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INVESTIGATION OF SOME SURFACE CHANGES OCCURRING AFTER BLEACHING TREATMENT ON AYOUS (*Triplochiton scleroxylon* K. Schum) WOOD

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Citation

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Abstract

Oxalic acid ($C_2H_2O_4$), hydrogen peroxide (H_2O_2), and sodium hydroxide (NaOH) chemicals are widely used in the bleaching industry. This research examined alterations in color parameters, glossiness values, and the whiteness index (*WI**) values following the application of bleaching agents, namely $C_2H_2O_4$ and H_2O_2 + NaOH solutions, on ayous (*Triplochiton scleroxylon* K. Schum) wood. A control group was established to compare the treated surfaces. The results indicate that variance analyses revealed significant differences across all tests concerning the type of bleaching chemical used. The application of bleaching chemicals resulted in increases in *WI** values in both directions. The Δ*E** values were determined to be 2.21 when using the $C_2H_2O_4$ chemical and 12.01 with the H_2O_2 + NaOH chemicals. It was determined that glossiness values decreased in both directions at 60 and 85 degrees. In addition, increases were observed in *L** and h^o values, while decreases were obtained in *C** and *a** values. It was observed that the surface properties of ayous wood changed with the chemicals used in the study.

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1. Introduction

Wood finishing involves a combination of processes like sanding, scraping, and planning to achieve a smooth surface for subsequent treatments. Following surface preparation, a range of finishes is applied, including varnishes, lacquers, and paints. Adhesives of various types are employed for bonding wood pieces together. Varnishes and lacquers are utilized to impart a glossy surface to the wood. Anti-bacterial paints serve to safeguard wood against bacterial decay. UV stabilizers and protectants are utilized to shield wood from sunlight. Wastewater generated from wood coating activities typically originates from these processes and the cleaning of process equipment (Badve et al., 2013). Color is an attribute of visual interpretation that is defined by the spectral makeup of light that is reflected off surfaces (Sandoval-Torres et al. 2010). Brightness is commonly described as the quality accountable for the glossy or shiny aspect of a coating. Assessing brightness becomes pivotal in scenarios necessitating the aesthetic allure of a coated varnish (Khanna and Kumar, 2008). Whiteness encompasses more than just lightness, which is measured by CIE Y values or CIE L^* values. Lightness, hue, and colorfulness-determined by CIE a^* and b^* values in the CIELAB space-all play a role in the perception of whiteness (Luo et al., 2009).

Color lightening methods can be categorized into oxidation-based and reduction-based color lightening techniques. Bleaching should only be undertaken when absolutely essential, as it has the potential to detract from the inherent beauty and lively aesthetic of solid wood or wood veneers. Color fading refers to the depletion of natural pigments in wood due to the action of different oxidation and reduction substances (Kurtoğlu, 2000). The aesthetic appeal of wood is influenced by its hue, grain pattern, sheen, and the techniques used for bleaching, filling, staining, and applying clear coatings. Given the vast array of color combinations and tones present in wood, offering exhaustive descriptions of all color variations is impractical. Nonetheless, the sapwood of many species tends to be light-colored, with some approaching near-whiteness (Forest Products Laboratory, 2000). The bleaching process carried out to remove lignin provides nearly permanent whiteness but is expensive (Shmulsky and Jones, 2011).

