A Study on the Application of Wax on Linden (*Tilia tomentosa* Moench.) Wood

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Abstract

Linden wood is used in match production, double bass making, carving, musical instrument crafting, and furniture production. This study examined the effects of applying varying numbers of wax coats (1, 2, and 3 coats) on the color parameters, glossiness values, and whiteness index (*WI**) values of linden (*Tilia tomentosa* Moench.) wood surfaces. A comparison was made between untreated surfaces and those treated with three different wax applications. According to the obtained results, all tests except for hue angle were found to be significant in the analysis of variance. The ΔE^* values were found to be 5.13 for the application of 1 coat of wax, 6.53 for the application of 2 coats of wax, and 6.95 for the application of 3 coats of wax. After applying waxes to the wood, reductions were noted in *WI** and *L** values, while enhancements were detected in glossiness readings at 60 and 85 degrees, as well as in *a**, *C**, h^o, and *b**values.

Keywords: Wax, color, linden, whiteness index, glossiness

Introduction

In English, the word "wax" refers to a solid substance that melts with heat, typically smooth and shiny. This term is often used to describe materials such as wax, beeswax, or polish. It is commonly used to refer to substances used in furniture polish, car wax, or candle making. Additionally, the term "wax" is also used to denote the wax used in the music recording industry for duplicating or preserving recordings. (Bulian and Graystone 2009).

Most wax polishes consist of blends of different grades of waxes, both natural and synthetic resins, and additional components to achieve specific desired properties. These ingredients are typically dissolved or dispersed in an appropriate solvent or dispersing medium (Roberts 1968).

The layer of plant wax comprises a complex mixture of various classes of compounds, including fatty acids and long-chain n-alkanes. Among these, the long-chain n-alkanes are particularly valuable biomarkers because of their high resistance to natural degradation (Eglinton and Eglinton 2008).

Due to increasing environmental awareness among consumers and the avoidance of wood treated with biocidal processes and unsustainable tropical forests, the importance of wax use in the wood preservation industry, especially in Europe, is increasing. Therefore, the industry is interested in developing alternatives such as treatments with waxes (Lesar *et al*. 2011).

The impregnation depth of wood depends on the viscosity of the wax and the porosity of the wood. After filling the cell voids, waxes can reduce hygroscopicity and water absorption (Papadopoulos and Pougioula 2010).

High gloss is predominantly achieved from waxes through a migration mechanism. Waxes tend to fill micro voids that form as the coating dries, providing a smooth, continuous film. Typically, only small amounts of waxes (0.5% to 2% solids) are needed to enhance gloss (Bower 2005).

The composition of crude oils includes several bipolar species capable of forming emulsions, and variations in the polar and non-polar parts of these species determine the diversity of emulsion sizes. Differences in chemical functionality (e.g., heterocyclic amines, sulfurs, oxides, carboxyl, poly- and mono-aromatic, alkane and alkene groups, etc.) and, consequently, variations in emulsion stabilities, are therefore prone to be extensive (Becker 1997).

Various types of beeswax and wax-containing chemicals prepared on different types of wood surfaces have been reported in the literature [beeswax and Manchurian ash (*Fraxinus mandshurica* Rupr.) wood (Niu and Song 2021), Ebony Macassar (*Diospyros celebica* Bakh.) (Kaplan *et al*. 2024), Siberian pine (*Pinus sibirica*) (Çamlıbel and Ayata, 2024a), ebony Afrika (*Diospyros crassiflora* Hiern.) (Çamlıbel and Ayata, 2024b), lemon (*Citrus limon* (L.) Burm.) (Çamlıbel and Ayata, 2024c), beeswax and poplar (*Populus ussuriensis* Kom) wood (Ren *et al*. 2016), wax and European walnut (*Juglans regia*) and sycamore maple (*Acer pseudoplatanus*) wood (Liu *et al*. 2022), beeswax and European cherry (*Prunus avium* L) and spruce (*Picea abies* (L) Karst) wood (Petric *et al*. 2004), polypropylene wax and Japanese elm (*Ulmus davidiana* Planch var. japonica) wood (Wang and Song 2022), beeswax and poplar (*Populus alba* L.), lime (*Tilia grandifolia* Ehrh.), Scots pine (*Pinus sylvestris* L.), and oriental beech (*Fagus orientalis* L.) wood (Akçay 2020), propolis and Scots pine (*Pinus sylvestris* L.), Nordmann fir (*Abies nordmanniana*), oriental spruce (*Picea orientalis* L.) wood (Akçay *et al*. 2022)].

