Investigation of Color Parameters in Pine, Limba, Sapele, Iroko, Oak, and Beech Wood Species Exposed to Outdoor Conditions in Van City, Turkey

Göksel Ulay *

Sapele, pine, limba, iroko, beech, and oak wood species are important species used indoors and outdoors, as supplied by furniture companies. It is known that the color changes in wood material when exposed to the external environment. This is an important factor for the outdoor use of wood material. In this study, the color parameters of Scotch pine (*Pinus sylvestris* L.), oriental beech (*Fagus orientalis* L.), limba (*Terminalia superba* Engl. et Diels), sapele (*Entandrophragma cylindricum*), sessile oak (*Quercus petraea* L.), and iroko (*Milicia excelsa*) wood species, which are used in both indoor and outdoor woodworking industries in Van city, Turkey were investigated after exposing them to natural weather conditions for 9 months in outdoor conditions. Each type of wood exhibited a different color behavior in outdoor conditions. In sapele and limba wood species, *b** and *a** values increased and *L** values decreased with increasing weathering time. It was observed that ΔE^* increased with increasing time of exposure in all tree species. At the end of 9 months of weathering, the highest ΔE^* value was determined in pine wood, followed by beech, sapele, limba, iroko, and oak wood species, respectively.

DOI: 10.15376/biores.18.3.5325-5333

Keywords: Color; Weathering; Sapele; Pine; Limba; Iroko; Beech; Oak

*Contact information: Van Yuzuncu Yil University, Van Vocational School, Department of Furniture and Decoration, Van, Turkey; *Corresponding author: g.ulay@yyu.edu.tr /gokselulay@gmail.com*

INTRODUCTION

When products, such as terraces, fences, garden furniture, facades, flooring, *etc*. are used outdoors, they are exposed to snow, rain, sunlight, intense changes in humidity and temperature, as well as photochemical and biological processes (Roux *et al*. 1988).

Weathering is the general term used to describe the slow degradation of materials when exposed to combinations of ultraviolet (UV) light and rainfall. It can be affected by various factors such as biological factors, of cyclic wetting and drying, sunlight, humidity, hot/cold, wind, or air pollutants (Williams 2005; Kropat *et al*. 2020). The surface deterioration that occurs when wood is used outdoors, and above ground is called weathering. Weathering should not be confused with decay caused by microorganisms. For example, *Basidiomycete* fungi can significantly reduce the strength of structural timber (Feist 1990).

During decomposition in wood, chromophoric groups can absorb ultraviolet (UV) light to form free radicals that can react with oxygen and cause surface changes in wood (Lin and Kringstad 1970). It is well known that natural untreated wood is susceptible to environmental degradation caused by weather conditions, such as temperature, solar radiation (infrared light and UV) (Vitt *et al*. 2020), moisture (dew, snow, rain, *etc*.), and

oxygen (Feist *et al*. 1990). Unlike other kinds of degradation, weathering only affects the surface of the wood (Hartwig 2018).

Lignin degradation implies the production of free radicals (Evans *et al*. 2002) that degrade lignin as well as affecting the composition of wood, hemicellulose, and cellulose (Evans *et al*. 1996). Weathering is a type of natural degradation of wood when exposed to sunlight (or UV) (Mohebby and Saei 2015) in addition to wetting. Weathering of wood is a degradation process involving a complex series of reactions (Rowell 2005).

The natural weathering process often causes discoloration (Budakçı and Karamanoğlu 2014), physical deterioration of the wood surface, and loss of paint-holding properties. The change in color is the first obvious indicator of chemical changes in wood during weathering (Jirous-Rajkovic *et al*. 2004). Rich colors have made wood aesthetically appealing in buildings, furniture, and other items (Surminski 2007; Karamanoğlu and Kaymakçı 2018). Color has an impact on the aesthetic properties of wooden surfaces (Karamanoğlu and Akyıldız 2013), and color changes affect everyone's perception of wooden building materials (Schnabel *et al*. 2009).

In this study, surface changes in sapele, pine, limba, iroko, beech, and oak wood species used in indoor and outdoor woodworking industrial establishments were examined after exposure to natural weathering conditions for 9 months under outdoor environmental conditions in the Van province, Turkey. Thus, the interaction of six different tree species, which have not been investigated before in the literature, with outdoor conditions in Van province (38.562354°N; 43.292386°E, 1726 m altitude) and their behavioral color characteristics in the outdoor environment were determined.

