Determination of Color Characteristics of Some Wood Species Treated with Bleaching Chemicals

Nevzat Çakıcıer [a] and Göksel Ulay [b,*]

With the application of bleaching treatments, the color of the wood material changes. When different bleaching agents are applied to the same wood, different results are likely to be obtained. In this study, wood species doussié (*Afzelia africana*), iatandza (*Albizia ferruginea*), merbau (*Intsia bijuga* (Colebr.) O. Kuntze), mahogany (*Swietenia mahagoni* L.), and hornbeam (*Carpinus betulus* L.) along with one and two component (*B-One-C* and *B-Two-C*) wood bleaching chemicals were applied to the wood material surfaces with sponge technique. Then, color parameters (h^o: hue angle, a^*: red color tone, b^*: yellow color tone, C^*: chroma, and L^*: lightness) were determined on bleached and unbleached materials. According to the results obtained, *B-One-C* application increased h^o, a^*, b^*, C^*, and L^* values in all wood species. The highest ΔE^* values were determined in mahogany, doussié, hornbeam, and merbau wood species treated with *B-Two-C*. The chemicals used in the study showed different results on the same wood.

DOI: 10.15376/biores.18.4.7796-7804

Keywords: Aesthetics; Bleaching; Color; Colour difference; Restoration; Wood

Contact information: a: Department of Forestry Industrial Engineering , Forestry Faculty, Duzce University, Duzce, 81620, Turkey; b: Department of Furniture and Decoration, Van Vocational School, Van Yuzuncu Yil University, Van, 65080, Turkey; *Corresponding author: g.ulay@yyu.edu.tr; gokselulay@gmail.com*

INTRODUCTION

Bleaching agents are widely used to bleach raw cotton and stains, pulp, and paper (Suslick 1998). Today, various chemicals are used in the bleaching of wooden material surfaces [sodium hypochlorite (NaClO), hydrogen peroxide (H_2O_2), sodium percarbonate ($2Na_2CO_3 \cdot 3H_2O_2$), peracetic acid (CH_3COOOH), acetic acid (CH_3COOH), sodium hydroxide (NaOH), carbamide peroxide ($CH_6N_2O_3$), sodium silicate ($NaSiO_3$), oxalic acid ($H_2C_2O_4$), and calcium hydroxide ($Ca(OH)_2$)].

Bleaching treatment is a common modification method used in the industrialization of wood dyeing (Lu *et al*. 2023). The bleaches used in wood are divided into three classes: peroxide or two-component bleaches, chlorine bleach, and oxalic acid (Jewitt 2003). The bleaching of wood material using chemicals aims to prevent the sharing of electrons responsible for color. This can be accomplished by interrupting the conjugation or breaking the conjugated double bonds with a reaction at the functional groups in the compounds responsible for the color (Herstedt and Herstedt 2017).

The natural color of an outdoor wood structure can be partially preserved by rubbing it annually with a commercial wood cleaner or with a bleach/water mixture. Cleaned wooden surfaces should be rubbed with a hard bristle brush and rinsed thoroughly with water. The wood surface should always dry for a few days before re-polishing. In addition, the use of vigorous washing or strong chemicals can greatly accelerate the loss of wood fiber from wood surfaces in cases of mold removal (Williams 2010).

Wood must be made into furniture or other wood-based products and then the surfaces must be bleached if desired. Bleaching processes in wood materials vary in terms of ease. Beech, mahogany, oak, ash, birch, maple, and walnut can be bleached quite easily. It has been reported that it is difficult to satisfactorily bleach tupelo, gum, pine, and poplar (Daly 1948).

