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APPLICATIONS OF NATURAL AND SYNTHETIC WAX BLENDS ON WOOD SURFACES OF MAGNOLIA (*Magnolia grandiflora* L.)

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Abstract

In this study, researchers investigated how surface properties, such as whiteness index (WI*) values, color parameters [total color differences (ΔE*), lightness (L*), red (a*) color tone, yellow (b*) color tone, chroma (C*) value, and hue (ho) angle], and glossiness values, were affected by wax applications with different coating layers on magnolia (*Magnolia grandiflora* L.) wood. A control group was set up, and the outcomes from samples with varying counts of wax layers were contrasted. The variance analyses conducted for the number of rocks factor in all tests were found to be significant. The ΔE* values were found to be 3.02 for the 1-layer application, 3.67 for the 2-layer application, and 4.80 for the 3-layer application. It was observed that as the number of layers increased in color parameters, the values of ho and L* decreased, while b*, C*, and a* values increased. Additionally, decreases in WI* values were detected in both directions (⊥ and ∥). It was observed that the waxes used in the study had a modifying effect on the selected surface properties of magnolia wood.

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APPLICATIONS OF NATURAL AND SYNTHETIC WAX BLENDS ON WOOD SURFACES OF MAGNOLIA (*Magnolia grandiflora* L.)

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1. Introduction

Wax is commonly a blend of organic compounds, frequently comprising elongated molecules. These molecules encompass hydrocarbons, esters derived from fatty acids, elongated chain alcohols, and similar constituents. The precise chemical makeup of wax is largely contingent upon its source, be it animal, plant, or mineral in origin (Regert et al. 2005; Peris-Vicente et al. 2006). Waxes play a role in establishing a tough and long-lasting shield on surfaces. This shield not only offers resilience but also establishes a waterproof barrier, shielding the surface from a range of external factors. They find extensive applications across furniture, upholstery, and plastic goods. In the realm of art, waxes serve as a crucial tool for creating resist paintings. Artists apply them selectively to areas where exposure to acid is undesirable, effectively protecting those regions from the potential corrosive effects of acid (Hammond et al., 1969).

The Magnolia genus, belonging to the Magnoliaceae family, consists of about 90 species of trees or shrubs. These are mainly found in temperate and tropical regions, with distribution extending across countries such as India, Malaysia, Japan, and China (Anonymous, 1996). *Magnolia grandiflora* L., commonly known as the Southern magnolia tree, is a tree reaching heights of 5-20 meters, native to the southeastern states of the United States and Mexico (Vázquez, 1990). When newly cut, the wood displays a white coloration; however, upon exposure to air, it undergoes a transformation to a brown hue (Elias, 1980). This tree exhibits remarkable resistance to wind and is suitable for use in shelterbelt plantings (Huxley, 1992).

Wood has a restricted range of uses; however, it can be employed in crafting furniture, paneling, cladding, commodities, and cabinets (Brown and Kirman, 1990). The timber is utilized in small amounts for fuel, basketry, crate construction, wooden crafts, and furniture making (Vines, 1982; Sargent, 1965). While the wood is hard and relatively dense, it lacks significant flexibility and durability (Vines, 1982). Wood stands as one of the foremost renewable construction materials. It can be easily molded, demands minimal energy during processing, and exhibits exceptional structural characteristics (Scheffer and Cowling, 1966).

Magnolia wood had a fully dry density of 581.12 kg/m^3, tangential shrinkage of 6.16%, radial shrinkage of 4.66%, longitudinal shrinkage of 0.54%, volumetric shrinkage of 11.36%, fiber saturation point of 19.56%, moisture absorption after two weeks of 68.46%, bending strength of 85.56 N/mm^2, modulus of elasticity of 6375.66 N/mm^2, dynamic bending (shock) resistance of 0.378 kg/cm^2, tangential surface Janka hardness of 57.51 N/mm^2, radial surface Janka hardness of 49.50 N/mm^2, transverse surface Janka hardness of 62.73 N/mm^2 (Çavuş, 2019), and air-dry density of 647.00 kg/m^3, with screw holding capacity of 32.53 N/mm^2 on the radial surface, 38.40 N/mm^2 on the tangential surface, and 30.40 N/mm^2 on the transverse surface (Çavuş and Ayata, 2018).