EXPERIMENTAL

Obtaining Wood Samples

The test material was obtained from a commercial enterprise in Bursa/İnegöl district in first class quality with dimensions 85 × 300 × 25 mm. Scotch pine (*Pinus sylvestris* L.), limba (*Terminalia superba* Engl. et Diels), sapele (*Entandrophragma cylindricum*), sessile oak (*Quercus petraea* L.), iroko (*Milicia excelsa*), and oriental beech (*Fagus orientalis* L.), wood species, which are frequently used in furniture, joinery, building materials, and manufacturing industries, were selected. The samples were randomly selected, knot-free, crack-free, straight fiber, test sample surfaces were taken from radial sections and were prepared in accordance with TS ISO 13061-1 (2021).

Natural Weathering

The outdoor weathering test was completed in a total of 9 months between 28.06.2022 and 28.03.2023 in the city of Van (38.562354°N; 43.292386°E, 1726 m altitude), located in the east of Turkey. In Van province, the daily average sunshine duration is 7.9 h, the annual average temperature is 9.4 °C, the minimum temperature (-28.7 °C) and the maximum temperature (37.5 °C) (MGM 2023/ https://tr.weatherspark.com/). The samples were positioned outdoors, facing south, at 45° inclination, and at a height of one meter from the ground according to the ASTM D1641 (2004) standard. These samples were subjected to technical drying at a temperature of 20 °C ± 2 °C with a relative humidity of 65% ± 3% to achieve an air-dried moisture content of 12%, as per TS ISO 642 554 (1997).

Determination of Optical Properties

A CS-10 (CHNSpec Technology Co., Ltd., Hangzhou, China) brand 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] *via* ASTM D 2244-3 (2007) method (Ayata *et al*. 2021a,b). Changes in color parameters were determined after 3, 6, and 9 months of exposure.

Analysis usually consists of characterizing a trivariate color. These are: -*a**: green, +*a**: red, *L**: lightness, -*b**: blue +*b**: yellow component (AATCC 1997; MacDougall 2001; Bristow 2009). Color difference formulas are commonly used to evaluate the color difference between two samples (Wang *et al*. 2012). The following Eqs. 1 through 8 were used to calculate the color change (Ayata *et al*. 2018):

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

$$\text{Chroma } (C^*) = [(a^*)^2 + (b^*)^2]^{0.5} \quad (2)$$

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

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

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

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

$$\Delta E^* = [(\Delta a^*)^2 + (\Delta L^*)^2 + (\Delta b^*)^2]^{0.5} \quad (7)$$

$$\Delta H^* = [(\Delta E^*)^2 - (\Delta C^*)^2 - (\Delta L^*)^2]^{0.5} \quad (8)$$

Statistical Analysis

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

RESULTS AND DISCUSSION

Color measurement results before and after natural weathering for all tree species *b**, *L** and a* are given in Table 1, and *h*° and *C** are given in Table 2. In oak, *L** values first increased during weathering and decreased at the end of weathering. The *a** and *b** showed an opposite process to the *L** value. While those values decreased in the 3- and 6-month periods of weathering, they increased in the 9-month period. While *L** values decreased (from 79 to 61), *a** (from 9 to 17) and *b** (from 26 to 39) values increased after weathering in pine wood. In beech wood, *L** values increased in the 3-month period of weathering and decreased towards the last periods. The *a** and *b** values showed the opposite situation. After weathering, they first decreased and then increased. *L** values increased with increasing weathering time in sapele wood. Values of *b** and *a** first increased and then decreased. In limba wood, *L** values decreased, *b** and *a** values increased by natural weathering. In iroko wood, *L** values first decreased and then increased compared to control samples. An opposite situation was observed for *a** and *b** values (Table 1). The changes in the *a** parameter are mainly related to the changes in the chromophoric groups in the extractives (Oberhofnerová *et al*. 2017). The UV light can able to penetrate deep into the wood, causing degradation of the lignin. At that point, lignin

degradation products can be leached out by rainfall. This process can repeat itself in multiple cycles, such that a substantial layer of the surface of the wood becomes depleted of lignin. At that point, the surface will be rich in cellulose, which is not bothered by UV light at all. The cellulose will tend to scatter incident light of all wavelengths. (Kropat *et al*. 2020).