Linden wood is used in the production of drawing boards and picture frames, carving, turning, and modeling, as well as for hat molds, boxes, chests, beehives, plywood, blockboard, and primer coating areas (Hammond *et al*. 1969).

In the literature, it has been observed that wax application on the surfaces of linden wood used in wood processing industries has not been conducted. This study was conceived to address this gap. Additionally, testing wax application is important for introducing a new perspective on the usage areas of linden wood.

In this study, wax applications of different coat numbers were tested on linden (*Tilia tomentosa* Moench.) wood, and whether there were differences between layers was examined through various surface tests.

Materials and Methods

Wood Material

Linden (*Tilia tomentosa* Moench.) wood samples were prepared in dimensions of 100 x 200 x 20 mm according to the TS ISO 13061-1 (2021) standard.

Wax

In the study, an oil mixture containing a combination of natural and synthetic waxes (appearance: paste, color: neutral, odor: characteristic, solubility in water: dispersible but insoluble, dry residue: 30%, and pH value: 7.6) was used. The wax was purchased from a specialized wood preservative supplier.

Application of Wax on Wooden Surfaces

The oil mixture containing a combination of natural and synthetic waxes was applied to wooden surfaces using a brush, in 1, 2, and 3 layers.

Determination of Some Surface Properties

Glossiness tests (ISO 2813 1994) (ETB-0833 model gloss meter), whiteness index (WI^*) values (ASTM E313-15e1 2015) (Whiteness Meter BDY-1), and color changes (ASTM D 2244-3 2007) (CS-10) were measured. Total color differences were calculated using the following formulas.

$$\Delta L^* = (L^*_{\text{wax applied sample}} - L^*_{\text{control}}) \quad (1)$$
$$C^* = [(a^*)^2 + (b^*)^2]^{0.5} \quad (2)$$
$$h^o = \arctan (b^*/a^*) \quad (3)$$
$$\Delta H^* = [(\Delta E^*)^2 - (\Delta L^*)^2 - (\Delta C^*)^2]^{0.5} \quad (4)$$
$$\Delta C^* = (C^*_{\text{wax applied sample}} - C^*_{\text{control}}) \quad (5)$$
$$\Delta a^* = (a^*_{\text{wax applied sample}} - a^*_{\text{control}}) \quad (6)$$
$$\Delta E^* = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{0.5} \quad (7)$$
$$\Delta b^* = (b^*_{\text{wax applied sample}} - b^*_{\text{control}}) \quad (8)$$

ΔC^*: chroma difference or saturation difference, and ΔH^*: hue difference or shade difference are indicated. Table 1 provides important information on other parameters (Lange, 1999). ΔE^* comparison criteria (DIN 5033 1979) are given in Table 2.

Table 1. Information regarding Δa^*, ΔL^*, Δb^*, and ΔC^* values (Lange 1999)

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

Table 2. Comparison criteria for ΔE^* assessment (DIN 5033 1979)

Visual	Total Colour Difference	Visual	Total Colour Difference
Undetectable	<0.2	Distinct	1.5 - 3.0
Very Weak	0.2 - 0.5	Very Distinct	3.0 - 6.0
Weak	0.5 - 1.5	Strong	6.0 - 12.0
		Very Strong	> 12.0

Statistical Analysis

A statistical program was utilized to calculate standard deviations, variance analysis results, means, minimum and maximum values, homogeneity groups, and percentages (%) of changes.

Results and Discussion

According to the variance analysis results presented in Table 3, it is observed that the applied wax coat number factor is insignificant for the hue angle (h^o) value, while for all other tests, the applied wax coat number factor is found to be significant (Table 3).

