Kastamonu Uni., Orman Fakültesi Dergisi, 2024, 24(1): 59-73
Kastamonu Univ., Journal of Forestry Faculty
Doi:10.17475/kastorman.1460453 Research Article

Color Change Analysis of Wood Materials Treated with Different Varnishes: A Comparative Study

Kenan KILIÇ*[1], Cevdet SÖĞÜTLÜ[2]

[1]Department of Wood Products Industrial Engineering, Graduate School of Natural and Applied Sciences, Gazi University, Ankara, TÜRKİYE
[2]Gazi University, Faculty of Technology, Wood Products Industrial Engineering, Ankara, TÜRKİYE
*Corresponding Author: kenan.kilic@bozok.edu.tr

Received Date: 16.06.2023 Accepted Date: 22.01.2024

Abstract

Aim of the study: This study examines the overall color change values from applying water-based, polyurethane, and acrylic varnishes on newly prepared and naturally aged wood materials.

Materials and methods: The Turkish woodworking industry commonly selects oak (*Quercus petrea* L.), chestnut (*Castanea sativa* M.), and scotch pine (*Pinus sylvestris* L.) as the preferred wood type for preparing test samples. A total of 360 test samples are prepared for the experiments. The color difference (ΔE*) between two colors is measured using a Minolta CR-231 color measurement device, following the principles outlined in ASTM-D 2244.

Main results: On the C.I.E. Lab* color plane, a higher ΔE* indicates a more significant difference between the compared colors. Among the wood type, oak exhibited the highest color change (ΔE*), while chestnut displayed the lowest. Fresh wood materials showed higher color change values (ΔE*) than naturally aged wood materials. The radial section direction also is showed higher color change values (ΔE*) than the tangential section direction.

Research highlights: Regarding varnish type, acrylic varnish indicated a minor color change, followed by polyurethane and water-based varnishes, respectively. Acrylic varnish is recommended for studies with minimal color change and for preserving the wood material's natural color.

Keywords: Finishing, Wood, Color Change, Varnish, Natural Aged Wood

Farklı Verniklerle İşlem Görmüş Ahşap Malzemelerin Renk Değişim Analizi: Karşılaştırmalı Bir Çalışma

Öz

Çalışmanın amacı: Yeni ve doğal olarak yaşlanmış ahşap malzemelere su bazlı, poliüretan ve akrilik verniklerin uygulanması sonucunda ortaya çıkan toplam renk değişim değerlerini incelemektir.

Materyal ve yöntem: Türk Ağaçişleri Endüstrisinde yaygın olarak kullanılan meşe (*Quercus petrea* L.) ve kestane (*Castanea sativa* M.) ağaçları ile sarıçam (*Pinus sylvestris* L.) test örnekleri olarak seçilmiştir. Deneyler için toplamda 360 test numunesi hazırlanmıştır. Renk farkı (ΔE*) iki renk arasında, ASTM-D 2244 standartlarına uygun olarak Minolta CR-231 renk ölçüm cihazıyla ölçülmüştür. Yeni Ahşap: Yeni kesilmiş, işlenmemiş ve genellikle yüksek nem içeren ahşap malzemeleri tanımlamaktadır.

Temel sonuçlar: CIE Lab* renk düzleminde, daha yüksek ΔE* değeri karşılaştırılan renkler arasındaki farkı göstermektedir. Ahşap türleri arasında, meşe en yüksek renk değişimini (ΔE*) gösterirken, kestane en düşük renk değişimini göstermiştir. Yeni ahşap malzemeler doğal olarak yaşlanmış ahşap malzemelere göre daha yüksek renk değişim değerleri (ΔE*) sergilemiştir. Radyal kesit yönü ayrıca teğet kesit yönüne göre daha yüksek renk değişim değerleri (ΔE*) göstermektedir.

Araştırma vurguları: Vernik türleri açısından, akrilik vernik en az renk değişimini göstermiştir ve onu poliüretan ve su bazlı vernikler izlemiştir. Akrilik vernik, renk değişiminin minimum düzeyde olduğu çalışmalarda kullanılması önerilir ve ahşap malzemenin doğal rengini korumak istenen çalışmalarda da uygun bir seçenektir.

Anahtar Kelimeler: Üstyüzey İşlemleri, Ağaç Malzeme, Renk değişimi, Vernik, Doğal Yaşlanmış Ahşap.

Citation (Atıf): Kilic, K., & Sogutlu, C. (2024). Color Change Analysis of Wood Materials Treated with Different Varnishes: A Comparative Study. *Kastamonu University Journal of Forestry Faculty*, 24 (1), 59-73.

Introduction

Wood is an organic and natural substance renowned for its attractive visual characteristics and environmentally friendly attributes (Aydemir & Gündüz, 2009). However, wood components, such as lignin and cellulose, are susceptible to damage from ultraviolet (U.V.) radiation and other environmental factors (Pelit & Korkmaz, 2019). Exposure to U.V. rays, rain, snow, moisture, mechanical forces, and microorganisms can degrade the appearance and properties of wood, leading to discoloration and surface deterioration (Rowell, 2005; Evans et al., 1996).

Various surface treatments are applied to protect the wood from these detrimental effects. One of the most commonly used approaches involves the application of protective coatings such as impregnating agents, varnishes, and paints (Vardanyan et al., 2015). These treatments create a protective layer that extends the lifespan and enhances wooden surfaces' visual, economic, and functional aspects (Bulian & Graystone, 2009).

In studies comparing different varnish types applied to wood type like chestnut, oak, scoth pine, and beech, the synthetic varnish is found to have the most significant effect on color change, bringing the surfaces closer to scoth and red tones (Sönmez, 1997). Synthetic varnish decreased luminosity (L*) compared to untreated samples. Conversely, water-based varnish exhibited the lowest total color change (ΔE*) among the varnishes (Aykaç & Sofuoğlu, 2020).