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

Test	Weathering Time	Sessile Oak				Scotch Pine			
		Mean	*SD*	*HG*	%	Mean	*SD*	*HG*	%
*L**	Control	62.78	1.77	C	-	79.79	0.92	A*	-
	3 months	67.08	1.02	B	↑6.85	65.93	2.29	B	↓17.37
	6 months	69.04	1.71	A*	↑9.97	63.05	1.66	C	↓20.98
	9 months	55.38	1.32	D**	↓11.79	61.53	0.94	D**	↓22.89
*a**	Control	12.24	0.58	B	-	9.57	0.63	D**	-
	3 months	8.92	0.54	C	↓27.12	11.08	1.78	C	↑15.78
	6 months	7.80	0.32	D**	↓36.27	13.24	0.84	B	↑38.35
	9 months	16.13	0.46	A*	↑31.78	17.32	0.22	A*	↑80.98
*b**	Control	25.24	0.67	B	-	26.70	0.88	C	-
	3 months	21.11	1.07	C	↓16.36	25.60	3.10	C**	↓4.12
	6 months	18.43	0.60	D**	↓26.98	29.49	1.68	B	↑10.45
	9 months	37.19	1.10	A*	↑47.35	39.55	0.77	A*	↑48.13
Test	Weathering Time	Oriental Beech				Sapele			
		Mean	*SD*	*HG*	%	Mean	*SD*	*HG*	%
*L**	Control	66.70	1.89	B	-	36.56	1.46	D**	-
	3 months	69.68	0.85	A*	↑4.47	38.30	0.57	C	↑4.76
	6 months	62.10	0.67	C	↓6.90	49.41	0.63	B	↑35.15
	9 months	59.56	0.73	D**	↓10.70	53.34	1.22	A*	↑45.90
*a**	Control	12.10	0.64	C	-	16.76	0.86	B	-
	3 months	6.78	0.22	D**	↓43.97	19.10	0.49	A*	↑13.96
	6 months	16.52	0.19	B	↑36.53	9.39	0.44	C	↓43.97
	9 months	17.56	0.18	A*	↑45.12	7.01	0.36	D**	↓58.17
*b**	Control	23.35	1.29	C	-	22.20	1.00	B	-
	3 months	17.32	0.74	D**	↓25.82	27.64	0.53	A*	↑24.50
	6 months	37.33	0.51	B	↑59.87	18.85	1.04	C	↓15.09
	9 months	42.29	1.03	A*	↑81.11	14.63	0.73	D**	↓34.10
Test	Weathering Time	Limba				Iroko			
		Mean	*SD*	*HG*	%	Mean	*SD*	*HG*	%
*L**	Control	74.29	1.34	A*	-	50.45	2.15	C	-
	3 months	73.30	0.86	B	↓1.33	49.21	0.86	C**	↓2.46
	6 months	70.67	0.72	C	↓4.87	54.27	1.44	B	↑7.57
	9 months	69.69	0.98	D**	↓6.19	61.22	2.23	A*	↑21.35
*a**	Control	7.90	0.73	C**	-	12.72	0.72	B	-
	3 months	12.13	0.52	B	↑53.54	14.34	0.30	A*	↑12.74
	6 months	13.05	0.56	A	↑65.19	10.28	0.69	C	↓19.18
	9 months	13.33	0.41	A*	↑68.73	7.38	0.80	D**	↓41.98
*b**	Control	21.92	1.14	D**	-	24.96	0.76	B	-
	3 months	33.64	0.99	C	↑53.47	29.98	0.66	A*	↑20.11
	6 months	35.00	1.18	B	↑59.67	19.84	1.68	C	↓20.51
	9 months	36.14	0.79	A*	↑64.87	15.59	1.23	D**	↓37.54

HG: Homogeneity group, *SD*: Standard deviation, N: Number of measurements,
For the HG column *: Highest value, **: Lowest value

Wood materials of black locust, oak, maple, alder, and poplar were exposed to outdoor environmental conditions for 3-, 6-, 12-, and 24-months by Kubovský *et al*. (2018). According to the results, at the end of the 3rd month, *L** values increased in oak wood and decreased in maple, alder, poplar, and black locust wood species. In addition, it was reported that *a** values decreased in maple, alder, and oak wood species, increased in poplar and black locust wood species. Values of *b** decreased in oak, black locust and alder wood species, and increased in poplar and maple wood species. In the natural weathering study conducted by Ayata (2022), it was reported that while *L** and *a** parameters decreased, *h*°, *C**, and *b** parameters increased in red pine wood. The reason for the decrease in L* can be attributed to the increase in the surface oxidation degree of the weathered samples (Evans et al. 1996).