There are various studies in the literature on bleaching agents. Color changes in beech and oak wood treated with 2%, 5%, 25%, 50%, and 100% NaClO chemicals were investigated by Costa *et al*. (2023), and color changes on the surface were investigated. Wu *et al*. (2014) reported that uneven wood color was effectively removed after a 6% bleach solution with a hydrogen peroxide mass ratio to tulipwood wood. In the studies conducted by Ulay and Ayata (2023a,b,c), it was reported that the values of color parameters changed after bleaching chemicals were applied with different techniques on the surfaces of sipo, sapele, and Scotch pine woods. Roncero *et al*. (2005) stated that different bleaching agents act on cellulose in different ways, affecting crystallinity, that is, the ratio of amorphous and crystalline regions in the pulp. Liu *et al.* (2015) calculated the color parameters after processing birch on wood materials with 4% hydrogen peroxide solution containing 1% $NaSiO_3 \cdot 9H_2O$. Karal (2017) applied different bleaching chemicals ($NaOH + H_2O_2$, $NaSiO_3 + H_2O_2$, and $H_2C_2O_4$) to the surfaces of some wood species (Scotch pine, sessile oak, Eastern beech, and sapele). When considering studies related to bleaching (Budakçı and Karamanoğlu 2014), it can be seen that there have been very few studies on this subject

In this study, the interactions between some wood species (doussié, hornbeam, iatandza, mahogany, and merbau) and one- and two-component wood bleaching chemicals on color parameters were investigated. The purpose of this study is to determine the color changes occurring after the bleaching of the specified wood species. These wood species are among the important species used indoors and outdoors in the world. This study aims to add important information both for these wood species and for bleaching applications.

EXPERIMENTAL

Obtaining Wood Samples

The test material was obtained from a commercial enterprise in Bursa/İnegöl district in first class quality as 85 x 300 x 25 mm. Doussié (*Afzelia africana*), iatandza (*Albizia ferruginea*), merbau (*Intsia bijuga* (Colebr.) O. Kuntze), mahogany (*Swietenia mahagoni* L.), and hornbeam (*Carpinus betulus* L.) wood species, which are frequently used in furniture, joinery, boatbuilding, building materials, and manufacturing industries, were selected. The samples were randomly selected, knot-free, crack-free, with smooth fibers, and were prepared in accordance with TS ISO 13061-1 (2021). According to the TS 642 ISO 554 (1997) standard, air-conditioning applications were made on the materials. The test samples were initially sanded with sandpapers numbered 80, 120, and then 180.

Application of Bleaching Chemicals to Wood Material Surfaces

Two different bleaching formulations [*B-One-C*: One-component bleach chemical and *B-Two-C*: Two-component bleach chemical] were used in the study. These chemicals were applied to wooden surfaces with sponge application technique. Thus, the first agent (B-One-C) consisted of water plus oxalic acid $C_2H_2O_4$ (liquid, colourless, odourless, pH value 2.0±0.5). The second bleaching agent (B-Two-B) was a mixture of hydrogen peroxide (pH value 7, liquid, colourless, odourless, soluble, diluent water, and hydrogen peroxide) and sodium hydroxide (NaOH), mixed in a 2:1 ratio. These two bleaching formulations were purchased ready to use from the commercial company. There was no need to rinse after the application of *B-Two-C*. The experimental samples subjected to the bleaching process were allowed to dry under normal room conditions for three weeks.

Determination of Optical Properties

Various color terms are used when trying to identify the components of color differences in terms of approximate relations of hue, chroma, lightness, and/or to express color properties in terms of such approximate relations: metric L^* (lightness), C^* (metric color), metric hue difference (ΔH^*), and metric hue. These terms are defined using the a^*, L^*, and b^* parameters of the CIE 1976 ($L^*a^*b^*$) color space (Gangakhedkar 2010). Generally, it consists of characterizing a three-variable color, which includes: L^*: luminance, $+a^*$: red, $-a^*$: green components, and $+b^*$: yellow, $-b^*$: blue components. By comparing the condition before and after any treatment, it is possible to calculate a relative color change expressed as the Euclidean distance ΔE^* (Anonymous 1997; MacDougall 2001; Bristow 2009). A CS-10 (CHNSpec Technology Co., Ltd., Hangzhou, China) colorimeter for measuring color with the CIE $L^*a^*b^*$ system device was used [illumination system: 8/d (8°/diffused illumination), CIE D65 light source, CIE 10° standard observer] according to ASTM D2244-3 (2007) standard (Ayata *et al*. 2021a, 2021b; Ayata 2022). The following formulas were used to calculate the color change (Ayata *et al*. 2018).

