Delta E^* \leq 0.5$, which is defined as negligible; $0.5 < \Delta E^* \leq 1.5$, which is defined as slightly perceivable; $1.5 < \Delta E^* \leq 3$, which is noticeable; $3 < \Delta E^* \leq 6$, which is appreciable; $6 < \Delta E^* \leq 12$, which is very appreciable; and more than 12.0, which is totally changed.

2.4. Color Preference Survey

Consumer preferences were ascertained using a public survey regarding the bamboo colors they like for household furniture applications. The survey was conducted at the University of Lampung, Bandar Lampung, Indonesia. The survey method was used to select respondents who were willing and ready to participate and were students of the University of Lampung. The survey was conducted by distributing an online questionnaire containing images of untreated bamboo (control) and bamboo after oil heat treatment at various temperatures (180°C, 200°C, 220°C, and 240°C). Respondents were asked to fill out a form that included (name, student identification number, gender, bamboo images) and to choose their preferred color from each provided bamboo image, then explain why they chose the bamboo with that color. The survey had 100 participants, with 50 males and 50 females.

3. Results and Discussion

3.1. Color Change

The results show that **Fig. 1** below illustrates the color alterations of andong bamboo before and after oil heat treatment. The bamboo exhibits a dark hue (brownish-black) post-heat treatment, but the untreated bamboo (control) retains a vibrant color (yellowish). Zhang et al. (2018) indicated that heat treatment of bamboo at 140°C results in a color alteration to a deeper hue relative to untreated bamboo (control). According to Hidayat et al. (2017), the lightness level of bamboo color decreases, and the change is visually apparent. Bamboo has significant physical characteristics when its color changes. This tendency indicates the condition and quality of the bamboo as well as its usage. The initial temperature and humidity levels are usually associated with changes in bamboo color (Zhang et al., 2015). In general, color changes are closely related to treatment temperature, treatment duration (Lou et al., 2020; Zhang et al., 2015), and initial moisture content of bamboo (Hong et al., 2020).

Fig.1. Visual of andong bamboo before (control) and after oil heat treatment.

Fig. 2 below indicates a considerable reduction in the lightness (*L**) following oil heat treatment. Oil heat-treated bamboo exhibited varying colors at each treatment temperature. Bamboo subjected to temperatures of 180°C, 200°C, 220°C, and 240°C exhibits a deeper coloration than untreated bamboo (control). Heat-treated bamboo undergoes a reduction in lightness due to the loss of chemical constituents. According to the research conducted by Hidayat et al. (2023), there is a correlation between elevated temperature treatment and a significant reduction in lightness in jabon wood. The reduction in *L** in *Paulownia tomentosa* and *Pinus koraiensis* wood was attributed to elevated temperatures and prolonged curing duration (Suri et al., 2021). The reduction in *L** of betung bamboo (*Dendrocalamus asper*) occurs as the treatment temperature increases (Suri et al., 2024). According to **Fig. 2**, oil heat treatment of andong bamboo results in a reduction of lightness as the temperature increases. A lower *L** indicates a deeper color resulting from the breakdown of the bamboo’s chemical constituents.

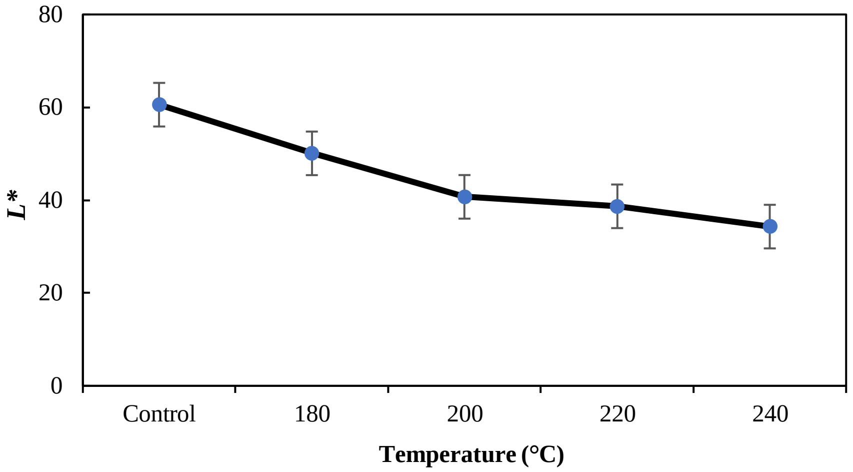

Fig. 2. Changes in lightness value (*L**) after oil heat treatment.

