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INVESTIGATION OF SURFACE CHANGES AFTER COATING OF AMERICAN WALNUT (Juglans nigra L.) WOOD WITH OIL-MODIFIED BEESWAX

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Abstract:
In this study, surface changes between American walnut (Juglans nigra L.) wood and modified beeswaxes were investigated. A control group was established, and various beeswax mixtures [coconut oil (coconut oil + beeswax mixture), linseed oil (linseed oil and beeswax mixture), and protective oil (olive oil + beeswax mixture)] were individually applied to wooden surfaces using a brush. Subsequently, color parameters (a, C*, b*, L*, and h^o), whiteness index (WI*), and gloss properties were examined. The obtained measurement results were compared with each other. According to the results obtained, modified beeswax types were significantly identified for all tests through variance analysis. When all modified beeswaxes were applied to the wood material surfaces, reductions were noted in the b*, L*, C*, and h^o values, whereas increments were observed in the a* values. The ∆E* values were found to be 18.37 for olive oil + beeswax, 18.91 for flaxseed oil + beeswax, and 15.69 for coconut oil + beeswax. Furthermore, a decrease in WI* values was observed in both directions with the application of all modified beeswaxes. The surface properties of the wood material were observed to have been altered by the chemicals used in the applications.*

Key words: *beeswax, linseed oil, color, glossiness, whiteness index.*

INTRODUCTION

Beeswax finds wide-ranging applications, including but not limited to candle production, sculpting, jelly coating, pharmaceuticals, varnishes, and cosmetics (Bogdanov 2009, Dinker et al. 2017). The quality of beeswax is predominantly influenced by the manufacturing methods, which encompass melting or chemical extraction processes. Melting is the prevalent approach, achievable through various techniques such as forced immersion with hot water extraction, boiling water and wax press extraction, combined steam and press extraction, steam extraction, and centrifuge extraction. Chemical extraction using solvents is typically confined to laboratory settings, mainly when producing beeswax on a small scale. Among these methods, forced immersion with hot water extraction stands out as the most widely utilized (Saralaya et al. 2021).

Freshly produced beeswax starts off as white and eventually transitions to a yellow hue over time. The infusion of propolis and pollen dyes contributes to this distinctive golden coloration. Beeswax emanates a unique fragrance, comprised of elements such as beeswax, honey, propolis, and pollen. Its aroma is characterized by sweet, warm, and balsamic notes, reminiscent of the scent of honey, rendering it a coveted gourmet item (Gupta and Anjali 2023). In order to enhance their resilience, they often incorporate tung oil along with a variety of animal and plant-based waxes like beeswax. Linseed oil varnishes boast high flexibility and micro-porosity, even in their glossiest forms. They can be diluted with natural resin such as genuine turpentine and are deemed non-toxic, ensuring their suitability for applications like children's toys, among others (Butcher 1992).

In the literature, various wood species have been subjected to applications of bee or natural waxes [poplar (Ren et al. 2016), magnolia (Ayata et al. 2024), poplar and beech (Németh et al. 2014), bamboo (Piao et al. 2022), beech (Waßmann and Ahmed 2020), balau red (Peker et al. 2024c), plum (Peker et al. 2024b), spruce (Janesch et al. 2020), red sanders, rosewood (Liu et al. 2020), olive (Peker et al. 2024a), Siberian pine (Çamlıbel and Ayata 2024), Manchurian ash (Niu and Song 2021), lime, beech, poplar, and Scots pine (Akçay 2020), poplar (Ning et al. 2022)], but there is no evidence of any such application being made to the *Juglans nigra* L. tree species. Here's a brief overview of this tree: American walnut wood is utilized in the furniture industry as solid wood, plywood, and veneer. In Turkey, it is commonly used in furniture production and interior design for covering large and long surfaces. However, it has a weak bonding quality with adhesives (Şanıvar and Zorlu 1980).