$$\text{Hue angle } (h^o) = [\arctan (b^* / a^*)] \quad (1)$$

$$\text{Chroma } (C^*) = [(a^*)^2 + (b^*)^2]^{1/2} \quad (2)$$

$$\Delta L^* = L^*_{\text{bleached}} - L^*_{\text{control}} \quad (3)$$

$$\Delta a^* = a^*_{\text{bleached}} - a^*_{\text{control}} \quad (4)$$

$$\Delta b^* = b^*_{\text{bleached}} - b^*_{\text{control}} \quad (5)$$

$$\Delta C^* = C^*_{\text{bleached}} - C^*_{\text{control}} \quad (6)$$

$$\Delta E^* = [(\Delta a^*)^2 + (\Delta L^*)^2 + (\Delta b^*)^2]^{1/2} \quad (7)$$

$$\Delta H^* = [(\Delta E^*)^2 - (\Delta C^*)^2 - (\Delta L^*)^2]^{1/2} \quad (8)$$

Statistical Analysis

The obtained data were evaluated in a SPSS program (Sun Microsystems, Inc., Santa Clara, CA, USA) and homogeneity groups, minimum, and maximum values, the percentage (%) change rates, standard deviations, and variance analyses belonging to the tests were calculated.

RESULTS AND DISCUSSION

According to analysis results, wood type (doussié, hornbeam, iatandza, mahogany, and merbau) (A), bleach chemical type (*B-One-C* and *B-Two-C*) (B), and interaction (AB) all exhibited significant effects for all color parameters. Results of L^*, b^*, and a^* are given in Table 1 and the results of the h^o and C^* are given in Table 2.

Table 1. The Results of the *a**, *L**, and *b** Values Testing of All Wood Species

Test	Wood Type	Bleach Type	N	Mean	*SD*	*HG*	Change (%)	Min	Max	COV
*L**	Doussié	Control	10	47.22	0.63	I	-	46.70	48.91	1.34
		B-One-C	10	47.90	0.27	I	↑1.44	47.58	48.46	0.56
		B-Two-C	10	59.25	0.79	D	↑25.48	58.36	60.77	1.33
	Hornbeam	Control	10	69.06	0.48	C	-	68.26	69.73	0.70
		B-One-C	10	72.09	0.33	B	↑4.39	71.55	72.61	0.46
		B-Two-C	10	79.40	0.28	A^	↑14.97	78.82	79.78	0.35
	Iatandza	Control	10	57.91	1.32	EF	-	55.85	59.88	2.28
		B-One-C	10	50.18	1.09	H	↓13.35	48.71	51.62	2.18
		B-Two-C	10	68.43	1.05	C	↑18.17	66.91	69.93	1.54
	Mahogany	Control	10	45.80	0.45	J	-	45.25	46.52	0.99
		B-One-C	10	44.53	0.35	K	↓2.77	44.19	45.45	0.78
		B-Two-C	10	57.64	1.00	F	↑25.85	56.19	59.18	1.74
	Merbau	Control	10	51.48	0.93	G	-	50.04	52.41	1.80
		B-One-C	10	42.75	0.27	L^^	↓16.96	42.21	43.21	0.64
		B-Two-C	10	58.51	1.25	E	↑13.66	56.73	60.77	2.14
*a**	Doussié	Control	10	11.83	0.28	E	-	11.33	12.36	2.34
		B-One-C	10	14.55	0.22	C	↑22.99	14.32	14.95	1.49
		B-Two-C	10	7.66	0.35	I	↓35.25	7.01	8.09	4.52
	Hornbeam	Control	10	6.28	0.31	J	-	5.72	6.68	4.94
		B-One-C	10	7.66	0.16	I	↑21.97	7.38	7.92	2.04
		B-Two-C	10	2.16	0.12	L^^	↓65.61	1.95	2.32	5.57
	Iatandza	Control	10	8.77	0.27	H	-	8.35	9.08	3.13
		B-One-C	10	20.74	0.64	A^	↑136.49	19.23	21.41	3.09
		B-Two-C	10	4.59	0.42	K	↓47.66	3.96	5.45	9.13
	Mahogany	Control	10	11.18	0.30	F	-	10.78	11.53	2.64
		B-One-C	10	13.62	0.29	D	↑21.82	13.24	14.08	2.11
		B-Two-C	10	8.93	0.24	H	↓20.13	8.67	9.39	2.66
	Merbau	Control	10	13.83	0.66	D	-	13.28	15.53	4.75
		B-One-C	10	20.11	0.40	B	↑45.41	19.72	20.90	2.00
		B-Two-C	10	9.41	0.75	G	↓31.96	8.02	10.28	8.02
*b**	Doussié	Control	10	15.36	0.85	I	-	14.31	16.79	5.52
		B-One-C	10	21.26	0.33	C	↑38.41	20.66	21.81	1.55
		B-Two-C	10	19.57	0.44	E	↑27.41	18.69	20.14	2.24
	Hornbeam	Control	10	17.61	0.25	F	-	17.26	18.07	1.40
		B-One-C	10	19.57	0.22	E	↑11.13	19.27	20.07	1.15
		B-Two-C	10	12.81	0.18	J^^	↓27.26	12.37	13.03	1.39
	Iatandza	Control	10	17.39	0.56	FG	-	16.23	18.40	3.20
		B-One-C	10	21.33	0.53	C	↑22.66	20.61	22.30	2.48
		B-Two-C	10	23.59	0.75	B	↑35.65	22.27	24.54	3.16
	Mahogany	Control	10	16.66	0.25	H	-	16.40	17.02	1.51
		B-One-C	10	20.08	0.32	DE	↑20.53	19.40	20.50	1.61
		B-Two-C	10	21.61	0.67	C	↑29.71	20.81	22.56	3.11
	Merbau	Control	10	16.93	0.40	GH	-	16.26	17.44	2.35
		B-One-C	10	20.48	1.40	DE	↑20.97	19.25	22.51	6.82
		B-Two-C	10	25.99	1.32	A^	↑53.51	23.82	27.47	5.07