As **Fig. 3** shows, the decline is expressed in the red/green chromaticity (*a**). The temperature range of 180°C to 220°C shows the most clear drop. These computed values also help to assess color variations. Ly et al. (2020) make clear that a positive *a** value denotes a color movement towards red; a negative *a** value denotes a shift towards green. Therefore, following the heat treatment of the oil at each treatment temperature, the color of the andong bamboo shifted towards red, as depicted in **Fig. 3**. Additionally, research by Suri et al. (2024) also examined changes in the *a** value, where it was observed that *Dendrocalamus asper* exhibited a decrease in the *a** value. Furthermore, the *a** parameter during heat treatment allows a color transition towards red at lower temperatures and green at higher treatment temperatures. Changes in the sample's chemical composition and extractive substances can also occur during the heat treatment process (Suri et al., 2021).

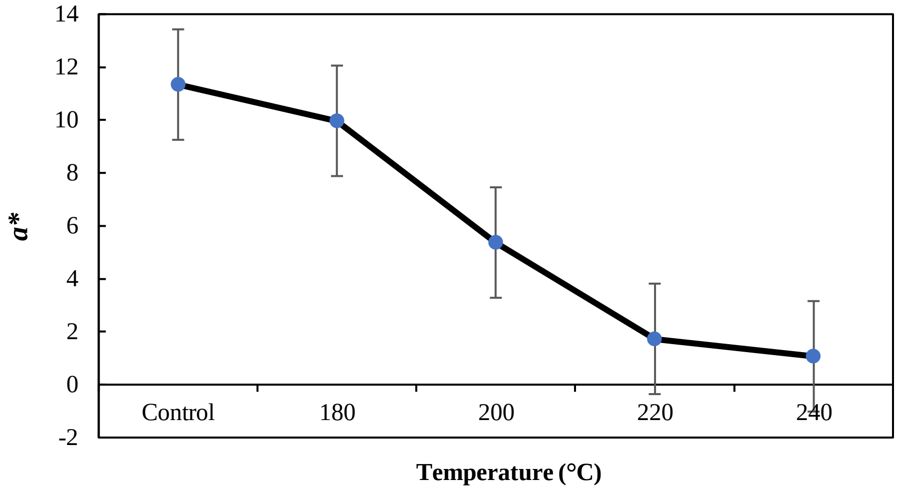

Fig. 3. Change in red/green chromaticity value (*a**) after oil heat treatment.

A graph showing the drop in *b** value of andong bamboo following oil heat treatment is shown in **Fig. 4**. Especially in the temperature range of 180–200°C, oil heat reduces the *b** value of the andong bamboo. One can examine the color changes in andong bamboo using the computation of the *b** value. Ly et al. (2020) pointed out that a positive *b** value denotes a color change toward yellow, whereas a negative *b** value denotes a movement toward blue. Regarding the positive value it exhibits, bamboo exhibits a yellow color change at every tested treatment temperature. Previous studies have indicated that the *b** value decreases following heat treatment, as well as a *b** value pointing *Paulownia tomentosa* and *Pinus koraiensis* blue shift away (Suri et al., 2022). Hidayat et al. (2017) report that the *b** value dropped following treatment at a temperature of 160°C. A reduction in the *b** value of *Dendrocalamus asper* occurs at temperatures of 180–200°C (Suri et al., 2024). One of the elements influencing the change in the color characteristics of the sample is damage to the chemical content following heat treatment of the oil (Lee et al., 2015).