In *Juglans nigra* L. wood, the air-dried density is 796 kg/m^3. The Janka hardness values are 89.38 N/mm^2 for the tangential surface, 85.53 N/mm^2 for the radial surface, and 101.94 N/mm^2 for the transverse surface. Regarding nail holding resistance, it is 18.65 N/mm^2 for the radial surface, 15.33 N/mm^2 for the tangential surface, and 13.92 N/mm^2 for the transverse surface (Ayata and Bal 2019). The wood composition includes 43.00% cellulose, 76.40% holocellulose, and 21.80% lignin. Additionally, ethanol solubility is 5.90%, while pentosans content is 17.40%, hemicellulose content is 33.40%, and hexosans content is 16.00% (Waliszewska et al. 2015).

OBJECTIVE

In this study, surface changes between American walnut (*Juglans nigra* L.) wood and modified beeswaxes were investigated, and the circumstances under which these changes occurred were examined. The aim was to determine the interactions between the obtained results and modified beeswaxes with wooden materials, with the goal of providing new insights for both producers and consumers.

MATERIALS

Samples of American walnut (*Juglans nigra* L.) wood were obtained in dimensions of 100 x 200 x 20 mm. The samples were prepared according to the TS ISO 13061-1 (2021) standard. Coconut oil (mixture of coconut oil and beeswax), flaxseed oil (mixture of flaxseed oil and beeswax), and protective oil (mixture of olive oil and beeswax) were used. Ten samples were prepared per group, and ten measurements were taken for each test conducted per group.

METHODS

Modified beeswaxes were applied to the wood material surfaces using a brush as a single layer.

The Whiteness Meter BDY-1 device was utilized in this study to determine the whiteness index (*WI**) values in both parallel and perpendicular directions, following the ASTM E313-15e1 (2015) standard. Glossiness tests were performed using the ETB-0833 model gloss meter device in accordance with the ISO 2813 (1994) standard at three different angles (20°, 60°, and 85°) in both perpendicular and parallel directions to the fibers. The color change of the samples was measured using the CS-10 (CHN Spec, China) device according to ASTM D 2244-3 (2007) [CIE 10° standard observer; CIE D65 light source, illumination system: 8/d (8°/diffuse illumination)]. In the literature, ΔC^* is defined as chroma difference or saturation difference and ΔH^* as hue difference or shade difference, and definitions for other parameters are presented in Table 1 (Lange 1999).

Table 1

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

Test	Positive Description	Negative Description
Δb^*	More yellow than the reference	More blue than the reference
ΔL^*	Lighter than the reference	Darker than the reference
Δa^*	More red than the reference	More green than the reference
ΔC^*	Clearer, brighter than the reference	More dull, matte than the reference

The comparison criteria for the visual evaluation of the calculated ΔE^* color difference are provided in Table 2 according to DIN 5033 (1979).

Table 2

Comparison criteria for ΔE^* evaluation (DIN 5033 1979)

Visual	Total Color Difference
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
Very Strong	> 12.0

The results of total color differences were determined using the following formulas.

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

A statistical program was employed to calculate standard deviations, maximum and minimum mean values, measurement values associated with the mean, homogeneity groups, multivariate analysis of variance, and percentage (%) change rates based on the measurement values obtained in the study.

RESULTS AND DISCUSSION

The results of the analysis of variance are provided in Table 3. According to these results, it is observed that the factor of the type of beeswax applied for all tests was obtained significantly (Table 3).

Table 3

Multivariate analysis of variance results

Test	Sum of Squares	Degrees of Freedom	Mean Square	F Value	Sig.
L*	1998.105	3	666.035	1308.581	0.000*
a*	104.866	3	34.955	52.096	0.000*
b*	400.565	3	133.522	221.719	0.000*
C*	335.710	3	111.903	100.100	0.000*
***h*°**	2601.747	3	867.249	263.812	0.000*
⊥20° glossiness	0.048	3	0.016	36.000	0.000*
⊥60° glossiness	8.846	3	2.949	417.921	0.000*
⊥85° glossiness	15.628	3	5.209	244.188	0.000*
‖20° glossiness	0.012	3	0.004	6.000	0.002*
‖60° glossiness	10.315	3	3.438	175.570	0.000*
‖85° glossiness	111.123	3	37.041	712.327	0.000*
WI* (⊥)	503.506	3	167.835	5036.911	0.000*
WI* (‖)	141.891	3	47.297	2432.417	0.000*