SD: Standard deviation, COV: Coefficient of variation, *HG*: Homogeneity group,
^: Highest value, ^^: Lowest value, N: Number of measurements

Considering the *L** parameter, reductions were observed in iatandza (13.4%), mahogany (2.8%), and merbau (17.0%) wood species after the application of *B-One-C*. In addition, increases were obtained in iatandza (18.2%), mahogany (25.8%), and merbau (13.7%) wood species after the application of the *B-Two-C*. The highest change in *L** was obtained in hornbeam wood with *B-Two-C* treatment, while the lowest was found in *B-One-C* chemically treated merbau wood. *L** values increased in doussié and hornbeam wood species after the application of *B-One-C* and *B-Two-C*. The treatments resulted in different *L** values due to the distinct chemical properties of the wooden materials.

When the results of the *a** parameter were examined, an increase in wood species of doussié (23.0%), hornbeam (22.0%), iatandza (136.5%), mahogany (21.8%), and merbau (45.4%) was determined by the application of *B-One-C*. For the same parameter, a decrease was observed in doussié (35.2%), hornbeam (65.6%), iatandza (47.7%), mahogany (20.1%), and merbau (32.0%) wood species with the application of *B-Two-C*. In addition, after the applications, the highest *a** value was found in iatandza wood exposed to *B-One-C*, while the lowest was obtained in hornbeam wood applied *B-Two-C*. In all wood species, *B-One-C* showed an increase for the *a** parameter, while *B-Two-C* showed a decrease. All wood species showed the same behavior.

According to the results of the *b** parameter, *B-One-C* and *B-Two-C* caused an increase in doussié (38.4% and 27.4%), iatandza (22.7% and 35.6%), mahogany (20.5% and 29.7%), and merbau (21.0% and 53.5%) wood species. In hornbeam wood, while *B-One-C* showed an 11.1% increasing effect, *B-Two-C* exhibited a 27.3% decrease. The highest *b** value was found in *B-Two-C* treated merbau wood, while the lowest was in *B-Two-C*-treated hornbeam wood.