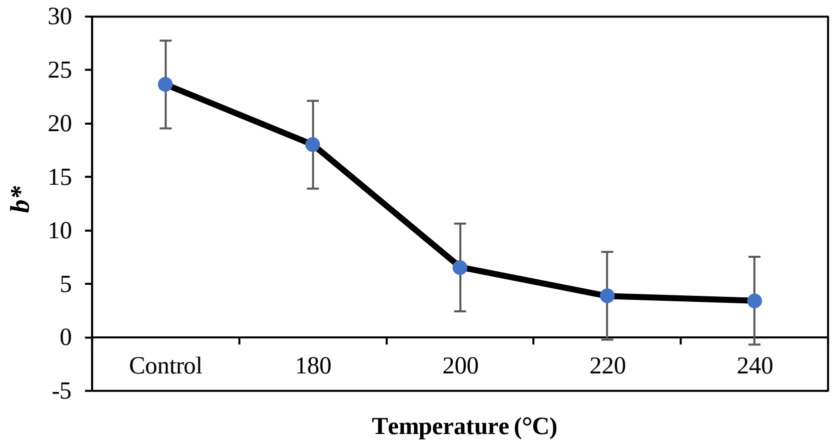

Fig. 4. Changes in yellow/blue chromaticity value (*b**) after oil heat treatment.

Based on **Fig. 5**, the bamboo color underwent significant changes and was completely transformed after the oil heat treatment. Previous research has shown a tendency for the ΔE^* of wood to increase with rising treatment temperatures (Hidayat et al., 2023; Suri et al., 2021). The calculation of color change in andong bamboo shows ΔE^* >12, indicating a significant color change in andong bamboo. Color change by previous research by Zhang et al. (2018) showed ΔE^* >12 at higher temperatures (210–240°C) after oil heat treatment on moso bamboo. Andong bamboo turned darker than moso bamboo due to the difference in temperature and duration. Color change of *Dendrocalamus asper* showed ΔE^* >12, a static rate of decrease in ΔE^* in the temperature range of 180–200°C, and a significant rate of decrease in the temperature range of 200°C–220°C (Suri et al., 2024). All the bamboo experienced a total color change due to the oil heat treatment. The oil heat treatment significantly affects the color change of bamboo due to the heat from the oil and its absorption into the bamboo (Zhang et al., 2015).

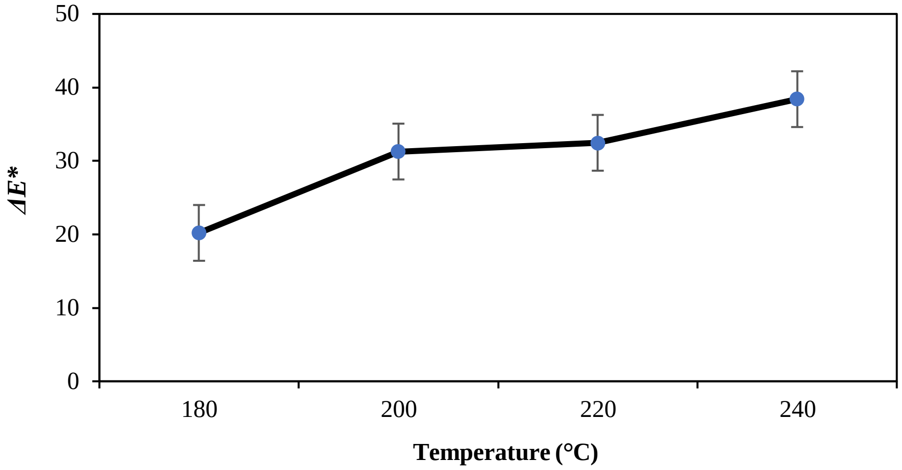

Fig. 5. Graph of the change in color change value (ΔE*) after oil heat treatment.