***: Significant**

The results for the color parameters are presented in Table 4. Decreases in *L**, *b**, *C**, and *h*° values were observed when all modified beeswaxes were applied to the wood material surfaces, while increases were detected in the *a** values. For the *L** value, the highest result was found on the control samples (46.90), while the lowest result was obtained in the sample group with flaxseed oil + beeswax application (29.77). Alternatively, the control samples yielded the lowest result for the *a** value (6.84), whereas the sample group treated with coconut oil + beeswax application achieved the highest result (10.72). In other words, the control samples exhibited the highest results for the *b** (15.77) and *C** (17.20) values, whereas the lowest results were observed in the sample group treated with Flaxseed oil + beeswax application (*b**: 7.78 and *C**: 15.60) (Table 4).

Similarly, for the *h*° value, the highest result was recorded in the control samples (66.56), while the lowest result was observed in the sample group treated with coconut oil + beeswax application (46.62). The highest decrease rate in the *L** parameter was observed in the samples treated with flaxseed oil + beeswax application, with a rate of 36.52%, while the lowest decrease rate was found in the samples treated with coconut oil + beeswax application, with a rate of 30.98% (Table 4).

The lowest increase rate in the *a** parameter was found to be 3.22% in the samples treated with flaxseed oil + beeswax application, while the highest increase rate was observed in the samples treated with coconut oil + beeswax application, with a rate of 56.73%. In other words, the samples subjected to flaxseed oil + beeswax application exhibited the highest reduction in the *b** parameter, with a rate of 50.67%, whereas the samples treated with coconut oil + beeswax application showed the lowest reduction rate, which was 28.22% (Table 4).

The samples undergoing treatment with flaxseed oil + beeswax showed the most significant decline in the *C** value, registering at 38.90%, whereas those treated with coconut oil + beeswax exhibited the least decline, measuring only 9.30%. Alternatively, the samples treated with olive oil + beeswax application exhibited the smallest reduction rate in the *h*° value, recorded at 25.09%, whereas the samples treated with coconut oil + beeswax application showed the highest reduction rate, which was measured at 29.96% (Table 4).

According to Akçay (2020), beeswax application to linden, beech, poplar, and pine woods resulted in a decrease in *L** values and an increase in *a** and *b** values. Similarly, Liu et al. (2022) observed that applying beeswax to European walnut (*Juglans regia*) and sycamore maple (*Acer pseudoplatanus*) woods led to decreased *L** values and increased *a** and *b** values. These outcomes align with the findings of our study. Çamlıbel and Ayata's (2024) research investigated the impact of modified beeswaxes on various surface properties of Siberian pine (*Pinus sibirica*) wood. The study revealed that the application of all modified beeswaxes resulted in a decrease in *L** and *h*° values across all directions and degrees on the wood surfaces. Conversely, there was an increase in *b**, *C**, and *a** values.