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

Test	Weathering Time	Sessile Oak				Scotch Pine			
		Mean	*SD*	*HG*	%	Mean	*SD*	*HG*	%
*C**	Control	28.06	0.83	B	-	28.37	1.03	C	-
	3 months	22.91	1.19	C	↓18.35	27.90	3.55	C**	↓1.66
	6 months	20.02	0.66	D**	↓28.65	32.32	1.85	B	↑13.92
	9 months	40.54	1.17	A*	↑44.48	43.18	0.77	A*	↑52.20
h°	Control	64.15	0.61	C**	-	70.29	0.67	A*	-
	3 months	67.11	0.29	A*	↑4.61	66.70	0.90	B	↓5.11
	6 months	67.06	0.36	A	↑4.54	65.33	1.64	C**	↓7.06
	9 months	66.55	0.30	B	↑3.74	66.35	0.29	B	↓5.61
Test	Weathering Time	Oriental Beech				Sapele			
		Mean	*SD*	*HG*	%	Mean	*SD*	*HG*	%
*C**	Control	26.30	1.42	C	-	27.82	1.08	B	-
	3 months	18.60	0.75	D**	↓29.28	33.60	0.63	A*	↑20.78
	6 months	40.83	0.53	B	↑55.25	21.06	1.10	C	↓24.30
	9 months	45.79	1.01	A*	↑74.11	16.23	0.77	D**	↓41.66
h°	Control	62.61	0.51	D**	-	52.94	1.52	C**	-
	3 months	68.61	0.63	A*	↑9.58	55.36	0.60	B	↑4.57
	6 months	66.13	0.13	C	↑5.62	63.50	0.67	A	↑19.95
	9 months	67.44	0.32	B	↑7.71	64.40	0.95	A*	↑21.65
Test	Weathering Time	Limba				Iroko			
		Mean	*SD*	*HG*	%	Mean	*SD*	*HG*	%
*C**	Control	23.30	1.31	D**	-	27.93	0.73	B	-
	3 months	35.76	1.11	C	↑53.48	33.24	0.71	A*	↑19.01
	6 months	37.35	1.28	B	↑60.30	22.34	1.81	C	↓20.01
	9 months	38.52	0.87	A*	↑65.32	17.25	1.44	D**	↓38.24
h°	Control	70.21	0.83	A*	-	63.35	0.94	B	-
	3 months	70.17	0.29	A	↓0.06	64.48	0.28	A	↑1.78
	6 months	69.55	0.38	B**	↓0.94	62.67	0.64	B**	↓1.07
	9 months	69.75	0.24	AB	↓0.66	64.71	0.94	A*	↑2.15

HG: Homogeneity group, *SD*: Standard deviation, N: Number of measurements;
For the HG column *: Highest value, **: Lowest value

The results of the total color differences calculated for all wood species are shown in Table 3. According to these results, it is apparent that Δ*E** values increased with increasing weathering time (from 3-months to 9-months) in all wood species. At the end of 9-months, the highest Δ*E** value was obtained in pine (23.63) wood, followed by beech (20.96), sapele (20.83), limba (15.90), iroko (15.24), and oak (14.58). It can be said that

different results were obtained because of the different anatomical properties of wood species. The action of solar radiation, air humidity, and air oxygen provides oxidation of lignin, resulting in the formation of chromophoric groups that give the wood surface a dark color (Williams 2005) In outdoor conditions with different humidity levels, fungal colonization may be the cause, which usually darkens the wood or gives it a dull blue hue (Kropat et al. 2020). Understanding of the weathering process contributes to degradation behavior and affects the use of materials (Zhang et al. 2022). In the natural weathering study conducted by Ayata (2022), Δ*E** values were determined as 10.60, 10.58, and 11.65 at the end of the 1st, 2nd, and 3rd months, respectively, in red pine wood. Wood is known as a good light absorber. Visible light penetrates to approximately 200 µm and UV light to approximately 75 µm. It initiates photochemical reactions, primarily in lignin. It causes photo-degradation and photo-discoloration of cell wall polymers (Hon 1991). It has been reported (Oberhofnerová *et al*. 2017). It was reported by Bobadilha *et al*. (2021) that *b**, *a**, and *L** values decreased at the end of the 3rd month of natural weathering applied on large sea fir (*Tsuga* sp. and *Abies* sp.) wood. On the other hand, the obtained different results regarding the color values of similar woods in different studies may be due to the average humidity of the weathering condition and the height of the sea level (1726 m).