According to **Table 1**, this research reveals that within temperature ranges of 180°C, 200°C, 220°C, and 240°C, the overall color change (Δ*E**) altered following oil heat treatment. This clarification is based on the findings of Febrianto et al. (2015), who demonstrated that heat treatment reduces the lightness of bamboo, degrading its chemical components and causing the color shift. According to Li et al. (2022), the ultimate purpose of dark-colored bamboo is to increase its monetary worth. Bamboo with a darker color tends to be more attractive, often chosen as a material for decorations or furniture (Febrianto et al., 2015). Suri et al. (2021) also explained that heat treatment of oil causes wood to absorb oil during the treatment process, high temperatures, when reaching the boiling point of the oil, can also cause shifts in the chemical components of the wood material.

Table 1. Total color change of andong bamboo after heat treatment

OHT Temperature (°C)	Color				Values ΔE*
	*ΔL**	*Δa**	*Δb**	*ΔE**	
180	50,08 (1,42)	9,97 (0,52)	18,02 (1,53)	20,20 (0,63)	Totally Changed
200	40,71 (0,61)	5,37 (0,80)	6,54 (0,33)	31,27 (1,91)	Totally Changed
220	38,67 (0,48)	1,73 (0,25)	3,89 (0,18)	32,46 (1,28)	Totally Changed
240	34,30 (4,26)	1,07 (0,12)	3,43 (0,08)	38,40 (3,29)	Totally Changed

Notes: *ΔL**= lightness level; *Δa**= red/green chromaticity value, *Δb**= yellow/blue chromaticity value, *ΔE**= overal color change value. The number in parentheses is the standard deviation.

3.2. Consumer Preferences Regarding the Color Changes of Andong Bamboo After Oil Heat Treatment

One important consideration for forestry decision-makers is information about consumer preferences for wood products (Wan et al., 2021). Wood product manufacturers, marketers, and decision-makers can all benefit from studies that show what people want regarding building design and construction. One of the most important visual perception features that affects customers' choices to buy wood products is color (Wang et al., 2020). A preference for earth brown colors reinforces the desire to connect with nature in eco-friendly furniture (Hsu and Lin, 2015). Earthy brown evokes natural wood and organic materials, which supports sustainable material choices (Alamry, 2024). **Fig. 6** shows consumer preference for the color of andong bamboo (*Gigantochloa pseudoarundinacea*) before and after oil heat treatment.

The overall results of the color preference test in this study show that respondents favor the darker color of heat-treated bamboo over its natural color (control). After oil heat treatment, andong bamboo revealed that 43% of respondents picked the bamboo color at 200°C (**Fig. 6**). The color of the bamboo chosen is dark brown compared to the color of the bamboo at a lower temperature. Interviewing several customers, they decided on bamboo hue since it seemed more exotic than the lighter and darker ones. According to earlier studies by Hidayat et al. (2017) on customer color preferences, most people like wood treated between 200 °C and 220 °C for furniture and design, consumers today like and value dark brown. Geng et al. (2024) reported that dark brown is a color that customers widely prefer in the furniture, decoration, and flooring markets. Nguyen et al. (2020) also explained that wood color is an important material property and the first view consumers can see. **Fig. 7** shows consumer preference for the color of andong bamboo (*Gigantochloa pseudoarundinacea*) before and after oil heat treatment based on gender.