Regarding the transparent varnishing of wood, synthetic varnish produced the lightest color in beech, scoth pine, and ash, while acrylic varnish achieved the lightest shade in oak. Acid-catalyzed varnish led to the darkest color in beech, pine, and ash, whereas polyurethane varnish resulted in the darkest color in oak (Uysal et al., 1999).

An independent research investigation is carried out to assess how outdoor weather conditions affect wood color. The study involved the application of various types of varnishes, including cellulosic, synthetic, polyurethane, and acid-catalyzed varnishes, on wood type such as scoth pine, eastern beech, and chestnut. The results revealed that polyurethane varnish enhanced the scoth pine and red color tones, synthetic varnish reduced the yellow tone, and acid-catalyzed varnish intensified the red tone (Sönmez, 1997).

It is advised not to use polyurethane varnish on wood surfaces after decolorization to minimize the formation of a red tint. Alternatively, applying transparent colorless filler varnish can reduce the appearance of the red pigment (Özçifci & Atar, 2002).

The primary factors causing changes in wood color, hardness, gloss, and mechanical properties in outdoor conditions are sunlight, temperature variations, U.V. radiation, and humidity (Kurtoğlu, 2000). The environmental factors mentioned contribute to the swift alteration of wood color and a decline in its physical and mechanical characteristics caused by chemical transformations in the microstructure (Feist, 1990; Fengel, 1991; Anderson et al., 1991; Budakçı, 2006; Kılıç & Hafızoğlu, 2009; Sönmez & Söğütlü, 2009; Söğütlü et al., 2016).

Among these environmental factors, U.V. rays have been identified as the main cause of wood deterioration (Futo, 1974; Ayadi et al., 2003). Different wavelengths within the visible spectrum of sunlight (400-700 nm) determine the colors perceived (Nelson, 1995).

Natural ageing of wood refers to the irreversible changes in its physical and mechanical properties over time. These changes encompass physical, chemical, and biological degradation (Kılıç & Söğütlü, 2020; Kılıç & Söğütlü, 2023). Despite the abundance of studies investigating the physical and mechanical properties of naturally aged wood, there remains a dearth of research explicitly addressing color change measurements in naturally aged wood materials.

Hence, the primary objective of this study is to assess the color change values resulting from applying polyurethane, acrylic, and water-based varnishes on newly obtained and naturally aged wood materials. The study will utilize statistical analysis methods to evaluate and compare the color change measurements of varnishes on scotch pine, oak, and chestnut samples derived from naturally aged and new wood sources.

Materials and Methods

Material

The Turkish woodworking industry commonly selects oak (*Quercus Petrea* L.), chestnut (*Castanea sativa* M.), and scotch pine (*Pinus sylvestris* L.) as the preferred wood type for preparing test samples.

Naturally aged wood: It recognizes wood materials that change their color and properties over time by being exposed to environmental influences over a certain period of time. Fresh wood: Describes wood materials that have been freshly cut, untreated and often contain high moisture.

The naturally aged wood samples were sourced from three different provinces in Turkey. Specifically, chestnut wood is acquired from the Karamürsel district in the Kocaeli province, oak wood from the Sorgun district in the Yozgat province, and Scotch pine from the Ankara province.

To ensure the freshness of the wood materials, they are procured directly from lumber suppliers situated in the Ankara Furniture Sites. The specimens underwent preparation by sawing in both intangential and radial directions to meet the required specifications for further analysis.

Fresh wood materials are obtained from timber dealers located in Ankara (Furniture Makers Workplace Siteler). On the other hand, naturally aged wood materials are acquired from businesses known as "demolishers." These businesses specialize in buying and selling leftover materials from buildings demolished after approximately 100 years of use.

To conduct the research, we utilize Akzo Nobel's polyurethane varnish, acrylic varnish, and WoodSol's Gemine Gel-450 series water-based varnish with a silk matte finish for varnishing the test samples

Method

Preparation of test samples

The research involved preparing a total of 360 specimens, comprising ten samples for each unique combination of factors. These factors included wood type (3), cross-sectional direction (2), age period (2), and varnish type (3). The aim is to ensure an adequate representation of the different variables in the study and gather comprehensive data for analysis. The specimens are carefully selected to ensure uniformity in fibre distribution, absence of knots, cracks, rot, reaction wood, fungal and insect damage, and color and density differences.

Moisture content is determined according to the TS ISO 13061-1 standard, while density measurements follow the TS ISO 1306-2 standard. The varnishing process adhered to the principles outlined in the ASTM-D 3023 standard. Filling varnish and topcoat varnish application is carried out with the normal cross-coat method (perpendicular to the fibers and parallel to the fibers) at a height of 20 cm from the sample surface. The first application is made perpendicular to the fibers with a top tank spray gun with 1-2 bar (14-28 atu) air pressure and 1.4 mm gun tip opening. Then the second application is carried out parallel to the fibers. After both applications, each layer is left to dry for 24 hours. The dried samples are lightly sanded with 400 grit sandpaper to make them suitable for the next coat. This process is repeated for two coats of filler varnish and two coats of topcoat varnish. After each varnish application, the samples are placed in a dust-free environment for 24 hours for proper drying.

The samples underwent a careful preparation process to obtain the best possible outcomes. A specific procedure is followed to ensure a smooth and properly prepared surface for the subsequent layers of varnish. This procedure involves lightly sanding the surface with 400 grit sandpaper and remove any dust particles between the application of filler varnish and topcoat varnish layers. This step aims to ensure a smooth and properly prepared surface for the subsequent layers of varnish. The procedure is conducted in duplicate, applying two coats of filler varnish and two coats of topcoat varnish. The determination of the solid content of the varnishes adhered to the guidelines specified in the TS EN ISO 3251 standard, and this rigorous methodology is implemented to ensure precise measurements and dependable outcomes.