Table 4

The results for the color parameters

Test	Wax Type	N	Mean	Change (%)	Homogeneity Group	Standard Deviation	Minimum	Maximum	COV
*L**	No oil application	10	46.90	-	A*	1.07	44.12	47.92	2.28
	Olive oil + beeswax	10	30.10	↓35.82	C	0.80	29.05	31.57	2.65
	Flaxseed oil + beeswax	10	29.77	↓36.52	C**	0.31	29.30	30.25	1.04
	Coconut oil + beeswax	10	32.37	↓30.98	B	0.40	31.80	33.14	1.23
*a**	No oil application	10	6.84	-	B**	0.60	6.08	7.93	8.82
	Olive oil + beeswax	10	7.07	↑3.36	B	1.05	5.21	8.66	14.81
	Flaxseed oil + beeswax	10	7.06	↑3.22	B	0.85	5.10	8.13	12.10
	Coconut oil + beeswax	10	10.72	↑56.73	A*	0.70	9.15	11.64	6.56
*b**	No oil application	10	15.77	-	A*	0.88	14.65	17.22	5.60
	Olive oil + beeswax	10	8.36	↓46.99	C	1.07	7.22	9.95	12.80
	Flaxseed oil + beeswax	10	7.78	↓50.67	C**	0.48	6.79	8.33	6.17
	Coconut oil + beeswax	10	11.32	↓28.22	B	0.50	10.31	11.85	4.44
*C**	No oil application	10	17.20	-	A*	0.94	15.86	18.54	5.48
	Olive oil + beeswax	10	10.93	↓36.45	C	1.47	8.91	13.03	13.43
	Flaxseed oil + beeswax	10	10.51	↓38.90	C**	0.88	8.50	11.64	8.42
	Coconut oil + beeswax	10	15.60	↓9.30	B	0.80	13.79	16.50	5.15
h°	No oil application	10	66.56	-	A*	1.68	63.98	68.75	2.53
	Olive oil + beeswax	10	49.86	↓25.09	B	1.79	48.11	54.17	3.59
	Flaxseed oil + beeswax	10	47.91	↓28.02	C	2.38	45.69	53.07	4.97
	Coconut oil + beeswax	10	46.62	↓29.96	C**	1.20	45.15	48.40	2.58

***: Highest Value, **: Lowest Value, COV: Coefficient of Variation, N: Number of Measurements**

The whiteness index (*WI**) values are detailed in Table 5. According to these results, it is observed that *WI** values measured in both directions decreased with all modified beeswax applications (with reduction rates ranging between 62% and 80%). The highest results were obtained in the control samples where no application was made (*⊥: 10.79 and* ‖: 5.78). In the perpendicular direction, the highest reduction rate in *WI** values was 78.13% in samples with coconut oil + beeswax application, while the lowest was 73.22% in samples with olive oil + beeswax application. In the parallel direction, the highest reduction rate was 79.58% in samples with flaxseed oil + beeswax application, while the lowest was 62.98% in samples with coconut oil + beeswax application. The lowest results were found in samples with coconut oil + beeswax application in the ⊥ direction (2.36) for *WI** values, while in the ‖ direction, they were observed on samples with flaxseed oil + beeswax application (1.18) (Table 5). In their 2024 research, Çamlıbel and Ayata explored how different modified beeswaxes affect the surface properties of Siberian pine (*Pinus sibirica*) wood. The findings showed that using any modified beeswax led to a reduction in WI values.

Table 5

The results for the whiteness index (WI*) values

Test	Wax Type	N	Mean	Change (%)	Homogeneity Group	Standard Deviation	Minimum	Maximum	COV
*WI** ⊥	No oil application	10	10.79	-	A*	0.26	10.50	11.10	2.41
	Olive oil + beeswax	10	2.89	↓73.22	B	0.19	2.70	3.10	6.41
	Flaxseed oil + beeswax	10	2.58	↓76.09	C	0.08	2.50	2.70	3.06
	Coconut oil + beeswax	10	2.36	↓78.13	D**	0.16	2.10	2.50	6.68
*WI** ‖	No oil application	10	5.78	-	A*	0.20	5.50	6.00	3.54
	Olive oil + beeswax	10	1.24	↓78.55	C	0.12	1.10	1.40	9.47
	Flaxseed oil + beeswax	10	1.18	↓79.58	C**	0.08	1.10	1.30	6.68
	Coconut oil + beeswax	10	2.14	↓62.98	B	0.13	2.00	2.30	5.91

***: Highest Value, **: Lowest Value, COV: Coefficient of Variation, N: Number of Measurements**

The glossiness values are shown in Table 6. It is evident that there were reductions in glossiness values across all degrees and orientations with the application of three distinct modified beeswax treatments. The control samples exhibited the highest glossiness measurements. Moreover, the decrease in values observed with modified beeswax treatments yielded consistent outcomes in both perpendicular and parallel measurements at 20 degrees. At 60 and 85 degrees, the highest reduction rates in both directions were observed in samples with coconut oil + beeswax application (Table 6). Çamlıbel and Ayata's (2024) study examined the effects of modified beeswaxes on the surface characteristics of Siberian pine (*Pinus sibirica*) wood. The findings indicated that applying any type of modified beeswax led to a reduction in glossiness.