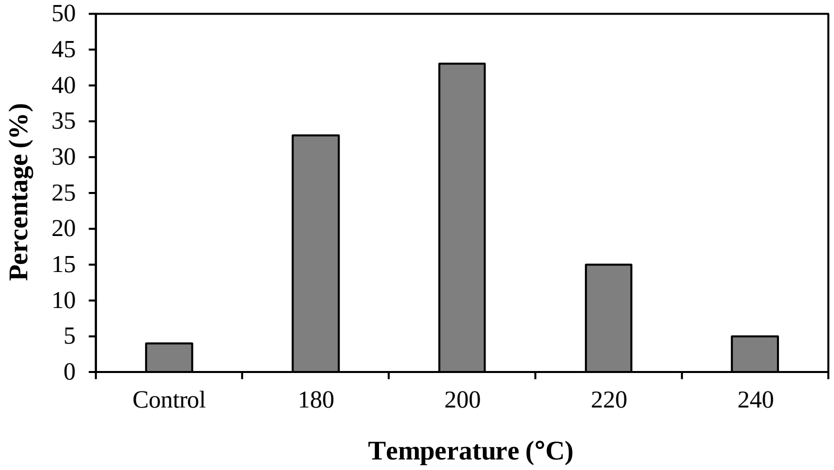

Fig. 6. Consumer preference for the color of andong bamboo (*Gigantochloa pseudoarundinacea*) before and after oil heat treatment.

The results of the consumer preference test based on gender (**Fig. 7**) show a difference in preference where the majority of women chose bamboo color at 180°C (46%). In comparison, most men chose bamboo color at 200°C (44%). This indicates that women prefer lighter bamboo colors than most men prefer darker colors. However, at the bamboo color of 200°C, 42% of women also liked this bamboo color. Another reason most women choose the bamboo color at 180 degrees is that it is brighter and looks more natural. Previous research by Hidayat et al. (2017) showed that both male and female consumers preferred darker wood colors after heat treatment as raw flooring and furniture materials. Comprehensive interviews with representative participants indicated a preference for the darkest of heat-treated andong bamboo. Nevertheless, the coloration of bamboo subjected to high-temperature treatment nearly eradicates its inherent texture and pattern.

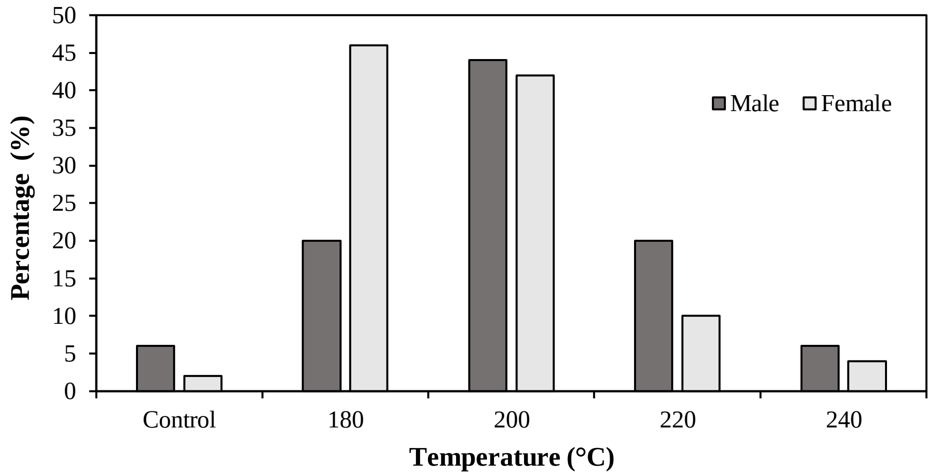

Fig. 7. Consumer preference for the color of andong bamboo (*Gigantochloa pseudoarundinacea*) before and after oil heat treatment based on gender.

4. Conclusion

A considerable color change (ΔE^*) is produced by the impact of oil heat treatment on the color change of andong bamboo, with a complete color change ($\Delta E^* > 12$). This is demonstrated by the data received. The heat treatment of andong bamboo (*Gigantochloa pseudoarundinacea*) has been shown to substantially impact the plant's color change. Because of the oil heat treatment method, the bamboo's chemical components (lignin) degradation is confirmed by reduced L values, which has resulted in the color shift to a deeper tint. When it comes to the color of andong bamboo, the findings of the consumer preference study indicate that respondents preferred the color of bamboo that had been subjected to oil heat treatment at temperatures of 180°C and 200°C. This is because the bamboo color was more exotic and appealing. This research is expected to provide consumers with options for choosing the use of bamboo after oil heat treatment as a raw material for furniture and other building materials.

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Conflicts of Interest: The authors declare no conflict of interest.

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