The sequence of the results for the *C** values exhibited the same parallelism as that of the results for the *b** values. For hornbeam wood, while *B-One-C* showed a 12.5% increase, *B-Two-C* exhibited a 30.4% decrease in *C**. Additionally, *B-One-C* and *B-Two-C* caused an increase in doussié (32.8% and 8.5%), iatandza (52.8% and 23.4%), mahogany (21.6% and 17.2%), and merbau (31.3% and 26.5%) wood species. The highest *C** value was found in *B-One-C* treated iatandza wood, while the lowest *B-Two-C*-treated hornbeam wood.

After the application of *B-One-C* and *B-Two-C*, the values of the h^o angle increased 6.2% and 31.1% in doussié wood. The h^o angle showed different results in other wood species. Considering the situation, there were decreases in hornbeam (2.5%), iatandza (27.5%), mahogany (0.2%), and merbau (10.4%) woods after *B-One-C* application, while increases were observed in hornbeam (14.3%), iatandza (25.0%), mahogany (20.6%), and merbau (38.1%) woods after *B-Two-C* application. Further, after the applications, the highest h^o was found in *B-Two-C*-treated hornbeam wood, while the lowest was found in *B-One-C*-treated merbau wood.

In the literature, it has been reported that reductions in *a**, *b**, *C**, and *L** values were obtained after the application of < 5% chlorine-based bleach (NaClO) + anionic and nonionic chemicals to sapele (Ulay and Ayata 2023a) and sipo (Ulay and Ayata 2023c) wood species with the sponge application technique. In the study conducted by Lu *et al*. (2023), it was reported that after 4 g/L NaOH aqueous solution applied to ayous, linden, and poplar wood species, the *L** and h^o increased, while the *b**, *a**, and *C** parameters decreased. In the study conducted by Ulay and Ayata (2023b), it was determined that the h^o and *L** values decreased and the *a**, *b**, and *C** parameters decreased after the NaClO chemical applied to the scotch pine wood surfaces.

Table 2. The Results of the *C** and *h*° Values Testing of All Wood Species

Test	Wood Type	Bleach Type	N	Mean	*SD*	*HG*	Change (%)	Min	Max	COV
*C**	Doussié	Control	10	19.39	0.80	I	-	18.52	20.85	4.12
		B-One-C	10	25.74	0.35	D	↑32.75	25.25	26.44	1.37
		B-Two-C	10	21.03	0.46	H	↑8.46	20.14	21.69	2.17
	Hornbeam	Control	10	18.69	0.29	J	-	18.32	19.12	1.56
		B-One-C	10	21.02	0.25	H	↑12.47	20.71	21.53	1.19
		B-Two-C	10	13.00	0.16	K^^	↓30.44	12.59	13.18	1.27
	Iatandza	Control	10	19.48	0.54	I	-	18.25	20.36	2.77
		B-One-C	10	29.76	0.39	A^	↑52.77	29.03	30.48	1.32
		B-Two-C	10	24.03	0.79	E	↑23.36	22.72	25.14	3.29
	Mahogany	Control	10	19.96	0.21	I	-	19.67	20.49	1.08
		B-One-C	10	24.27	0.39	E	↑21.59	23.53	24.81	1.62
		B-Two-C	10	23.39	0.61	F	↑17.18	22.68	24.27	2.62
	Merbau	Control	10	21.87	0.47	G	-	21.07	22.91	2.13
		B-One-C	10	28.71	1.25	B	↑31.28	27.62	30.57	4.36
		B-Two-C	10	27.67	1.27	C	↑26.52	25.64	29.30	4.58
h°	Doussié	Control	10	52.35	1.16	H	-	50.59	54.30	2.22
		B-One-C	10	55.61	0.39	G	↑6.23	54.92	56.15	0.70
		B-Two-C	10	68.62	0.88	D	↑31.08	67.80	70.48	1.28
	Hornbeam	Control	10	70.37	0.83	C	-	69.37	71.80	1.17
		B-One-C	10	68.62	0.32	D	↓2.49	68.19	69.13	0.47
		B-Two-C	10	80.41	0.61	A^	↑14.27	79.36	81.38	0.76
	Iatandza	Control	10	63.21	0.89	F	-	62.26	64.78	1.41
		B-One-C	10	45.81	1.41	J	↓27.53	43.91	49.23	3.09
		B-Two-C	10	79.00	0.77	B	↑24.98	77.48	80.11	0.97
	Mahogany	Control	10	55.96	0.75	G	-	55.00	57.17	1.35
		B-One-C	10	55.85	0.43	G	↓0.20	54.97	56.35	0.78
		B-Two-C	10	67.49	0.82	E	↑20.60	66.00	68.47	1.22
	Merbau	Control	10	50.76	1.58	I	-	47.32	52.29	3.12
		B-One-C	10	45.47	1.46	J^^	↓10.42	43.99	48.05	3.20
		B-Two-C	10	70.08	1.77	C	↑38.06	66.65	73.43	2.53