Throughout the experimental procedures, the dry film thickness of the varnish layer, once completely dried on the surface of the samples, is measured. This measurement is carried out using a compass with a precision of 5 µm, following the guidelines specified in the ASTM D-1005-95 standard.

This measurement ensures an accurate and consistent assessment of the varnish layer thickness across all samples. By adhering to standardized measurement techniques, reliable data is obtained for further analysis and comparison.

Color measurement

Color measurements follow the guidelines outlined in ASTM D 2244-2 e1, utilizing the MINOLTA CR-231 color measurement device. Figure 1 illustrates the cross-sectional view of the device employed for the color measurements (Minolta CR-231, 1990; Söğütlü, 2004).

Figure 1. Chroma meter.

The color analysis conducted in this study is based on the C.I.E. Lab* color system, which is widely used to assess color differences and determine color positions using the L*, a*, and b* coordinates. In this system, the L* axis represents the black-white spectrum, with L*=0 representing black and L*=100 representing white. The a* coordinate corresponds to the red-green spectrum, where positive values indicate red and negative values indicate green. Similarly, the b* coordinate represents the yellow-blue spectrum, with positive values indicating yellow and negative values indicating blue (Oliver et al., 1992). A visual representation of the three-dimensional C.I.E. Lab* color space is provided in Figure 2.

Figure 2 visually illustrates the three-dimensional C.I.E. Lab* color coordinates and the color measurement system used to analyze color changes. The individual values of a* (red color), b* (yellow color), and L* (color brightness) are examined for this analysis. The overall color change (ΔE*) is calculated using equation (1), and a lower ΔE* value indicates minimal color change (Söğütlü and Sönmez, 2006).

The main objective of this study is to analyze color changes by evaluating the values of red color (a*), yellow color (b*), and color brightness (L*) independently. Additionally, the overall color change (ΔE*) is calculated to assess color differences comprehensively.

$$\Delta E^{*} = \sqrt{(\Delta L)^{2} + (\Delta a^{*})^{2} + (\Delta b^{*})^{2}} \qquad (1)$$

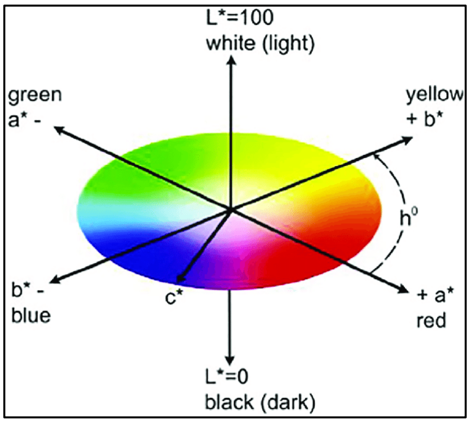

Figure 2. illustrates the three-dimensional C.I.E. Lab* color coordinate system and the corresponding color measurement system (Johansson, 2005).

Data analyses

The color change values obtained from the experiment are subjected to statistical analysis using the MSTAT-C package program with a confidence level of 0.95. Multiple analysis of variance (MANOVA) is conducted to assess the differences in color change values among the 360 experimental samples. The main objective is to examine the impact of polyurethane, acrylic, and water-based varnishes on the color changes of both naturally aged and fresh wood materials.

If significant differences are observed between the groups, the Duncan test is employed to compare the mean values and determine the rankings of the factors. The factors are categorized into homogeneous groups based on the critical value of the least significant difference (L.S.D.). This approach allowed for the identification of the effects of different varnishes on the color change of wood materials and provided insights into the relative effectiveness of each factor.

In this study, Python software language is used to visualize the data. The JupyterLab environment is utilized, and the Matplotlib library arguments are employed.

Results and Discussion

Solid Content and Dry Film Thickness

Table 1 gives the technical properties of the varnishes used in the experiments.

Table 1. The varnishes properties

Varnish Type	pH	Solids Ratio (%) Filling varnish	Solids Ratio (%) The top coat of varnish	Density (gr/ml) (20°C)	Dry Film Thickness (µm)	Viscosity (Sec. DIN cup/4mm)
Acrylic	4.00	25	35	0.90-0.94	120	18 sec.
Polyurethane	5.71	40	40	0.93-0.97	130	18 sec.
Water-based	7.80	35	35	1.02-1.04	120	18 sec.

This table provides insights into the characteristics and performance parameters of different varnish types. The "Filling Varnish" exhibits a moderately acidic pH and a 25% solids ratio for surface coverage. In contrast, "The Top Coat of Varnish" is characterized by a neutral pH of 4.00, a higher solids ratio of 35%, and a density ranging from 0.90 to 0.94 at 20°C. The dry film thickness is 120 µm, and the viscosity is 18 seconds according to the DIN cup/4mm. "Acrylic" varnish, with a neutral pH of 4.00, showcases a 25% solids ratio, a density between 0.90 and 0.94, a dry film thickness of 120 µm, and a viscosity of 18 seconds. "Polyurethane" varnish, with a slightly basic pH of 5.71, demonstrates a high solids ratio of 40%, a density between 0.93 and 0.97, a dry film thickness of 130 µm, and a viscosity of 18 seconds. "Water-based" varnish, featuring an alkaline pH of 7.80, presents a 35% solids ratio, a density between 1.02 and 1.04, a dry film thickness of 120 µm, and a viscosity of 18 seconds. These observations offer insights into the chemical properties and application performance of each varnish type, guiding considerations for specific use cases.