In the literature, there are reports of bleaching treatments conducted on various wood species using different bleaching agents [balau red (*Shorea guiso*) (Peker et al., 2024), bulletwood (*Manilkara bidentata* (A.DC.) A. Chev.) (Peker et al., 2023a), movingui (*Distemonanthus benthamianus*) (Peker et al., 2023b), Japanese larch (*Larix kaempferi*) and Mongolian oak (*Quercus mongolica*) (Park et al., 2022), satinwood ceylon (*Chloroxylon swietenia* DC) (Ayata and Çamlıbel, 2023), bamboo (Nguyen et al., 2019), ilomba (*Pycnanthus angolensis* Exell) (Ayata and Bal, 2023), okoumé (*Aucoumea klaineana*) (Çamlıbel and Ayata, 2024a), birch (Yamamoto et al., 2017), canelo (*Drimys winteri* J.R. Forst. & G. Forst.) (Peker, 2023a), birch (Liu et al., 2015), oak, birch, Norway maple, European larch (Möttönen et al. 2003), olon (*Zanthoxylum heitzii*) (Peker and Ayata, 2023), lotofa (*Sterculia rhinopetala*) (Peker, 2023b), cocobolo (*Dalbergia retusa* Hemsl.,) (Çamlıbel and Ayata, 2024b), black locust (*Robinia pseudoacacia* L.) (Peker and Ulusoy, 2023), linden (*Tilia tomentosa* - Moench.) (Çamlıbel and Ayata, 2023a), basralocus (*Dicorynia guianensis* Amshoff) (Ayata and Bal, 2024), maritime pine (Mehats et al., 2021), ekop (*Tetraberlinia bifoliolata* Haum.) (Çamlıbel and Ayata, 2023b), birch (Mononen et al. 2005), and izombé (*Testulea gabonensis*) (Peker et al., 2023c).

It has been observed in the literature that ayous wood has not been bleached using $C_2H_2O_4$ and H_2O_2 + NaOH bleaching chemicals. To provide a brief overview of this wood species:

According to reports, ayous wood pulp has potential for producing paper of medium quality (Louppe et al. 2008). In the United Kingdom, "ayous (*Triplochiton scleroxylon* K. Schum)" timber finds application in pattern making, skirting, furniture, and shelf construction. It is capable of taking a fine polish and should be seasoned before use (Boulton and Price, 1931). Although ayous wood is lightweight, its strength values are notable owing to its density (Bosu and Krampah, 2005).

In ayous wood, the thermal conductivity value was determined as 0.14 W/m.K, lignin content was 32.40%, water extraction was 2.28%, cellulose content was 40.40%, pentosan content was 17.00%, silica content was 0.019%, ash content was 2.19%, and ethanol extraction was 1.99% (Gérard et al., 2019). Weight losses for *Poria placenta* were 42%, for *Irpex lacteus* were 56%, for *Gloeophyllum trabeum* were 24%, and for *Trametes versicolor* were 61% (Nzokou et al., 2003). Shore D hardness was 37.65 HD, air-dried density was 384 kg/m^3, and Janka hardness values were 21.01 N/mm^2, 17.87 N/mm^2, and 28.69 N/mm^2 in tangential, radial, and tangential directions, respectively. Nail holding resistance values were 4.69 N/mm^2, 4.39 N/mm^2, and 4.41 N/mm^2 in tangential, radial, and tangential directions, respectively (Ayata, 2020).

In this study, certain surface changes resulting from the bleaching of ayous wood were investigated. The aim of this study was to enable the emergence of a new situation in terms of the applications of ayous wood with the results obtained from this study.

2. Materials and Methods

2.1. Material

2.1.1. Wood Material

In this research, ayous (*Triplochiton scleroxylon* K. Schum) wood was employed as the primary material. The wood was obtained from a reliable commercial supplier to ensure top quality and had dimensions measuring 100 x 100 x 16 mm. In adherence to these selection criteria, the specimens were prepared according to the protocols outlined in ISO 554, (1976). Prior to the bleaching procedure, the test samples underwent sanding with grits 80, 120, and 180, followed by surface cleaning using compressed air.

2.1.2. Bleaching Chemicals

In the study, single-component [oxalic acid ($C_2H_2O_4$): liquid, colorless, odorless, pH value 2.0±0.5] and two-component [pH value 7, liquid, odorless, colorless, soluble, solvent water, hydrogen peroxide (H_2O_2): component A and sodium hydroxide (NaOH): component B, in a ratio of 2:1] chemicals were utilized.