Table 6

The results for the glossiness values

Test	Wax Type	N	Mean	Change (%)	Homogeneity Group	Standard Deviation	Minimum	Maximum	COV
$\perp 20^{o}$	**No oil application**	**10**	0.18	-	A*	0.04	0.10	0.20	23.42
	Olive oil + beeswax	**10**	0.10	↓44.44	B**	0.00	0.10	0.10	0.00
	Flaxseed oil + beeswax	**10**	0.10	↓44.44	B**	0.00	0.10	0.10	0.00
	Coconut oil + beeswax	**10**	0.10	↓44.44	B**	0.00	0.10	0.10	0.00
$\perp 60^{o}$	**No oil application**	**10**	2.28	-	A*	0.10	2.20	2.40	4.53
	Olive oil + beeswax	**10**	1.37	↓39.91	B	0.12	1.20	1.50	8.46
	Flaxseed oil + beeswax	**10**	1.33	↓41.67	B	0.05	1.30	1.40	3.63
	Coconut oil + beeswax	**10**	1.02	↓55.26	C**	0.04	1.00	1.10	4.13
$\perp 85^{o}$	**No oil application**	**10**	1.82	-	A*	0.21	1.60	2.10	11.81
	Olive oil + beeswax	**10**	1.22	↓32.97	B	0.15	1.00	1.40	12.10
	Flaxseed oil + beeswax	**10**	0.82	↓54.95	C	0.13	0.70	1.00	16.06
	Coconut oil + beeswax	**10**	0.10	↓94.51	D**	0.00	0.10	0.10	0.00
$\parallel 20^{o}$	**No oil application**	**10**	0.14	-	A*	0.05	0.10	0.20	36.89
	Olive oil + beeswax	**10**	0.10	↓28.57	B**	0.00	0.10	0.10	0.00
	Flaxseed oil + beeswax	**10**	0.10	↓28.57	B**	0.00	0.10	0.10	0.00
	Coconut oil + beeswax	**10**	0.10	↓28.57	B**	0.00	0.10	0.10	0.00
$\parallel 60^{o}$	**No oil application**	**10**	2.50	-	A*	0.24	2.20	2.90	9.61
	Olive oil + beeswax	**10**	1.35	↓46.00	BC	0.05	1.30	1.40	3.90
	Flaxseed oil + beeswax	**10**	1.42	↓43.20	B	0.10	1.30	1.60	7.27
	Coconut oil + beeswax	**10**	1.24	↓50.40	C**	0.08	1.10	1.30	6.80
$\parallel 85^{o}$	**No oil application**	**10**	4.62	-	A*	0.18	4.40	4.90	3.93
	Olive oil + beeswax	**10**	1.32	↓71.43	B	0.37	0.90	1.90	27.85
	Flaxseed oil + beeswax	**10**	1.14	↓75.32	B	0.17	0.90	1.30	15.02
	Coconut oil + beeswax	**10**	0.22	↓95.24	C**	0.10	0.10	0.30	46.95

***: Highest Value, **: Lowest Value, COV: Coefficient of Variation, N: Number of Measurements**

The results for the total color differences calculated using color parameters are provided in Table 7. When examining the results for color difference (ΔE^*), it is observed that it was determined as 18.37 for olive oil + beeswax, 18.91 for flaxseed oil + beeswax, and 15.69 for coconut oil + beeswax. When all modified oils with beeswax were applied to wooden surfaces, the ΔL^*, Δb^*, and ΔC^* values were found to be negative (indicating respectively: darker than the reference, bluer than the reference, and duller than the reference), while the Δa^* values were positive (indicating redder than the reference). The ΔH^* values were determined as 3.96 for olive oil + beeswax, 4.39 for flaxseed oil + beeswax, and 5.69 for coconut oil + beeswax. Upon comparing the results from this study with the color criteria (DIN 5033, 1979), it became evident that all modified beeswaxes yielded outcomes classified as "very strong (> 12.0)" (Table 7).