Density Values

Table 2 presents the air-dry and full-dry density values of wood materials. The procedure involved performing duplicate experiments, including applying two coats of filler varnish and two coats of topcoat varnish.

Table 2. Air dry and full dry density values (g/cm^3)

Wood material/	Fresh wood		Natural aged wood	
Age period	Air dry	Full dry	Air dry	Full dry
Scotch pine	0.55	0.51	0.48	0.73
Quercus	0.77	0.73	0.70	0.66
Chestnut	0.62	0.58	0.58	0.54

According to the Table 2 the color change values of different wood materials in fresh and naturally aged conditions are examined. New wood materials generally have higher color change values, while naturally aged wood materials have lower color change values. In addition, the complete drying of the wood also affects the color change values, which are slightly lower in thoroughly dried wood materials.

Total Color Change

Table 3 presents the pre- and post-experiment measurements of red hue (a), yellow hue (b), and color brightness (L), as well as the corresponding differences.

Table 3. Pre-experimental and post-experimental measurements.

Wood Type	Section Direction	Color Value	Varnish Type								
			Water-based			Polyurethane			Acrylic		
			PV	AV	Difference	PV	AV	Difference	PV	AV	Difference
Fresh Scoth Pine	Radial	a*	-71.710	-76.990	5.280	-65.990	-61.450	-4.540	-66.590	-71.330	4.740
		b*	23.210	-8.610	31.820	21.1400	31.200	-10.060	20.920	-1.1100	22.030
		L*	84.630	104.900	-20.260	80.13	73.990	6.140	81.170	97.920	-16.750
	Tangent	a*	-69.500	-77.520	8.020	-71.400	-69.830	-1.570	-71.960	-71.410	-0.550
		b*	22.600	-4.360	26.960	23.120	33.650	-10.530	22.540	29.100	-6.560
		L*	82.640	102.930	-20.290	84.340	79.890	4.450	84.870	82.310	2.560
Natural Aged Scoth Pine	Radial	a*	-56.470	-73.810	17.340	-69.240	-66.920	-2.320	-69.810	-66.710	-3.100
		b*	17.630	-2.670	20.300	22.170	34.020	-11.840	23.030	30.780	-7.750
		L*	82.640	102.930	-20.290	82.800	77.610	5.190	83.150	78.230	4.920
	Tangent	a*	-69.410	-47.650	5.240	-66.210	-60.990	-5.220	-78.000	-52.720	-25.280
		b*	22.510	-4.410	26.930	25.840	38.460	-12.620	2.700	34.580	-31.890
		L*	82.880	99.730	-16.850	78.840	72.020	6.720	97.850	64.260	33.590
Fresh Chestnut	Radial	a*	-62.060	-63.250	1.190	-76.310	-54.740	-21.560	-61.820	-53.500	-8.320
		b*	17.780	-9.550	27.330	-7.870	27.770	-35.640	17.520	26.080	-8.570
		L*	73.420	87.400	-13.980	98.770	63.290	35.480	73.420	63.300	10.110
	Tangent	a*	-62.240	-62.440	0.200	-60.590	-52.190	-8.410	-61.130	-53.110	-8.030
		b*	18.330	-8.570	26.900	17.700	28.060	-10.360	17.380	27.580	-10.200
		L*	73.460	86.000	-12.530	71.750	60.880	10.870	72.280	61.340	10.940
Natural Aged Chestnut	Radial	a*	-62.000	-64.780	2.780	-51.920	-39.990	-11.930	-56.820	-45.730	-11.090
		b*	19.850	-4.930	24.780	21.450	30.450	-9.000	22.450	33.750	-11.310
		L*	73.460	87.010	-13.540	60.700	46.810	13.890	65.740	53.030	12.710
	Tangent	a*	-62.130	-64.910	2.780	-62.330	-53.990	-8.650	-55.740	-43.920	-11.820
		b*	19.620	-4.430	24.050	19.290	30.340	-10.610	22.160	33.020	-10.850
		L*	73.090	86.100	-13.010	73.650	64.180	10.130	64.240	50.890	13.350
Fresh Quercus	Radial	a*	-67.180	-56.520	-10.660	-70.350	-45.850	-24.500	-56.580	-57.200	0.620
		b*	23.880	-2.030	25.900	-4.080	30.620	-34.700	18.720	13.500	5.220
		L*	80.560	73.550	7.210	88.520	53.180	35.340	65.830	67.040	-1.210
	Tangent	a*	-59.470	-61.180	1.710	-71.910	-48.620	-23.290	-58.3000	-61.820	3.530
		b*	18.100	-6.390	24.480	-3.250	30.870	-34.120	18.890	11.700	7.190
		L*	69.740	82.610	-12.870	90.140	55.140	34.600	68.330	74.340	-6.010
Natural Aged Quercus	Radial	a*	-74.440	-61.700	-12.740	-57.320	-45.190	-12.130	-56.820	-45.730	-11.090
		b*	1.790	2.400	-0.620	22.380	34.190	-11.810	22.450	33.750	-11.310
		L*	90.470	78.100	12.370	66.020	52.070	13.960	65.740	53.030	12.710
	Tangent	a*	-57.330	-60.640	3.310	-56.310	-44.450	-11.860	-55.740	-43.920	-11.820
		b*	22.100	3.870	18.240	21.670	32.770	-11.100	22.160	33.020	-10.850
		L*	66.040	76.350	-10.310	64.620	51.060	13.560	64.240	50.890	13.350

PV: Pre-Varnish; AV: After Varnish; Note: Minus (-) values represent an increase.

The following table provides a brief analysis of the table you provided, which includes wood types, section directions, color values, and varnish types (water-based, polyurethane, acrylic) along with their respective effects. It is important to note that "PV" refers to Pre-Varnish values, while "AV" represents After Varnish values. Negative (-) values indicate an increase.