In the literature, numerous studies have investigated the application of various wax treatments on wooden surfaces (Garai et al., 2005; Lesar et al., 2011; Avramidis et al., 2011; Wang et al., 2014; Yuqing et al., 2016; Humar et al., 2017; Akçay, 2020; Janesch et al., 2020; Yang et al., 2020; Niu and Song, 2021; Zhang et al., 2022; Arminger et al., 2022; Liu et al., 2022; Ning et al., 2022; Piao et al., 2022; Peker et al., 2024a, 2024b, 2024c). The changes in surface alterations between the applied wax and wooden material have been attempted to be explained using various tests in conducted studies. Nevertheless, there seems to be a notable gap in research concerning the surface alterations resulting from the application of different coating layers specifically on magnolia wood.

In this study, variations in surface properties resulting from wax applications with different coating layers were investigated on magnolia (*Magnolia grandiflora* L.) wood. The obtained results were believed to have made a significant contribution to the knowledge domain regarding both the researchers involved in the wax application study and the potential applications of this specific tree species.

2. Materials and Methods

2.1. Material

2.1.1. Wood Material

In this study, magnolia (*Magnolia grandiflora* L.) wood was utilized as the principal material. The wood was sourced from a reputable commercial supplier to ensure high quality and had dimensions of 100 x 200 x 15 mm. Following these selection criteria, the samples were prepared in accordance with the standards specified in ISO 554, (1976). Prior to bleaching, the test samples underwent sanding with grits 80, 120, and 180, followed by surface cleaning using compressed air.

2.1.2. Wax

In the research, a blend of natural and synthetic wax with oil (appearance: paste, odor: characteristic, color: neutral, solubility in water: dispersible but not soluble, dry residue: 30%, and pH value: 7.6) was employed.

2.2. Method

2.2.1. Application of Wax on Wooden Material Surfaces

In the study, oil with a mixture of natural and synthetic wax was applied to wooden material surfaces using a brush in 1, 2, and 3 layers.

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

The use of Whiteness Meter BDY-1 device determined the whiteness index (*WI**) values in parallel and perpendicular directions to the fibers (ASTM E313-15e1, 2015). Glossiness tests were conducted using the ETB-0833 model gloss meter device at three different angles (20°, 60°, and 85°) in perpendicular and parallel directions to the fibers according to ISO 2813 (1994) standard. The color change 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 explanations for Δa^*, ΔC^*, Δb^*, and ΔL^* are outlined in Table 1 based on 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^*	Redder than the reference	Greener than the reference
ΔC^*	Clearer, brighter than the reference	Duller, matte than the reference

Alternative criteria for comparing the visual assessment of the calculated ΔE^* color difference are presented in Table 2 following DIN 5033, (DIN 1979) standards.

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.

$$\Delta a^* = [a^*_{\text{wax applied}}] - [a^*_{\text{control}}] \quad (1)$$

$$\Delta L^* = [L^*_{\text{wax applied}}] - [L^*_{\text{control}}] \quad (2)$$

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

2.2.3. Statistical Analysis

Statistical analysis was conducted utilizing a statistical software package and the study's measurement data. This involved computing standard deviations, determining maximum and minimum mean values, calculating measurement values associated with the mean, identifying homogeneity groups, conducting variance analyses, and determining percentage (%) change rates.

3. Results

The analysis of variance results for color parameters (a^*, b^*, C^*, h^o, and L^*) is provided in Table 3.

Table 3: Analysis of variance results for color parameters (a^*, b^*, C^*, h^o, and L^*)

Source	Test	Sum of Squares	df	Mean Square	F	Sig.
Number of Layer	L^*	53.376	3	17.792	12.078	0.000*
	a^*	5.553	3	1.851	43.418	0.000*
	b^*	69.555	3	23.185	60.099	0.000*
	C^*	73.946	3	24.649	61.155	0.000*
	h^o	7.686	3	2.562	15.753	0.000*
Error	L^*	53.032	36	1.473		
	a^*	1.535	36	0.043		
	b^*	13.888	36	0.386		
	C^*	14.510	36	0.403		
	h^o	5.855	36	0.163		
Total	L^*	203697.927	40			
	a^*	502.140	40			
	b^*	21337.849	40			
	C^*	21839.021	40			
	h^o	264669.499	40			
Corrected Total	L^*	106.408	39			
	a^*	7.087	39			
	b^*	83.444	39			
	C^*	88.456	39			
	h^o	13.541	39			

*: Significant

Table 4 presents the measurement results for color parameters (a^*, b^*, C^*, h^o and L^*).