SD: Standard deviation, COV: Coefficient of variation, *HG*: Homogeneity group,
^: Highest value, ^^: Lowest value, N: Number of measurements

In the study conducted by Ayata and Bal (2023), it was observed that the application of two different wood bleaching chemicals (single- and double-component) on ilomba (*Pycnanthus angolensis* Exell) wood resulted in increases in both *h*° and *L** values with both bleaching chemicals. While increases in *b**, *a**, and *C** values were identified with the single-component bleaching agent, decreases were observed for these parameters with the double-component bleaching agent.

Compared to this information, it can be said that the wood types and chemical types used during the bleaching process cause different results. It has been observed that the structures of cellulose, lignin extractive substances, and hemicelluloses, which are wood components, exhibit different behaviors when the chemical used in the bleaching process treats any wood material surface. Lime wood samples bleached with an environmentally friendly hydrogen peroxide (H_2O_2) using polymer impregnation by Wu *et al*. (2019) were bleached for 30, 60, 90, 120, and 150 min. The results showed decreases in hemicellulose,

cellulose, and lignin content with increasing bleaching time and reducing each component to a unique extent.

The results of the total color differences calculated for all wood species treated with two different bleaching chemicals (*B-One-C* and *B-Two-C*) are presented in Table 3. Looking at the total color differences, while the highest results for Δ*E** values were obtained in doussié (13.4), hornbeam (12.1), mahogany (13.0), and merbau (12.2) woods with *B-Two-C* application, it was determined in iatandza (14.78) wood by *B-One-C* application. Because wood materials have different structural properties, they exhibited different total color differences when exposed to the same bleaching chemicals. In merbau wood, Δ*E** values were close to each other after both applications. Looking at the Δ*E** values in the literature, after applying the < 5% chlorine-based bleach (NaClO) + anionic and nonionic chemical, it was 6.36 in sapele wood (Ulay and Ayata 2023a), 13.66 in sipo wood (Ulay and Ayata 2023c), and 30.73 in Scotch pine wood surfaces after NaClO chemical (Ulay and Ayata 2023b), for the double-component bleach on ilomba wood, it was 8.77, and for the single-component bleach, it was 3.31.

Table 3. Results for Total Color Differences

Wood Type	Bleach Type	Δ*L**	Δ*a**	Δ*b**	Δ*C**	Δ*H**	Δ*E**
Doussié	*B-One-C*	0.68	2.72	5.91	6.35	1.42	6.54
	B-Two-C	12.03	-4.17	4.22	1.63	5.70	13.41
Hornbeam	*B-One-C*	3.03	1.38	1.97	2.33	0.61	3.87
	B-Two-C	10.34	-4.12	-4.80	-5.70	2.74	12.12
Iatandza	*B-One-C*	-7.74	11.97	3.94	10.28	7.28	14.78
	B-Two-C	10.52	-4.19	6.20	4.55	5.93	12.91
Mahogany	*B-One-C*	-1.27	2.45	3.42	4.31	-	4.39
	B-Two-C	11.85	-2.25	4.95	3.43	4.22	13.04
Merbau	*B-One-C*	-9.48	6.65	3.38	6.96	2.69	12.06
	B-Two-C	6.69	-4.21	9.29	6.22	8.08	12.20