This table presents the analysis of different wood types in terms of their color values and the effects of varnish types, including water-based, polyurethane, and acrylic, in both the Pre-Experiment (PE) and After Experiment (AE) stages. The table includes the following observations:

Fresh Scotch Pine:

Radial: The red-green hue (a*) and blue-yellow hue (b*) values increased, indicating more intense colors. The brightness (L*) value decreased, suggesting a darker appearance.

Tangent: In the tangent direction, the red-green hue (a*) value slightly decreased, the blue-yellow hue (b*) value increased, and the brightness (L*) value remained mostly unchanged.

Natural Aged Scotch Pine:

Radial: Both the red-green hue (a*) and blue-yellow hue (b*) values increased, indicating more intense colors. The brightness (L*) value decreased, suggesting a darker appearance.

Tangent: In the tangent direction, the red-green hue (a*) value significantly decreased, the blue-yellow hue (b*) value increased, and the brightness (L*) value slightly increased.

Fresh Quercus:

Radial: The red-green hue (a*) value decreased, indicating a shift away from red-green hues. The blue-yellow hue (b*) value increased, suggesting more intense yellow-blue hues. The brightness (L*) value slightly decreased, suggesting a slightly darker appearance.

Tangent: In the tangent direction, the red-green hue (a*) value slightly decreased, the blue-yellow hue (b*) value increased, and the brightness (L*) value remained mostly unchanged.

Natural Aged Quercus:

Radial: Both the red-green hue (a*) and blue-yellow hue (b*) values decreased, indicating a shift away from intense colors. The brightness (L*) value increased, suggesting a brighter appearance.

Tangent: In both the radial and tangent directions, both the red-green hue (a*) and blue-yellow hue (b*) values decreased, while the brightness (L*) value increased.

Fresh Chestnut:

Radial: The red-green hue (a*) and blue-yellow hue (b*) values remained almost unchanged, indicating minimal color shifts. The brightness (L*) value decreased, suggesting a darker appearance.

Tangent: In both the radial and tangent directions, the red-green hue (a*) and blue-yellow hue (b*) values remained almost unchanged, while the brightness (L*) value decreased.

Natural Aged Chestnut:

Radial: The red-green hue (a*) and blue-yellow hue (b*) values remained almost unchanged, indicating minimal color shifts. The brightness (L*) value increased, suggesting a brighter appearance.

Tangent: In both the radial and tangent directions, the red-green hue (a*) and blue-yellow hue (b*) values remained almost unchanged, while the brightness (L*) value increased.

These observations describe the changes in color values (a*, b*) and brightness (L*) for each wood type and the effects of varnish types. The table also demonstrates the varying effects of different varnish types. By comparing the PE and AE values, it is possible to observe how each varnish type influenced the wood colors. For example, the use of water-based varnish generally led to a decrease in a* values, an increase in b* values, and a decrease in L* values. On the other hand, polyurethane varnish tended to increase both a* and b* values and decrease L* values. Acrylic varnish resulted in a decrease in a* values, an increase in b* values, and slight changes in L* values. Values for total color change value differences are given in Table 4.

Table 4. Values for total color change value differences.

Wood Type/ Age Period	Water-based				Polyurethane				Acrylic			
	Radial		Tangent		Radial		Tangent		Radial		Tangent	
	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
F. Scoth pine	38.10	0.93	34.69	1.03	12.64	0.38	11.60	0.41	28.09	1.24	7.14	0.83
NA. Scoth pine	41.06	1.99	32.20	0.86	13.15	0.44	15.25	1.31	9.75	0.35	52.78	1.23
F. Quercus	28.95	0.76	27.72	0.90	55.26	1.06	53.90	1.23	6.06	1.79	10.04	1.33
NA. Quercus	17.78	0.80	21.22	0.44	21.96	1.17	21.18	0.67	20.33	1.29	20.88	0.82
F. Chestnut	30.73	0.93	29.70	1.16	54.72	1.07	17.23	0.54	15.66	0.58	16.98	0.55
NA. Chestnut	28.38	1.25	27.50	2.07	20.41	0.38	16.80	0.55	15.84	0.84	14.81	0.74

$\bar{X}$: Arithmetic mean; s: Standard deviation; F: Fresh; NA: Natural aged

Table 4 presents a comprehensive overview of the total color change values, taking into account various factors such as wood type, cutting direction, varnish type, and age period. The objective is to examine the variations in these values across different conditions. Additionally, Figure 1 showcases the outcomes of the conducted Analysis of Variance, which aims to identify the primary factor contributing to these observed variations. The table furnishes detailed data on the color change values, measured in units, for distinct wood types and age periods when subjected to water-based, polyurethane, and acrylic varnishes. The findings aim to provide a comprehensive understanding of the impact of these factors on the overall color change. The measurements are recorded for the wood samples' radial and tangential directions. For example, in the case of fresh Scotch pine wood, applying water-based varnish resulted in a color change value of 38.10 units (radial) and 0.93 units (tangential). The polyurethane varnish caused a color change of 34.69 units (radial) and 1.03 units (tangential), while the acrylic varnish resulted in a color change of 12.64 units (radial) and 0.38 units (tangential).

For naturally aged Scotch pine wood, the color change values are slightly different. The water-based varnish led to a color change of 41.06 units (radial) and 1.99 units (tangential), while the polyurethane varnish caused a color change of 32.20 units (radial) and 0.86 units (tangential). The acrylic varnish resulted in a color change of 13.15 units (radial) and 0.44 units (tangential).