Table 4: Measurement results for color parameters (a^*, b^*, C^*, h^o, and L^*)

Test	Wax Application	N	Mean	Change (%)	*HG*	*SS*	Minimum	Maximum	COV
L^*	Control	10	73.29	-	A*	1.18	71.34	75.19	1.61
	1-layer	10	70.99	↓3.14	B	1.42	67.93	72.32	2.00
	2-layers	10	70.82	↓3.37	B	1.19	68.82	71.83	1.68
	3-layers	10	70.28	↓4.11	B**	1.04	68.60	71.25	1.48
a^*	Control	10	2.99	-	D**	0.22	2.58	3.37	7.45
	1-layer	10	3.37	↑12.71	C	0.16	3.18	3.72	4.86
	2-layers	10	3.74	↑25.08	B	0.24	3.39	4.10	6.40
	3-layers	10	3.98	↑33.11	A*	0.19	3.46	4.15	4.83
b^*	Control	10	21.02	-	D**	0.71	20.09	22.48	3.37
	1-layer	10	22.93	↑9.09	C	0.64	21.63	23.81	2.78
	2-layers	10	23.62	↑12.37	B	0.65	22.63	24.57	2.75
	3-layers	10	24.63	↑17.17	A*	0.46	23.54	25.20	1.87
C^*	Control	10	21.23	-	D**	0.72	20.25	22.73	3.39
	1-layer	10	23.18	↑9.19	C	0.65	21.87	24.06	2.79
	2-layers	10	23.91	↑12.62	B	0.67	22.87	24.91	2.80
	3-layers	10	24.95	↑17.52	A*	0.48	23.79	25.52	1.92
h^o	Control	10	81.90	-	A*	0.51	81.17	82.68	0.63
	1-layer	10	81.63	↓0.33	A	0.26	80.96	81.96	0.32
	2-layers	10	81.01	↓1.09	B	0.44	80.47	81.67	0.55
	3-layers	10	80.83	↓1.31	B**	0.35	80.43	81.63	0.43
N: Number of Measurements, *SS*: Standard Deviation, *HG*: Homogeneity Group, COV: Coefficient of Variation, *: Lowest Value, **: Highest Value									

The variance analyses related to the glossiness values are shown in Table 5.

Table 5: Analysis of variance results for glossiness values

Source	Test	Sum of Squares	df	Mean Square	F	Sig.
Number of Layer	⊥20° glossiness	0.699	3	0.233	14.979	0.000*
	⊥60° glossiness	122.493	3	40.831	643.288	0.000*
	⊥85° glossiness	259.445	3	86.482	363.284	0.000*
	∥20° glossiness	3.395	3	1.132	93.440	0.000*
	∥60° glossiness	190.835	3	63.612	1072.607	0.000*
	∥85° glossiness	850.975	3	283.658	922.216	0.000*
Error	⊥20° glossiness	0.560	36	0.016		
	⊥60° glossiness	2.285	36	0.063		
	⊥85° glossiness	8.570	36	0.238		
	∥20° glossiness	0.436	36	0.012		
	∥60° glossiness	2.135	36	0.059		
	∥85° glossiness	11.073	36	0.308		
Total	⊥20° glossiness	44.940	40			
	⊥60° glossiness	1309.610	40			
	⊥85° glossiness	1339.240	40			
	∥20° glossiness	35.160	40			
	∥60° glossiness	1719.430	40			
	∥85° glossiness	4096.650	40			
Corrected Total	⊥20° glossiness	1.259	39			
	⊥60° glossiness	124.778	39			
	⊥85° glossiness	268.015	39			
	∥20° glossiness	3.831	39			
	∥60° glossiness	192.970	39			
	∥85° glossiness	862.048	39			
*: Significant						

Table 6 illustrates the measurement findings for glossiness values.