2.2. Method

2.2.1. Application of Bleaching

The chemicals were applied to the wooden surfaces using a sponge with the brushing technique, as a single layer.

2.2.2 Determination of Glossiness Values, Color Parameters, and Whiteness Index (*WI**) Properties

Glossiness assessments were carried out using the ETB-0833 model gloss meter device at three different angles (20°, 60°, and 85°) in both perpendicular and parallel directions to the fibers, in accordance with ISO 2813 (1994) specifications. The Whiteness Meter BDY-1 device was utilized to determine the whiteness index (*WI**) values in both parallel and perpendicular directions to the fibers, following the ASTM E313-15e1 (2015) standard. The color alteration of samples was measured using a CS-10 (CHN Spec, China) device based on the CIELAB color system and ASTM D 2244-3 (2007) standard [CIE 10° standard observer; CIE D65 light source, illumination system: 8/d (8°/diffuse illumination)]. The evaluations of total color difference were determined according to DIN 5033 (1979) standards. [undetectable (<0.2), very weak (0.2 - 0.5), weak (0.5 - 1.5), distinct (1.5 - 3.0), very distinct (3.0 - 6.0), strong (6.0 - 12.0), and very strong (> 12.0)]. Explanations for ΔC^*, Δa^*, Δb^*, and ΔL^* are detailed in Table 1, based on Lange (1999) guidelines.

Table 1: The definitions of Δa^*, ΔC^*, Δb^*, and ΔL^* (Lange 1999)

Test	Positive Description	Negative Description
Δb^*	More yellow than the reference	Bluer than the reference
ΔL^*	Lighter than the reference	Darker than the reference
Δa^*	Redder than the reference	Greener than the reference
ΔC^*	Clearer, brighter than the reference	Duller, matte than the reference

The total color differences were determined using the formulas below.

$\Delta a^* = [a^*_{\text{bleached}}] - [a^*_{\text{control}}]$ (1)
$\Delta L^* = [L^*_{\text{bleached}}] - [L^*_{\text{control}}]$ (2)
$\Delta b^* = [b^*_{\text{bleached}}] - [b^*_{\text{control}}]$ (3)
$\Delta E^* = [(\Delta L^*)^2 + (\Delta b^*)^2 + (\Delta a^*)^2]^{1/2}$ (4)
$C^* = [(a^*)^2 + (b^*)^2]^{1/2}$ (5)
$\Delta C^* = [C^*_{\text{bleached}}] - [C^*_{\text{control}}]$ (6)
$h^o = \arctan [b^*/a^*]$ (7)
$\Delta H^* = [(\Delta E^*)^2 - (\Delta L^*)^2 - (\Delta C^*)^2]^{1/2}$ (8)

2.2.3. Statistical Analysis

Statistical analysis was performed using statistical software, examining the measurement data from the study. This process included calculating identifying the maximum and minimum mean values, standard deviations, computing measurement values related to the mean, conducting variance analyses, establishing homogeneity groups, and determining percentage (%) change rates.

3. Results

Table 2 shows the recorded data for color parameters (a^*, b^*, C^*, h^o, and L^*).

Table 2: Measurement results for color parameters (a^*, b^*, C^*, h^o, and L^*)