Similar measurements are taken for fresh and naturally aged oak and chestnut wood. The color change values exhibited variations based on factors such as wood type, age period, and the type of varnish applied. It's worth noting that these values represent the arithmetic means, indicating the average color change for each combination of factors. The standard deviations, which measure the variation within each group, are not shown in the table. Analysis of Variance (ANOVA) results of total color change values are given in Figure 1. Total color change Analysis of Variance (ANOVA) is given in Table 5.

Table 5 Total color change Analysis of Variance (ANOVA).

Factors	Degrees of freedom	Sum of Squares	Mean Squares	*F* Value	*P* ≤0.05
Wood Type (A)	2	5217.528	2608.764	3112.0498	0.0000*
Age Period (B)	1	33.181	33.181	39.5824	0.0000*
Interaction (AB)	2	654.978	327.489	390.6684	0.0000*
Sectional Direction (C)	1	28.829	28.829	34.3903	0.0000*
Interaction (AC)	2	2069.217	1034.608	1234.2061	0.0000*
Interaction (BC)	1	507.262	507.262	605.1236	0.0000*
Interaction (ABC)	2	715.995	357.998	427.0628	0.0000*
Varnish Type (D)	2	10951.247	5475.624	6531.9867	0.0000*
Interaction (AD)	4	2932.177	733.044	874.4638	0.0000*
Interaction (BD)	2	3574.698	1787.349	2132.1665	0.0000*
Interaction (ABD)	4	1765.598	441.400	526.5549	0.0000*
Interaction (CD)	2	1093.506	546.753	652.2330	0.0000*
Interaction (ACD)	4	1652.981	413.245	492.9689	0.0000*
Interaction (BCD)	2	20.808	10.404	12.4111	0.0000*
Interaction (ABCD)	4	379.203	94.801	113.0899	0.0000*
Error	324	271.602	0.838		
Total	359	31868.810			

**: The difference is significant compared to 0.05*

This table presents the results of an analysis conducted on an experiment. The factors analyzed include Wood Type (A), Age Period (B), Sectional Direction (C), and Varnish Type (D), along with various interactions between these factors. The table includes degrees of freedom, sum of squares, mean squares, F values, and p-values. Significantly high F values and low p-values suggest meaningful effects of the factors or interactions on the outcomes. For instance, Wood Type, Age Period, Sectional Direction, and Varnish Type all exhibit statistically significant effects on the results, as indicated by their respective F values and p-values. Additionally, the interactions between these factors also show significant impacts. Overall, the statistical analyses confirm the significance of the considered factors and interactions, providing valuable insights into the experiment's findings.

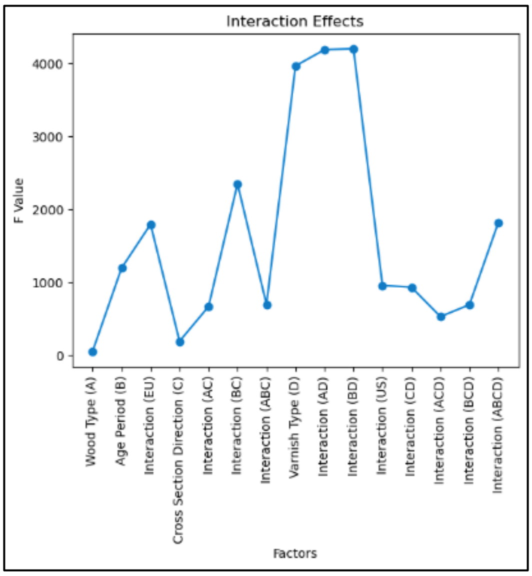

Figure 1. Total color change values Analysis of variance (ANOVA) results.

This table presents color value data for different wood types (Fresh Scotch Pine, Natural Aged Scotch Pine, Fresh Quercus, Natural Aged Quercus, Fresh Chestnut, Natural Aged Chestnut) in two section directions (Radial, Tangent) and under three different varnish types (Water-based, Polyurethane, Acrylic). The color values are represented by three parameters: a*, b*, and L*.

The table provides the color value differences between the pre-experiment (P.E.) and post-experiment (A.E.) stages for each combination of wood type, section direction, and varnish type. The differences are calculated by subtracting the P.E. value from the A.E. value.

For example, in the Fresh Scotch Pine, under the Radial section direction and using Water-based varnish, the a* color value decreased by 71.71 units from the P.E. to the A.E. measurement. However, the b* color value increased by 23.21 units, and the L* color value decreased by 20.26 units.

The table compares color changes for wood types, section directions, and varnish types. It allows us to observe how each combination affects the color properties of the wood, as indicated by the changes in the a*, b*, and L* values. Negative values represent a decrease in color, while positive values indicate an increase.

It's important to note that these color values are specific to the experimental conditions and may not represent the overall color characteristics of the wood types in all situations.

Wood type, age period, cross-section direction and varnish type and their interactions are found to be statistically significant (α=0.05). Total color change test results at wood type level are given in Figure 2.

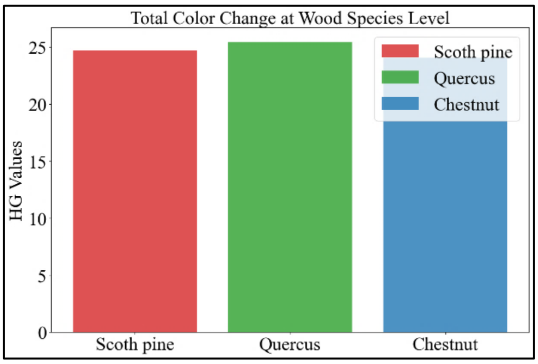

Figure 2. Test results of total color change at the wood type level.

Accordingly, ΔE* is highest in oak samples, followed by scotch pine and chestnut samples.

Duncan's test results at the age period level are given in Figure 3.