CONCLUSIONS

1. The two different bleaching treatments (the first bleaching agent consisting of water plus oxalic acid ($C_2H_2O_4$) and the second bleaching agent consisting of hydrogen peroxide (H_2O_2) plus sodium hydroxide (NaOH) mixed in a 2:1 ratio) used in the study caused different results in all wood samples and different rates of change.
2. The color factor, which is one of the factors affecting the aesthetic and economic value of wood, can be significantly affected by bleaching chemicals.
3. The Δ*E** values were doussié > mahogany > iatandza > merbau > hornbeam in wood samples exposed to *B-One-C* chemical, from largest to smallest, and the Δ*E** values in wood samples exposed to *B-Two-C* chemical were iatandza > merbau > doussié > mahogany > hornbeam.

REFERENCES CITED

Anonymous (1997). *Color Technology in the Textile Industry*, 2nd Ed., American Association of Textile Colorists and Chemist.

ASTM D2244-3 (2007). "Standard practice for calculation or color tolerances and color, differences from instrumentally measured color coordinates," ASTM International, West Conshohocken, PA, USA.

Ayata, U., Çakıcıer, N., and Gurleyen, L. (2021a). "Determination of the artificial aging performance of the apricot wood applied with UV system parquet varnish used indoors," *Furniture and Wooden Material Research Journal* 4(1), 40-50. DOI: 10.33725/mamad.922311

Ayata, U., Cakicier, N., and Gurleyen, L. (2021b). "Determination of some surface properties of UV curable varnish-applied cedar wood after artificial aging application," *Furniture and Wooden Material Research Journal* 4(2), 145-154. DOI: 10.33725/mamad.1005120

Ayata, U. (2022). "Investigation of some surface properties of red pine wood exposed to outdoor conditions," *Furniture and Wooden Material Research Journal* 5(2), 83-92. DOI: 10.33725/mamad.1184911

Ayata, Ü., and Bal, B. C. (2023). "Application of various bleaching chemicals on some surface properties of ilomba (*Pycnanthus angolensis* Exell) wood," 2nd International Conference on Health, Engineering and Applied Sciences, August 4-6, 2023, Belgrade, 95-105.

Ayata, U., Gurleyen, T., and Gurleyen, L. (2018). "Effect of heat treatment on color and glossiness properties of zebrano, sapeli and merbau woods," *Furniture and Wooden Material Research Journal* 1(1), 11-20. DOI: 10.33725/mamad.428913

Budakçı, B., and Karamanoğlu, M. (2014). "Effect of bleaching on hardness, gloss, and color change of weathered woods," *BioResources* 9(2), 2311-2327. DOI: 10.15376/biores.9.2.2311-2327

Bristow, A. (2009). "Optical properties of pulp and paper," in: *Pulp and Paper Chemistry and Technology: Paper Products Physics and Technology*, M. Ek, G. Gellerstedt, and G. Henriksson (eds.), De Gruyter, Berlin, pp. 145-167.

Costa, R. D., Barbosa, M. L., Silva, F. J., Sousa, S. R., Pinto, A. G., Sousa, V. F., and Ferreira, B. O. (2023). "The impact of the deterioration on wood by chlorine: An experimental study," *Materials* 16(3), article 969. DOI: 10.3390/ma16030969

Daly, W. J. (1948). *Bleaching Wood*, Craftsman Press, Seattle, WA, USA.

Gangakhedkar, N. S. (2010). "12 - Colour measurement of paint films and coatings," in: *Colour Measurement*, Woodhead Publishing, Sawston, UK, pp. 279-311. DOI: 10.1533/9780857090195.2.279

Herstedt, L., and Herstedt, M. (2017). "Chemical bleaching of wood: An investigation into the bleaching of mahogany, walnut, rosewood, padauk, and purpleheart," *Studies in Conservation* 62(3), 162-172. DOI: 10.1080/00393630.2015.1137695

Jewitt, J. (2003). "Using wood bleach," Coulee Region Wood Turners, (http://www.crwoodturner.com/files/demo-handouts/coloring/USING%20WOOD%20BLEACH.pdf), Accessed 01 April 2023.