Test	Bleaching Chemical Type	N	Mean	Change Ratio (%)	*HG*	Standard Deviation	Mini-mum	Maxi-mum	Coefficient of Variation
L^*	Control	10	64.65	-	C**	0.46	63.87	65.37	0.71
	$C_2H_2O_4$	10	66.69	↑3.16	B	0.63	66.01	67.69	0.94
	H_2O_2 + NaOH	10	75.43	↑16.67	A*	0.44	75.00	76.13	0.59
a^*	Control	10	7.73	-	A*	0.28	7.26	8.07	3.68
	$C_2H_2O_4$	10	7.02	↓9.18	B	0.26	6.69	7.51	3.71
	H_2O_2 + NaOH	10	3.44	↓55.50	C**	0.14	3.28	3.79	4.06
b^*	Control	10	24.03	-	B	0.32	23.36	24.34	1.33
	$C_2H_2O_4$	10	24.49	↑1.91	A*	0.54	23.92	25.57	2.20
	H_2O_2 + NaOH	10	20.98	↓12.69	C**	0.52	20.31	22.13	2.48
C^*	Control	10	25.35	-	A*	0.52	24.46	26.34	2.04
	$C_2H_2O_4$	10	25.27	↓0.32	A	0.79	23.68	26.57	3.13
	H_2O_2 + NaOH	10	21.25	↓16.17	B**	0.54	20.57	22.46	2.52
h^o	Control	10	72.16	-	C**	0.43	71.60	72.86	0.60
	$C_2H_2O_4$	10	74.01	↑2.56	B	0.46	73.04	74.41	0.62
	H_2O_2 + NaOH	10	80.68	↑11.81	A*	0.18	80.27	80.84	0.23

N: Number of Measurements, *HG*: Homogeneity Group, *: Lowest Value, **: Highest Value

Table 3 presents the results for the total color differences (ΔE^*).

Table 3: Results for the total color differences

Bleaching Chemical Type	ΔL^*	Δa^*	Δb^*	ΔC^*	ΔH^*	ΔE^*	Color Change Criteria (DIN 5033, 1979)
$C_2H_2O_4$	2.04	-0.72	0.45	-0.07	0.84	2.21	Distinct (1.5 - 3.0)
H_2O_2 + NaOH	10.78	-4.29	-3.06	-4.09	3.31	12.01	Very Strong (> 12.0)

Table 4 outlines the measured glossiness values.

Table 4: Measurement results for glossiness values

Test	Bleaching Chemical Type	N	Mean	Change Ratio (%)	*HG*	Standard Deviation	Mini-mum	Maxi-mum	Coefficient of Variation
⊥20°	Control	10	0.40	-	B**	0.00	0.40	0.40	0.00
	$C_2H_2O_4$	10	0.41	↑2.50	B	0.09	0.30	0.50	21.36
	H_2O_2 + NaOH	10	0.50	↑25.00	A*	0.00	0.50	0.50	0.00
⊥60°	Control	10	1.86	-	A*	0.15	1.70	2.10	8.09
	$C_2H_2O_4$	10	1.28	↓31.18	C**	0.10	1.20	1.40	8.07
	H_2O_2 + NaOH	10	1.68	↓9.68	B	0.13	1.50	1.80	7.84
⊥85°	Control	10	0.45	-	A*	0.14	0.30	0.60	30.09
	$C_2H_2O_4$	10	0.10	↓77.78	B**	0.00	0.10	0.10	0.00
	H_2O_2 + NaOH	10	0.10	↓77.78	B**	0.00	0.10	0.10	0.00
‖20°	Control	10	0.40	-	B**	0.00	0.40	0.40	0.00
	$C_2H_2O_4$	10	0.40	0.00	B**	0.00	0.40	0.40	0.00
	H_2O_2 + NaOH	10	0.46	↑15.00	A*	0.05	0.40	0.50	11.23
‖60°	Control	10	2.17	-	A*	0.16	2.00	2.40	7.54
	$C_2H_2O_4$	10	1.76	↓18.89	B**	0.21	1.60	2.00	11.74
	H_2O_2 + NaOH	10	1.79	↓17.51	B	0.09	1.70	1.90	4.89
‖85°	Control	10	0.45	-	A*	0.14	0.30	0.60	30.09
	$C_2H_2O_4$	10	0.18	↓60.00	B	0.10	0.10	0.30	57.38
	H_2O_2 + NaOH	10	0.10	↓77.78	B**	0.00	0.10	0.10	0.00
N: Number of Measurements, *HG*: Homogeneity Group, *: Lowest Value, **: Highest Value									

Table 5 illustrates the obtained values for whiteness index (*WI**).