Table 6: Measurement results for glossiness values

Test	Wax Application	N	Mean	Change (%)	*HG*	*SS*	Minimum	Maximum	COV
⊥20º	Control	10	0.86	-	C**	0.22	0.60	1.10	25.83
	1-layer	10	1.00	↑16.28	B	0.00	1.00	1.00	0.00
	2-layers	10	1.10	↑27.91	B	0.08	1.00	1.20	7.42
	3-layers	10	1.22	↑41.86	A*	0.08	1.10	1.30	6.47
⊥60º	Control	10	2.50	-	C**	0.00	2.50	2.50	0.00
	1-layer	10	5.99	↑139.60	B	0.22	5.70	6.20	3.64
	2-layers	10	6.18	↑147.20	B	0.34	5.70	6.50	5.54
	3-layers	10	7.10	↑184.00	A*	0.30	6.60	7.40	4.20
⊥85º	Control	10	0.82	-	C**	0.19	0.70	1.10	23.56
	1-layer	10	6.39	↑679.27	B	0.09	6.30	6.50	1.37
	2-layers	10	6.21	↑657.32	B	0.92	4.90	7.00	14.83
	3-layers	10	7.28	↑787.80	A*	0.24	6.90	7.60	3.35
‖20º	Control	10	0.50	-	C**	0.00	0.50	0.50	0.00
	1-layer	10	0.88	↑76.00	B	0.13	0.70	1.00	14.96
	2-layers	10	0.84	↑68.00	B	0.05	0.80	0.90	6.15
	3-layers	10	1.32	↑164.00	A*	0.17	1.10	1.50	12.78
‖60º	Control	10	2.53	-	C**	0.05	2.50	2.60	1.91
	1-layer	10	6.91	↑173.12	B	0.16	6.70	7.10	2.31
	2-layers	10	6.93	↑173.91	B	0.18	6.70	7.10	2.64
	3-layers	10	8.34	↑229.64	A*	0.42	7.80	8.80	5.03
‖85º	Control	10	1.36	-	D**	0.05	1.30	1.40	3.80
	1-layer	10	9.90	↑627.94	C	0.43	9.40	10.40	4.34
	2-layers	10	11.05	↑712.50	B	0.19	10.80	11.30	1.72
	3-layers	10	13.66	↑904.41	A*	1.00	11.90	14.60	7.35
N: Number of Measurements, *SS*: Standard Deviation, *HG*: Homogeneity Group, COV: Coefficient of Variation, *: Lowest Value, **: Highest Value									

Table 7 presents the results for the total color differences (ΔE^*).

Table 7: Results for the total color differences

Wax Application	ΔL^*	Δa^*	Δb^*	ΔC^*	ΔH^*	ΔE^*	Color change criteria (DIN 5033, 1979)
1-layer	-2.31	0.38	1.90	1.94	-	3.02	Very distinct (3.0 to 6.0)
2-layers	-2.48	0.74	2.60	2.68	0.34	3.67	
3-layers	-3.01	0.98	3.61	3.72	0.40	4.80	

Table 8 displays the recorded data for whiteness index (WI^*) values.

Table 8: Analysis of variance results for whiteness index (WI^*) values

Source	Test	Sum of Squares	df	Mean Square	F	Sig.
Number of Layer	WI^* (⊥)	359.827	3	119.942	404.907	0.000*
	WI^* (‖)	510.864	3	170.288	743.977	0.000*
Error	WI^* (⊥)	10.664	36	0.296		
	WI^* (‖)	8.240	36	0.229		
Total	WI^* (⊥)	29714.380	40			
	WI^* (‖)	22646.720	40			
Corrected Total	WI^* (⊥)	370.491	39			
	WI^* (‖)	519.104	39			
*: Significant						

Table 9 showcases the measurement outcomes for whiteness index (WI^*) values.

Table 9: Measurement results for whiteness index (*WI**) values

Test	Wax Application	N	Mean	Change (%)	*HG*	*SS*	Minimum	Maximum	COV
*WI** ⊥	Control	10	31.38	-	A*	0.35	30.90	31.80	1.11
	1-layer	10	28.32	↓9.75	B	0.39	27.70	28.80	1.36
	2-layers	10	24.92	↓20.59	C	0.94	24.40	26.70	3.77
	3-layers	10	23.72	↓24.41	D**	0.18	23.40	23.90	0.76
*WI** ǁ	Control	10	29.38	-	A*	0.31	28.90	29.70	1.05
	1-layer	10	23.34	↓20.56	B	0.62	22.60	24.10	2.66
	2-layers	10	21.22	↓27.77	C	0.15	21.00	21.40	0.73
	3-layers	10	20.14	↓31.45	D**	0.64	19.00	20.70	3.19

N: Number of Measurements, *SS*: Standard Deviation, *HG*: Homogeneity Group, COV: Coefficient of Variation, *: Lowest Value, **: Highest Value

4. Discussion

In the provided test result tables, it was determined that the factor representing the number of categories significantly influenced the variance analyses (Table 3, 5, and 8).