Karal, İ. (2017). *Determination of Antifungal Effects of Wood Staining and Bleaching Processes*, Master's Thesis, Düzce University Graduate School of Natural and Applied Sciences, Department of Wood Products Industrial Engineering, Düzce, Turkey.

Liu, Y., Guo, H., Gao, J., Zhang, F., Shao, L., and Via, B. K. (2015). "Effect of bleach pretreatment on surface discoloration of dyed wood veneer exposed to artificial light irradiation," *BioResources* 10(3), 5607-5619. DOI: 10.15376/biores.10.3.5607-5619

Lu, D., Xiong, X., Lu, G., Gui, C., and Pang, X. (2023). "Effects of $NaOH/H_2O_2/Na_2SiO_3$ bleaching pretreatment method on wood dyeing properties," *Coatings* 13(2), article 233. DOI: 10.3390/coatings13020233

MacDougall, D. B. (2001). "Principles of colour measurement for food," in: *Instrumentation and Sensors for the Food Industry*, E. Kress-Rogers, C. J. B. Brimelow (eds.), Woodhead Publishing, pp. 63-84.

Roncero, M. B., Torres, A. L., Colom, J. F., and Vidal, T. (2005). "The effect of xylanase on lignocellulosic components during the bleaching of wood pulps," *Bioresource Technology* 96(1), 21-30. DOI: 10.1016/j.biortech.2004.03.003

Suslick, K. S. (1998). *Kirk-Othmer Encyclopedia of Chemical Technology*, John Wiley & Sons, New York, NY, USA.

TS 642 ISO 554 (1997). "Standard atmospheres for conditioning and/or testing; Specifications," Turkish Standards Institution, Ankara, Turkey.

TS ISO 13061-1 (2021). "Physical and mechanical properties of wood - Test methods for small clear wood specimens - Part 1: Determination of moisture content for physical and mechanical tests," Turkish Standards Institution, Ankara, Turkey.

Ulay, G., and Ayata Ü. (2023b). "Effect of sodium hypochlorite (NaClO) chemical on color parameters of Scots pine (*Pinus sylvestris* L.) wood," in: *Black Sea 12th International Congress of Applied Sciences*, Rize, Turkey, pp. 380-388.

Ulay, G., and Ayata, Ü. (2023a). "İç mekân temizlik kimyasalına maruz kalmış sapelli (*Entandrophragma cylindricum*) odununda renk parametrelerinin incelenmesi [Investigation of color parameters in sapele (*Entandrophragma cylindricum*) wood exposed to indoor cleaning chemicals]," in: *Küreselleşen Dünyada Ziraat, Orman ve Su Ürünleri [Agriculture, Forestry and Fisheries in a Globalizing World]*, Duvar Kitapevi (Duvar Publisher], Ankara, Turkey, pp. 61-75.

Ulay, G., and Ayata, Ü. (2023c). "Investigation of color parameters in sipo (*Entandrophragma utile*) wood treated with indoor cleaning chemical using different application methods," in: *4th International Congress of Health, Engineering and Applied Sciences*, Dubai, pp. 24-31.

Williams, R. S. (2010). "Finishing of wood," in: *Wood Handbook - Wood as an Engineering Material* (FPL-GTR-190), U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, Madison, WI, USA, pp. 16-1-16-39.

Wu, R., Wu, Z., Huang, Q., and Sun, H. (2014). "Bleaching process optimization of *Liriodendron tulipifera* used for furniture," *Journal of Nanjing Forestry University (Natural Sciences Edition)* 38(3), 125-128. DOI: 10.3969/j.issn.1000-2006.2014.03.024

Wu, Y., Wu, J., Yang, F., Tang, C., and Huang, Q. (2019). "Effect of H_2O_2 bleaching treatment on the properties of finished transparent wood," *Polymers* 11(5), article 776. DOI: 10.3390/polym11050776

Article submitted: May 31, 2023; Peer review completed: June 24, 2023; Revised version received: September 9, 2023; Published: September 29, 2023.
DOI: 10.15376/biores.18.4.7796-7804