Table 7

Results for total color differences

Wood Type	ΔL^*	Δa^*	Δb^*	ΔC^*	ΔH^*	ΔE^*	Criteria (DIN 5033, 1979)
Olive oil + beeswax	-16.81	0.23	-7.41	-6.27	3.96	18.37	Very strong (> 12.0)
Flaxseed oil + beeswax	-17.13	0.23	-7.99	-6.68	4.39	18.91	
Coconut oil + beeswax	-14.53	3.89	-4.45	-1.60	5.69	15.69	

In their study, Çamlıbel and Ayata (2024) found that the ΔE^* values for modified beeswaxes applied to Siberian pine (*Pinus sibirica*) wood were 9.65 for linseed oil + beeswax, 12.57 for coconut oil + beeswax, and 13.57 for olive oil + beeswax.

CONCLUSION

Reductions were observed in the C^*, b^*, L^*, and h^o values when all modified beeswaxes were applied to the wood material surfaces, while increases were noted in the a^* values. Moreover, a decline in WI^* values was noted in both orientations following the application of all modified beeswaxes. It is recommended to use these modified chemicals indoors. It is recommended to conduct natural or artificial weathering tests on materials coated with the obtained modified beeswax.

REFERENCES

AKÇAY Ç (2020) Determination of decay, larvae resistance, water uptake, color, and hardness properties of wood impregnated with honeybee wax. BioResources, 15(4), 8339-8354. DOI: 10.15376/biores.15.4.8339-8354.

ASTM D 2244-3 (2007) Standard practice for calculation or color tolerances and color, differences from instrumentally measured color coordinates, ASTM International, West Conshohocken, PA.

ASTM E313-15e1 (2015) Standard practice for calculating yellowness and whiteness indices from instrumentally measured color coordinates, ASTM International, West Conshohocken, PA.

AYATA Ü, BAL BC (2019) Determination of janka hardness value, nail holding resistance and surface roughness on American walnut wood, Cukurova 3. International Scientific Researches Conference, October 3-6, Adana, Turkey, 440-448.

AYATA Ü, BILGINER EH, ÇAMLIBEL O (2024) Applications of natural and synthetic wax blends on wood surfaces of magnolia (*Magnolia grandiflora* L.), Wood Industry and Engineering. In press.

BOGDANOV S (2009) The Beeswax Book, Chapter 1.

BUTCHER RA (1992) Varnish, Structural Survey, 10(2):137-143.

ÇAMLIBEL O, AYATA Ü (2024) Effects of modified beeswaxes on selected surface characteristics of Siberian pine (*Pinus sibirica*) wood, Latin America 9th International Conference on Scientific Researches, 1-5 May 2024, Havana, Cuba.

DIN 5033 (1979) Deutsche Normen, Farbmessung. Normenausschuß Farbe (FNF) im DIN Deutsches Institut für Normung eV, Beuth, Berlin März.

DINKER A, AGARWAL M, AGARWAL GD (2017) Preparation, characterization, and performance study of beeswax/expanded graphite composite as thermal storage material. Experimental Heat Transfer, 30(2):139-150. DOI: 10.1080/08916152.2016.1185198

GUPTA G, ANJALI K (2023) Environmentally Friendly Beeswax: Properties, Composition, Adulteration, and its Therapeutic Benefits. In IOP Conference Series: Earth and Environmental Science, 1110(1):012041. IOP Publishing. DOI: 10.1088/1755-1315/1110/1/012041.

ISO 2813 (1994) Paints and varnishes - determination of specular gloss of non-metallic paint films at 20 degrees, 60 degrees and 85 degrees, International Organization for Standardization, Geneva, Switzerland.

JANESCH J, ARMINGER B, GINDL-ALTMUTTER W, HANSMANN C (2020) Superhydrophobic coatings on wood made of plant oil and natural wax. Progress in Organic Coatings, 148:105891. DOI: 10.1016/j.porgcoat.2020.105891.