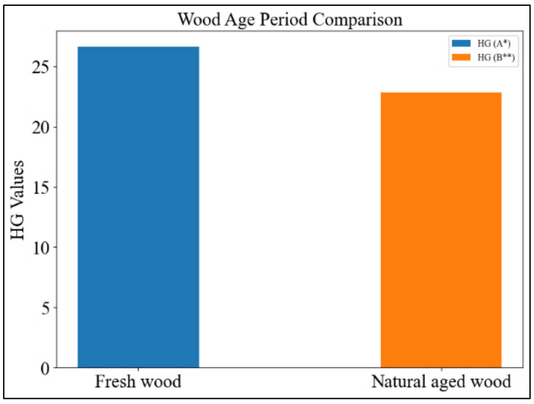

Figure 3. Duncan test results at age period level.

Accordingly, fresh wood's total color change value is higher than naturally aged wood material.

The results of the Duncan test at the wood type, age period level are given in Figure 4.

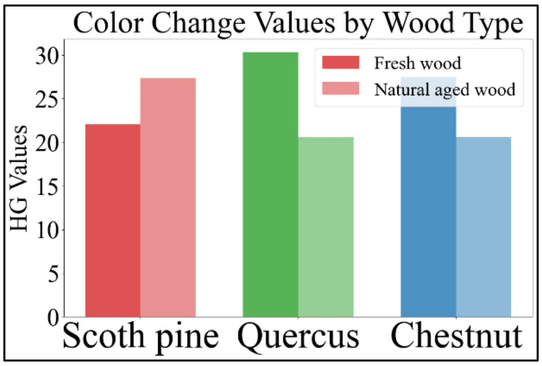

Figure 4. Duncan test results at the wood type-age period level.

Accordingly, ΔE* is highest in fresh oak samples and lowest in naturally aged oak samples. The difference between naturally aged scotch pine samples and new chestnut samples is statistically insignificant (α=0.05).

The results of the Duncan test at the cross-sectional direction level are given in Figure 5.

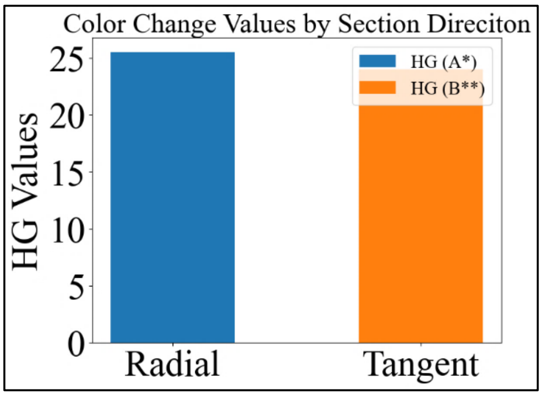

Figure 5. The results of the Duncan test conducted at the section direction level.

At the cross-sectional direction level, ΔE* is higher in the radial cross-section.

Duncan's test results and ΔE* values at the wood type, section direction level are given in Figure 6.

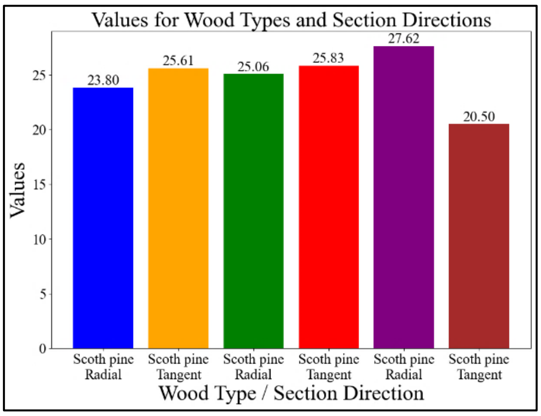

Figure 6. Duncan test results, ΔE* values at the wood -section direction level.

At the wood type, section direction level, ΔE* is highest in the radial direction of chestnut samples and lowest in the tangential direction. The difference between the tangential cross sections of scotch pine and oak samples is statistically insignificant (α=0.05).

Duncan test results at the age period-section direction level are given in Figure 7.

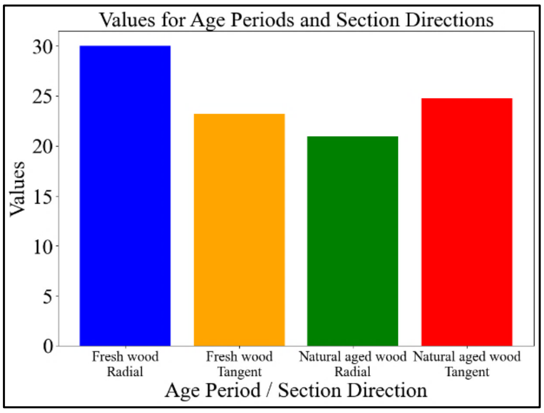

Figure 7. Duncan test results at age period-section direction level.

When considering the age period and section direction, it is observed that the highest ΔE* value is found in the radial direction of fresh wood. In contrast, the lowest ΔE* value is kept in the radial direction of naturally aged wood.

Duncan test results at the level of wood type, age period, section direction are given in Figure 8.

Figure 8. The Duncan test results at the wood type-age period-section direction level.

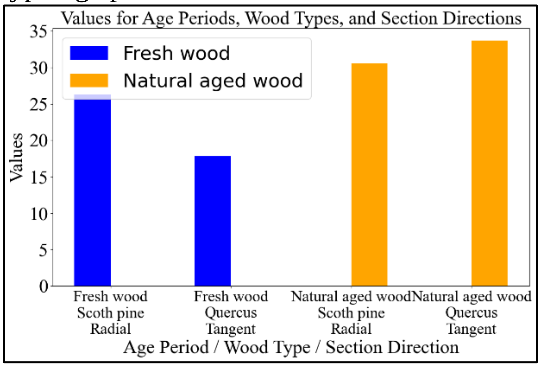

Figure 8. The Duncan test results at the wood type-age period-section direction level.