Table 3. Results for Total Color Differences

Wood Type	Weathering	Δ*L**	Δ*a**	Δ*b**	Δ*C**	Δ*H**	Δ*E**
Oak	3 months	4.31	-3.32	-4.14	-5.14	1.31	6.83
	6 months	6.26	-4.44	-6.81	-8.04	1.21	10.26
	9 months	-7.39	3.89	11.95	12.48	1.43	14.58
Pine	3 months	-13.87	1.50	-1.10	-0.47	1.80	13.99
	6 months	-16.74	3.67	2.79	3.96	2.37	17.37
	9 months	-18.26	7.75	12.85	14.81	2.40	23.63
Beech	3 months	2.98	-5.32	-6.03	-7.70	2.33	8.58
	6 months	-4.59	4.42	13.98	14.53	1.99	15.37
	9 months	-7.14	5.46	18.94	19.49	2.93	20.96
Sapele	3 months	1.73	2.34	5.45	5.78	1.31	6.18
	6 months	12.84	-7.38	-3.35	-6.77	4.45	15.18
	9 months	16.78	-9.76	-7.57	-11.59	4.24	20.83
Limba	3 months	-0.99	4.23	11.72	12.46	0.33	12.50
	6 months	-3.62	5.15	13.08	14.05	0.47	14.52
	9 months	-4.60	5.43	14.22	15.22	0.39	15.90
Iroko	3 months	-1.23	1.62	5.02	5.31	-	5.42
	6 months	3.82	-2.45	-5.13	-5.59	1.01	6.85
	9 months	10.77	-5.34	-9.37	-10.68	1.51	15.24

CONCLUSIONS

The following conclusions were derived from this study:

1. In univariate analysis, the weathering factor of all wood species was determined to be significant.
2. Darkening was obtained at the end of weathering in all wood species that were naturally weathered. According to the findings, wood species with different anatomical structures showed different results. During weathering, each type of wood exhibited a different behavior, especially with UV light.

3. Outdoor conditions have had a modifying effect on wood materials. Rates of change varied every 3 months.
4. With increasing weathering time, L^* values decreased, b^* and a^* values increased in limba and sapele wood species.
5. It was observed that the ΔE^* values increased with increasing weathering time in all wood species.
6. At the end of 9-months, the highest ΔE^* value was obtained in pine wood, followed by beech, sapele, limba, iroko, and oak, respectively.

ACKNOWLEDGMENTS

This work has been supported by Van Yuzuncu Yil University Scientific Research Projects Coordination Unit under grant number (FYD-2023-10425).

REFERENCES CITED

American Association of Textile Chemists and Colorists (AATCC) (1997). *Color Technology in the Textile Industry*, 2nd Rd., AATCC, Research Triangle Park, NC, USA.

ASTM D1641 (2004). "Standard practice for conducting outdoor exposure test of varnishes," ASTM International, West Conshohocken, PA, USA.

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. (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, 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., 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

Bobadilha, G. S., Stokes, E. C., Ohno, K. M., Kirker, G., Verly Lopes, D. J., and Nejad, M. (2021). "Physical, optical, and visual performance of coated cross-laminated timber during natural and artificial weathering," *Coatings* 11(2), article 252. DOI: 10.3390/coatings11020252

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, Germany, pp. 145-167.

Budakçı, M., 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

Evans, P. D., Owen, N. L., Schmid, S., and Webster, R. D. (2002). "Weathering and photostability of benzoylated wood," *Polymer Degradation and Stability* 76(2), 291-303. DOI: 10.1016/S0141-3910(02)00026-5

Evans, P. D., Thay, P. D., and Schmalzl, K. J. (1996). "Degradation of wood surfaces during natural weathering. Effects on lignin and cellulose and on the adhesion of acrylic latex primers," *Wood Science and Technology* 30, 411-422.

Feist, W. C., Rowell, R. M., and Barbour, R. J. (1990). "Outdoor wood weathering and protection, archaeological wood: Properties," *Chemistry and Preservation* 225, 263-298.

Feist, W. C. (1990). "Outdoor wood weathering and protection," in: *Archaeological Wood: Properties, Chemistry, and Preservation*, R. M. Rowell, and R. J. Barbour (eds.), American Chemistry Society, Washington D.C., USA

Hartwig, M. (2018). *Effects of Weathering on Thermally Modified Softwoods with Different Surface Treatments*, Master's Thesis, Luleå University of Technology, Department of Engineering, Sciences and Mathematics, Luleå, Sweden.