Table 3. Analysis of variance results (*: Significant)

Test	Sum of Squares	df	Mean Square	F value	Sig.
*L**	68.344	3	22.781	890.208	0.000*
*a**	16.627	3	5.542	196.854	0.000*
*b**	225.323	3	75.108	623.424	0.000*
*C**	241.858	3	80.619	626.260	0.000*
h^o	0.716	3	0.239	1.767	0.171**
⊥20° glossiness	2.167	3	0.722	86.382	0.000*
⊥60° glossiness	64.871	3	21.624	254.978	0.000*
⊥85° glossiness	248.850	3	82.950	1013.646	0.000*
‖ 20° glossiness	0.897	3	0.299	176.410	0.000*
‖ 60° glossiness	47.715	3	15.905	324.406	0.000*
‖ 85° glossiness	465.321	3	155.107	341.123	0.000*
*WI** (⊥)	489.280	3	163.093	1405.977	0.000*
*WI** (‖)	748.181	3	249.394	1105.959	0.000*

Table 4 presents the results for the color parameters. For the *L** value, the highest value was observed in the control experiment samples (78.45), while the lowest was obtained in the samples treated with 3 layers of wax (75.11). For *L**, decreases of 2.21%, 3.80%, and 4.26% were observed with 1, 2, and 3 layers of wax, respectively. It is determined that increases in the number of layers result in decreases in this parameter (Table 4).

The *a** parameter exhibited its lowest value in the control experiment group samples at 4.96, while the highest value was recorded in samples treated with three layers of wax, reaching 6.56. With the application of 1, 2, and 3 layers of wax, increases of 25.60%, 30.85%, and 32.26% were observed, respectively. This indicates a consistent trend of increasing values with each additional layer of wax, as indicated in Table 4.

In relation to the *b** value, the control experiment group samples exhibited the lowest measurement (16.81), whereas the samples treated with 3 layers of wax demonstrated the highest value (22.68). Incremental increases of 27.66%, 33.31%, and 34.92% were noted with 1, 2, and 3 layers of wax, respectively. The trend indicates that as the number of wax layers applied increases, so does this parameter (as depicted in Table 4).

In the case of the *C** value, the control experiment group samples exhibited the lowest value (17.52), whereas the samples treated with 3 layers of wax demonstrated the highest value (23.61). This resulted in increases of 27.57%, 33.16%, and 34.76% with 1, 2, and 3 layers of wax, respectively. The trend indicates that as the number of layers increases, so do the values of this parameter (Table 4).

In terms of the h^o value, the control group samples exhibited the lowest measurement at 73.54, whereas the highest reading was recorded in samples treated with three layers of wax, reaching 73.88. This indicates an incremental trend of 0.37%, 0.42%, and 0.46% with each successive layer of wax 1, 2, and 3 layers, respectively. These findings illustrate a proportional rise in values as the number of wax layers increases, as outlined in Table 4.

Akçay (2020) reported a decrease in *L** values and an increase in *a** and *b** values with the application of wax to linden, beech, poplar, and Scots pine woods, while *Liu et al*. (2022) reported similar results for European walnut and sycamore maple woods. These findings are consistent with the results obtained in our study.

Additionally, in the literature, studies have reported changes in color, glossiness, and whiteness index values when chemicals derived from waxes were applied to different wood material surfaces (Çamlıbel and Ayata, 2024a; b; c; Kaplan *et al.* 2024).

Table 4 Results of color parameters

Test	Wax Application	N	Mean	Change (%)	*HG*	Standard Deviation	Minimum	Maximum	COV
*L**	Control	10	78.45	-	A*	0.14	78.24	78.72	0.18
	1 layer	10	76.72	↓2.21	B	0.17	76.50	77.01	0.22
	2 layers	10	75.47	↓3.80	C	0.14	75.22	75.66	0.18
	3 layers	10	75.11	↓4.26	D**	0.19	74.80	75.41	0.25
*a**	Control	10	4.96	-	C**	0.16	4.72	5.19	3.25
	1 layer	10	6.23	↑25.60	B	0.15	5.98	6.51	2.38
	2 layers	10	6.49	↑30.85	A	0.16	6.26	6.80	2.41
	3 layers	10	6.56	↑32.26	A*	0.20	6.27	6.81	3.05
*b**	Control	10	16.81	-	C**	0.44	16.04	17.30	2.63
	1 layer	10	21.46	↑27.66	B	0.20	21.21	21.88	0.91
	2 layers	10	22.41	↑33.31	A	0.41	21.87	23.13	1.84
	3 layers	10	22.68	↑34.92	A*	0.28	22.32	23.12	1.23