Table 5: Measurement results for whiteness index (*WI**) values

*WI** ⊥	Control	10	22.82	-	B**	0.47	22.50	23.70	2.05
	$C_2H_2O_4$	10	23.06	↑1.05	B	0.44	22.60	23.60	1.89
	H_2O_2 + NaOH	10	33.28	↑45.84	A*	0.45	32.80	33.80	1.35
*WI** ‖	Control	10	15.26	-	C**	0.38	14.90	16.20	2.51
	$C_2H_2O_4$	10	19.46	↑27.52	B	0.14	19.30	19.70	0.73
	H_2O_2 + NaOH	10	30.18	↑97.77	A*	0.15	29.90	30.30	0.51
N: Number of Measurements, *HG*: Homogeneity Group, *: Lowest Value, **: Highest Value									

The Table 6 presents the analysis of variance outcomes for color parameters (*a**, *b**, *C**, *h*°, and *L**), glossiness values, and whiteness index (*WI**) values.

Table 6: Analysis of variance results for color parameters (*a**, *b**, *C**, *h*°, and *L**), glossiness values, and whiteness index (*WI**) values

Bleaching Chemical Type					
Test	Sum of Squares	df	Mean Square	F Value	Sig.
*L**	655.814	2	327.907	1221.444	0.000*
*a**	105.582	2	52.791	941.013	0.000*
*b**	72.928	2	36.464	164.752	0.000*
*C**	109.728	2	54.864	139.420	0.000*
h°	401.300	2	200.650	1387.159	0.000*
⊥20° glossiness	0.061	2	0.030	11.870	0.000*
⊥60° glossiness	1.763	2	0.881	52.184	0.000*
⊥85° glossiness	0.817	2	0.408	66.818	0.000*
‖20° glossiness	0.024	2	0.012	13.500	0.000*
‖60° glossiness	1.045	2	0.522	20.321	0.000*
‖85° glossiness	0.673	2	0.336	34.793	0.000*
*WI** (⊥)	713.059	2	356.529	1751.509	0.000*
*WI** (‖)	1183.883	2	591.941	9270.543	0.000*
*: Significant					

4. Discussion

Increases of 3.16% with $C_2H_2O_4$ and 16.67% with H_2O_2 + NaOH were obtained in the L^* parameter. Samples treated with the H_2O_2 + NaOH solution exhibited the highest L^* value (75.43), while the control experiment samples showed the lowest value (64.65) (Table 2). In the literature, the bleaching process with $C_2H_2O_4$ and H_2O_2 + NaOH chemicals were reported to increase the L^* values in bulletwood (Peker et al., 2023a), movingui (Peker et al., 2023b), ilomba (Ayata and Bal, 2023), olon (Peker and Ayata, 2023), canelo (Peker, 2023a), lotofa (Peker, 2023b), and black locust (Peker and Ulusoy, 2023) woods.

The lowest result for the a^* parameter was found on samples treated with the H_2O_2 + NaOH solution (3.44), while the highest was obtained in the control experiment samples (7.73). Decreases of 9.18% with $C_2H_2O_4$ and 55.50% with H_2O_2 + NaOH were found in the a^* value (Table 2). In the literature, it has been reported that satinwood ceylon (Ayata and Çamlıbel, 2023), lotofa (Peker, 2023b), and black locust (Peker and Ulusoy, 2023) woods subjected to bleaching with $C_2H_2O_4$ and H_2O_2 + NaOH chemicals exhibited increases in the a^* parameters.