Hon, D. N.-S. (1991). "Photochemistry of wood," in: *Wood and Cellulosic Chemistry* D. N.-S. Hon, and N. Shiraishi (eds.), Marcel Decker, New York, NY, USA, pp. 525-555.

Jirous-Rajkovic, V., Bogner, A., and Radovan, D. (2004). "The efficiency of various treatments in protecting wood surfaces against weathering," *Surface Coatings International Part B: Coatings Transactions* 87, B1, 1-5.

Karamanoglu, M. and Akyıldız, M.H. (2013), "Colour, gloss and hardness properties of heat-treated wood exposed to accelerated weathering," *ProLigno* 9(4), 729-738.

Karamanoğlu, M. and Kaymakçı , A. (2018). "The effect of hygrothermal aging on the color and hardness properties of heat-treated chestnut wood," *Furniture and Wooden Material Research Journal* 1(1), 31-37.

Kropat, M., Hubbe, M. A., and Laleicke, F. (2020). "Natural, accelerated, and simulated weathering of wood: A review," *BioResources* 15(4), 9998-10062. DOI: 10.15376/biores.15.4.Kropat

Kubovský, I., Oberhofnerová, E., Kačík, F., and Pánek, M. (2018). "Surface changes of selected hardwoods due to weather conditions," *Forests* 9(9), article 557. DOI: 10.3390/f9090557.

Lin, S. Y., and Kringstad, K. P. (1970). "Photosensitive groups in lignin and lignin model compounds," *Tappi* 53(4), 658-663.

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

MGM (2023). "Official statistics: Seasonal normal for Provinces (1991-2020)," Metereoloji Genel Müdürlüğü [General Directorate of Meteorology], (https://www.mgm.gov.tr/veridegerlendirme/il-ve-ilceler-istatistik.aspx?k=H&m=VAN), Accessed 01 March 2023.

Mohebby, B., and Saei, A. M. (2015). "Effects of geographical directions and climatological parameters on natural weathering of fir wood," *Construction and Building Materials* 94, 684-690. DOI: 10.1016/j.conbuildmat.2015.07.049

Oberhofnerová, E., Pánek, M., and García-Cimarras, A. (2017). "The effect of natural weathering on untreated wood surface," *Maderas. Ciencia y Tecnología* 19(2), 173-184. DOI: 10.4067/S0718-221X2017005000015

Rowell, R. M. (2005). "Chemical modification of wood: A short review," *Wood Material Science and Engineering* 1(1), 29-33. DOI: 10.1080/17480270600670923

Schnabel, T., Zimmer, B., and Petutschnigg, A. J. (2009). "On the modelling of colour changes of wood surfaces," *European Journal of Wood and Wood Products* 67, 141-149. DOI: 10.1007/s00107-008-0293-x

Surminski, J. (2007). *Wood Properties and Uses*, Springer, Amsterdam, Netherlands.

TS ISO 642 554 (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.

Vitt, R., Laschewski, G., Bais, A. F., Diémoz, H., Fountoulakis, I., Siani, A.-M., and Matzarakis, A. (2020). "UV-index climatology for Europe based on satellite data," *Atmosphere* 11, 727. DOI: 10.3390/atmos11070727

Wang, H., Cui, G., Luo, M. R., and Xu, H. (2012). "Evaluation of colour-difference formulae for different colour-difference magnitudes," *Color Research and Application* 37(5), 316-325. DOI: 10.1002/col.20693

Williams, R. S. (2005). "Weathering of wood," in: *Handbook of Wood Chemistry and Wood Composites*, 2nd ed., R. M. Rowell (Ed.), CRC Press, Boca Raton, FL, USA, pp. 139-185.

Zhang, Y. H., Ma, H. X., Qi, Y., Zhu, R. X., Li, X. W., Yu, W. J., and Rao, F. (2022). "Study of the long-term degradation behavior of bamboo scrimber under natural weathering," *NPJ Materials Degradation* 6, article 63. DOI: 10.1038/s41529-022-00273-x

Article submitted: April 19, 2023; Peer review completed: May 27, 2023; Revised version received: May 29, 2023; Accepted: June 18, 2023; Published: June 26, 2023.
DOI: 10.15376/biores.18.3.5325-5333