C^*	Control	10	17.52	-	C**	0.45	16.79	18.00	2.60
	1 layer	10	22.35	↑27.57	B	0.21	22.10	22.77	0.96
	2 layers	10	23.33	↑33.16	A	0.41	22.81	24.04	1.74
	3 layers	10	23.61	↑34.76	A*	0.31	23.21	24.09	1.32
h^o	Control	10	73.54	-	A**	0.39	72.87	74.03	0.53
	1 layer	10	73.81	↑0.37	A	0.31	73.29	74.30	0.42
	2 layers	10	73.85	↑0.42	A	0.41	73.27	74.55	0.56
	3 layers	10	73.88	↑0.46	A*	0.36	73.31	74.43	0.48

HG: Homogeneity Group, COV: Coefficient of Variation, N: Number of Measurements, *: Highest value, **: Lowest value

Table 5 shows the results of the glossiness values. Glossiness values at 60 and 85 degrees made in perpendicular and parallel directions showed an increase with the application of wax layers. In addition, decreases were obtained with 2 and 3 layers of wax applications for glossiness values made in both directions at 20 degrees (Table 5).

Table 5 Results of glossiness values

Test	Wax Application	N	Mean	Change (%)	*HG*	Standard Deviation	Minimum	Maximum	COV
⊥20°	Control	10	0.60	-	B**	0.00	0.60	0.60	0.00
	1 layer	10	0.60	0.00	B**	0.00	0.60	0.60	0.00
	2 layers	10	1.08	↑80.00	A*	0.04	1.00	1.10	3.90
	3 layers	10	1.05	↑75.00	A	0.18	0.90	1.30	16.95
⊥60°	Control	10	2.05	-	C**	0.33	1.70	2.50	16.14
	1 layer	10	3.64	↑77.56	B	0.12	3.50	3.80	3.22
	2 layers	10	5.16	↑151.71	A*	0.21	4.80	5.30	4.00
	3 layers	10	5.10	↑148.78	A	0.42	4.80	5.70	8.16
⊥85°	Control	10	0.22	-	D**	0.13	0.10	0.40	59.84
	1 layer	10	1.03	↑368.18	C	0.20	0.80	1.30	19.44
	2 layers	10	5.20	↑2263.64	B	0.19	5.00	5.50	3.63
	3 layers	10	5.91	↑2586.36	A*	0.48	5.40	6.50	8.19
‖ 20°	Control	10	0.62	-	C	0.04	0.60	0.70	6.80
	1 layer	10	0.60	↓3.23	C**	0.00	0.60	0.60	0.00
	2 layers	10	0.94	↑51.61	A*	0.05	0.90	1.00	5.49
	3 layers	10	0.87	↑40.32	B	0.05	0.80	0.90	5.55
‖ 60°	Control	10	2.18	-	D**	0.32	1.80	2.70	14.79
	1 layer	10	3.84	↑76.15	C	0.18	3.60	4.00	4.79
	2 layers	10	4.96	↑127.52	A*	0.13	4.90	5.20	2.55
	3 layers	10	4.73	↑116.97	B	0.21	4.50	5.00	4.35
‖ 85°	Control	10	0.14	-	C**	0.08	0.10	0.30	60.23
	1 layer	10	1.74	↑1142.86	B	0.16	1.60	2.00	9.46
	2 layers	10	7.78	↑5457.14	A*	1.31	6.80	10.20	16.89
	3 layers	10	7.55	↑5292.86	A	0.24	7.20	7.70	3.20