Decreases in *WI** were observed for both perpendicular and parallel directions to the fibers with applications of different coating ratios, while decreases were observed in h^o and *L** parameters. Increases were detected in *a**, *C**, and *b** values. The highest results for *L** and h^o values were found in the samples belonging to the control experimental group (73.29 and 81.90, respectively). Alternatively, the decline rates in the h^o values are recorded as 0.33% for 1-layer, 1.09% for 2-layer, and 1.31% for 3-layer. The highest reduction rate for *L** was determined to be 4.11% on surfaces treated with 3-layer of wax, while the lowest reduction rate was observed to be 3.14% on samples treated with 1-layer of wax. The lowest results for the *a**, *b**, and *C** parameters were found in the control samples (2.99, 21.02, and 21.23, respectively). Additionally, the highest values for these parameters were also observed on surfaces treated with 3-layer of wax (*a**: 3.98, *b**: 24.63, and *C**: 24.95, respectively). In the 3-layer wax application, the parameters *a**, *b**, and *C** experienced the highest increase rates, with percentages of 33.11%, 17.17%, and 17.52%, respectively, in that order (Table 4).

Wax applications on walnut and maple woods (Liu et al., 2022), along with beech, linden, poplar, and pine woods (Akçay, 2020), were noted to have resulted in a reduction in *L** and an increase in *a** and *b** values.

According to these results, increases in glossiness values were observed in all degrees and directions following the application of wax. Additionally, the lowest measurement results for all degrees and directions were obtained from the samples belonging to the control experimental group, while the highest results were found in the samples with 3-layer of wax application. Particularly, it was determined that the increase values in both directions at 85 degrees were above 600% (Table 6).

Following all applications, negative values were observed in Δ*L** (darker than the reference), while positive results were determined in Δ*a**, Δ*b**, and Δ*C** (redder, yellower, and clearer/brighter than the reference, respectively). The Δ*E** values were found to be 3.02 for the 1-layer wax application, 3.67 for the 2-layer wax application, and 4.80 for the 3-layer wax application. Additionally, the increase in the coefficients of Δ*E**, Δ*a**, Δ*b**, and Δ*C** corresponds to the increase. When compared with color change criteria (DIN 5033, 1979), it is evident that the result “very distinct (3.0 to 6.0)” was obtained after all applications (Table 7).

The *WI** values in the vertical direction relative to the fibers were found to be higher compared to those in the parallel direction to the fibers. The highest results for *WI** values were found in the control samples (⊥: 31.38 and ǁ: 29.38), while the lowest results were observed in the group of experimental samples with 3-layer of wax application (⊥: 23.72 and ǁ: 20.14). The values for *WI** were found as 9.75% in the ⊥ direction for 1-layer, 20.59% for 2-layer, and 24.41% for 3-layer, whereas in the ǁ direction, they were determined as 20.56% for 1-layer, 27.77% for 2-layer, and 31.45% for 3-layer (Table 9).

In the existing literature, alterations in color, glossiness, and whiteness index values resulting from the wax application on olive (Peker et al., 2024a), plum (Peker et al., 2024b), balau red (Peker et al., 2024c), and ebony Macassar (Kaplan et al., 2024) wood species were documented. In wax studies conducted on olive (Peker et al., 2024a) and plum (Peker et al., 2024b) woods with different application rates, it has been reported that *L** and h^o values decrease, and additionally, *a**, *b**, and *C** values increase. The results obtained in color measurements in this study are consistent with the literature.

5. Conclusion

The waxes utilized in the study were noted to alter the chosen surface characteristics of magnolia wood. Wax applications resulted in enhancements across all glossiness levels and orientations. The ΔE^* values were determined to be 3.02 for the 1-layer application, 3.67 for the 2-layer application, and 4.80 for the 3-layer application. A decline was noted in WI^* values in both directions (⊥ and ∥).

Disclosure Statement

No potential conflict of interest was reported by the authors.

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