LANGE DR (1999) Fundamentals of Colourimetry - Application Report No. 10e. DR Lange: New York, NY, USA.

LIU J, ZHANG QH MA F, ZHANG SF, ZHOU Q, HUANG AM (2020) Three-step identification of infrared spectra of similar tree species to *Pterocarpus santalinus* covered with beeswax. Journal of Molecular Structure, 1218, 128484. DOI: 10.1016/j.molstruc.2020.128484.

LIU X, TIMAR MC, VARODI AM, NEDELCU R, TORCĂTORU MJ (2022) Colour and surface chemistry changes of wood surfaces coated with two types of waxes after seven years exposure to natural light in indoor conditions. Coatings, 12(11):1689. DOI: 10.3390/coatings12111689.

NÉMETH R, TSALAGKAS D, BAK DTM (2014) Protecting Effect of Beeswax Impregnation on the Modulus of Elasticity During Soil Contact, Proceedings of the 57th International Convention of Society of Wood Science and Technology June 23-27, 2014 - Zvolen, Slovakia, 35-44.

NING L, ZHANG L, ZHANG S, WANG W (2022) How does surfactant affect the hydrophobicity of wax-coated wood? Colloids and Surfaces A: Physicochemical and Engineering Aspects, 650:129606. DOI: 10.1016/j.colsurfa.2022.129606.

NIU K, SONG K (2021) Surface coating and interfacial properties of hot-waxed wood using modified polyethylene wax. Progress in Organic Coatings, 150:105947. DOI: 10.1016/j.porgcoat.2020.105947.

PEKER H, BILGINER EH, AYATA Ü, ÇAMLIBEL O, GÜRLEYEN L (2024c) Identification of certain surface characteristics of balau red (*shorea guiso*) wood treated with wood bleaching chemicals followed by wax treatment. Turkish Journal of Science and Engineering, in press.

PEKER H, BILGINER EH, AYATA Ü, ÇAMLIBEL O, GÜRLEYEN L (2024b) Effects of different layering layers on some surface properties of wax-applied plum (*Prunus domestica* L.) wood. Sivas Cumhuriyet University Journal of Engineering Faculty. in press.

PEKER H, BILGINER EH, AYATA Ü, ÇAMLIBEL O, GÜRLEYEN L (2024a) The effects of wax application on certain surface properties of olive (*Olea europaea* L.) wood. Journal of Marine and Engineering Technology 4(1). in press.

PIAO X ZHAO, Z GUO H, WANG Z, JIN C (2022) Improved properties of bamboo by thermal treatment with wood wax oil. Colloids and Surfaces A: Physicochemical and Engineering Aspects 643, 128807. https://doi.org/10.1016/j.colsurfa.2022.128807

REN L, CAI Y, REN L, YANG H (2016) Preparation of modified beeswax and its influence on the surface properties of compressed poplar wood. Materials, 9(4):230. DOI: 10.3390/ma9040230.

ŞANIVAR N, ZORLU İ (1980) Ağaçişleri Gereç Bilgisi Temel Ders Kitabı, Mesleki Ve Teknik Öğretim Kitapları, Milli Eğitim Basımevi, İstanbul, Etüd ve Programlama Dairesi Yayınları No: 43.

SARALAYA S, JAYANTH BS, THOMAS NS, SUNIL SM (2021) Bee wax and honey-a primer for OMFS. Oral and Maxillofacial Surgery, 25(1):1-6. DOI: 10.1007/s10006-020-00893-0.

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, Ankara, Turkey.

WALISZEWSKA B, PRADZYNSKI W, ZBOROWSKA M, STACHOWIAK-WENCEK A, WALISZEWSKA H, MALYSKO E (2015) Chemical composition of black walnut wood. Annals of Warsaw University of Life Sciences-SGGW. Forestry and Wood Technology, 91:179-181.

WAßMANN O, AHMED SIU (2020) Slippery wood: low friction and low wear of modified beech wood. Tribology Letters, 68:1-10. DOI: 10.1007/s11249-020-01297-7.