HG: Homogeneity Group, COV: Coefficient of Variation, N: Number of Measurements, *: Highest value, **: Lowest value

Table 6 presents the results of the whiteness index (*WI**) values. For *WI** values, decreases were observed with all layer numbers in both directions. *WI** values perpendicular to the fibers were found to be higher than parallel to the fiber results. Decrease rates for *WI** values perpendicular to the fibers were determined to be 12.06%, 19.26%, and 21.98% with 1, 2, and 3 layer applications, respectively, while decrease rates for *WI** values parallel to the fibers were determined to be 24.10%, 26.03%, and 27.62% with 1, 2, and 3 layer applications, respectively. *WI** values decreased with an increase in the number of layers in both directions (Table 6).

Table 6 Results of whiteness index (*WI**) values

Test	Wax Application	N	Mean	Change (%)	*HG*	Standard Deviation	Minimum	Maximum	COV
*WI** ⊥	Control	10	41.12	-	A*	0.19	40.80	41.30	0.47
	1 layer	10	36.16	↓12.06	B	0.16	35.90	36.30	0.44
	2 layers	10	33.20	↓19.26	C	0.12	33.10	33.40	0.35
	3 layers	10	32.08	↓21.98	D**	0.62	31.50	32.80	1.94

	Control	10	38.30	-	A*	0.94	37.30	39.60	2.44
*WI**	1 layer	10	29.07	↓24.10	B	0.09	28.90	29.20	0.33
‖	2 layers	10	28.33	↓26.03	C	0.08	28.20	28.40	0.29
	3 layers	10	27.72	↓27.62	D**	0.10	27.60	27.90	0.37

HG: Homogeneity Group, COV: Coefficient of Variation, N: Number of Measurements, *: Highest value, **: Lowest value

Literature reports indicate that surface properties of wooden materials change with the application of waxes to various wood species such as olive (*Olea europaea* L.) (Peker *et al*. 2024a), balau red (*Shorea guiso*) (Peker *et al*. 2024b), American walnut (*Juglans nigra* L.) (Ayata 2024), American white oak (*Quercus alba*) (Ayata and Ayata 2024), American black cherry (*Prunus serotina*) (Ayata and Çamlıbel 2024), magnolia (*Magnolia grandiflora* L.) (Ayata *et al*. 2024), and plum (*Prunus domestica* L.) (Peker *et al*. 2024c), among others.

Table 7 shows the results of total color differences. ΔE^* values were found to be 5.13 with 1 layer of wax application, 6.53 with 2 layers of wax application, and 6.95 with 3 layers of wax application. ΔL^* values were determined to be negative for all layer numbers, while Δa^*, Δb^*, and ΔC^* values were obtained positively (Table 7).

ΔH^* values were determined to be 0.12 with 1 layer of wax application, 0.10 with 2 layers of wax application, and 0.11 with 3 layers of wax application, and the values were found to be very close to each other (Table 7).When compared with the values given in the color change criteria (DIN 5033, 1979), "very pronounced (3.0 to 6.0)" results were obtained with 1 layer of wax application, and "strong (6.0 to 12.0)" results were obtained with 2 and 3 layer wax applications (Table 7).

Table 7. Results of total color differences

Wax Application	ΔL^*	Δa^*	Δb^*	ΔC^*	ΔH^*	ΔE^*	The color change criteria (DIN 5033, 1979)
1 layer	-1.72	1.27	4.66	4.83	0.12	5.13	Very distinct (3.0 - 6.0)
2 layers	-2.98	1.53	5.61	5.81	0.10	6.53	Strong (6.0 - 12.0)
3 layers	-3.34	1.59	5.88	6.09	0.11	6.95	

Conclusions

Following the application of waxes to wood, decreases were observed in the *WI** and *L** values, while increases were obtained in the *C**, *a**, h^o, and *b** values, as well as in the glossiness values at 60 and 85 degrees. It is recommended to conduct a wetting test using different chemicals on the obtained materials. Considering the total color difference results obtained, it can be said that applying wax in two coats will be sufficient for linden wood.

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