The lowest result for the b^* parameter was determined on samples treated with the H_2O_2 + NaOH solution (20.98), while the highest result was detected in samples treated with $C_2H_2O_4$ (24.49). In the b^* test, a decrease of 1.91% was observed with $C_2H_2O_4$, and an increase of 12.69% was found with H_2O_2 + NaOH (Table 2). The studies on bleaching revealed that the application of $C_2H_2O_4$ led to an enhancement in the color of satinwood ceylon (Ayata and Çamlıbel, 2023), ilomba (Ayata and Bal, 2023), olon (Peker and Ayata, 2023), lotofa (Peker, 2023b), black locust (Peker and Ulusoy, 2023), and linden (Çamlıbel and Ayata, 2023a) wood species. Conversely, the use of H_2O_2 + NaOH resulted in a decrease in color for the same wood species.

The samples treated with the H_2O_2 + NaOH solution exhibited the lowest result for the C^* parameter (21.25), whereas the highest result was observed in the control experiment samples (25.25). In terms of C^* value, decreases of 0.32% with $C_2H_2O_4$ and 16.17% with H_2O_2 + NaOH were recorded (Table 2). In studies conducted on bleaching, decreases in the C^* values were reported in satinwood ceylon (Ayata and Çamlıbel, 2023) and black locust (Peker and Ulusoy, 2023) woods treated with bleaching agents $C_2H_2O_4$ and H_2O_2 + NaOH.

The h^o parameter reached its peak value in samples treated with the H_2O_2 + NaOH solution (80.68), whereas the lowest value was recorded in the control experiment samples (72.16). An increase of 2.56% was noted with $C_2H_2O_4$, and 11.81% with H_2O_2 + NaOH in the h^o value (Table 2). In previous studies, it has been noted that the h^o values increased in satinwood ceylon (Ayata and Çamlıbel, 2023), movingui (Peker et al., 2023b), ilomba (Ayata and Bal, 2023), izombé (Peker et al., 2023c), ekop (Çamlıbel and Ayata, 2023b), canelo (Peker, 2023a), olon (Peker and Ayata, 2023), and lotofa (Peker, 2023b) woods treated with bleaching agents $C_2H_2O_4$ and H_2O_2 + NaOH.

After the application of both solutions, ΔL^* values (lighter than the reference) were obtained positively, while ΔC^* values (duller, matte than the reference) and Δa^* values (greener than the reference) were determined negatively. Additionally, Δb^* values were found to be positive with $C_2H_2O_4$ (more yellow than the reference) and negative with H_2O_2 + NaOH (bluer than the reference). The ΔE^* values were calculated to be 2.21 with the $C_2H_2O_4$ chemical and 12.01 with the H_2O_2 + NaOH chemicals. When examining the outcomes based on color alteration criteria, it becomes evident that while the $C_2H_2O_4$ chemical resulted in a distinct (1.5 - 3.0) criterion, the H_2O_2 + NaOH chemical yielded a much stronger effect, meeting the very strong (> 12.0) criterion (Table 3).

Glossiness measurements conducted at 60 and 85 degrees in both directions indicated decreases with both bleaching solutions. Likewise, the control experiment group samples yielded the highest results at these degrees and directions (Table 4).

In both perpendicular (⊥) and parallel (∥) directions, the control experimental group exhibited the lowest WI^* values (⊥: 22.82 and ∥: 15.26). Conversely, the samples treated with the H_2O_2 + NaOH chemical solution yielded the highest WI^* values (⊥: 33.28 and ∥: 30.18). The WI^* ⊥ values exhibited increases of 1.05% and 45.84% with the $C_2H_2O_4$ and H_2O_2 + NaOH chemicals, respectively, while the WI^* ∥ values showed increases of 27.52% and 97.77%, respectively (Table 5).

The analysis of variance indicated that the factor representing the number of categories had a significant influence on the test results, as shown in Table 6.

5. Conclusion

Variance analyses were found to be significant across all tests. The WI^* values showed increases in both directions with the bleaching chemicals. It was noted that glossiness values declined in both directions at 60 and 85 degrees. Furthermore, there were increases in h^o and L^* values, while decreases were noted in a^* and C^* values.

Disclosure Statement

No potential conflict of interest was reported by the authors.

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