At the wood type, age period-section direction level, ΔE* is highest in the radial direction of chestnut samples and lowest in the tangential direction of scotch pine samples.

The difference between the radial direction of fresh chestnut and the tangential direction of naturally aged scotch pine, the tangential and radial direction of new oak, the radial direction of naturally aged scotch pine, and the tangential direction of naturally aged oak and the tangential direction of fresh chestnut is statistically insignificant (α=0.05).

Duncan test results at varnish type level are given in Figure 9.

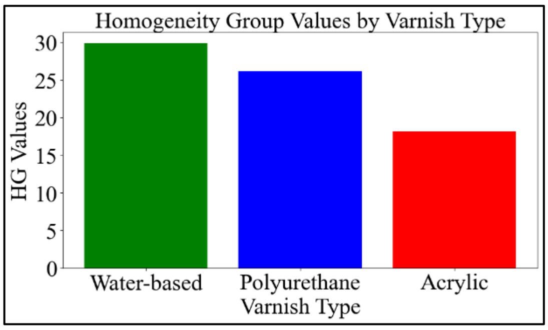

Figure 9. Duncan test results at the varnish type level.

At the varnish type level, ΔE* is highest for water-based varnish, followed by polyurethane and acrylic varnish.

Duncan's test results and ΔE* values at the wood type, varnish type level are given in Figure 10.

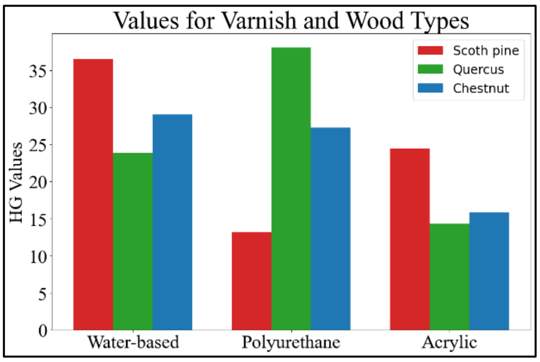

Figure 10. Duncan test results, ΔE* values at the wood tye-varnish type level.

At the wood type, varnish type level, ΔE* is highest for polyurethane-varnished oak samples and lowest for polyurethane-varnished scotch pine samples obtained in the instances.

Duncan's test results and ΔE* values at age period-varnish type level are given in Figure 11.

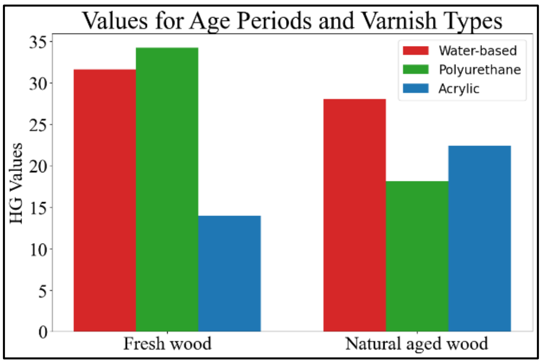

Figure 11. Duncan's test results and ΔE* values at age period-varnish type level.

At the specific age period and varnish type level, the highest color change (ΔE*) value is observed in fresh wood material treated with polyurethane varnish, while the lowest ΔE* value is found in newly-aged wood material treated with acrylic varnish. This indicates that the polyurethane varnish has a greater impact on altering the wood's color compared to the acrylic varnish, resulting in a more noticeable color change. On the other hand, the acrylic varnish demonstrates a relatively minimal effect on the color of the newly-aged wood.

Duncan test, ΔE* results for different wood type, age periods and varnish types are given in Figure 12.

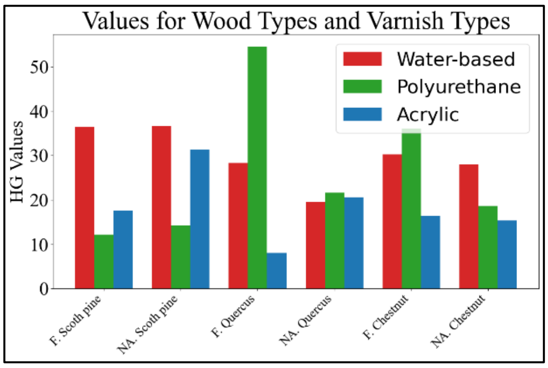

Figure 12. Duncan test, ΔE* results for different wood type-age periods and varnish types.

The new oak polyurethane varnish variety applied with polyurethane varnish exhibits the highest ΔE* value at the wood type, age period-varnish type level.

The results of Duncan's test for cross-section direction, varnish ΔE* are shown in Figure 13.

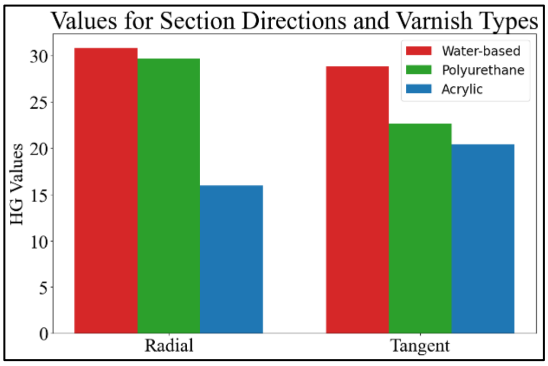

Figure 13. Results of Duncan test cross-section direction-varnish ΔE* results.

Duncan's test results and ΔE* values at the wood type, section direction-varnish type level are given in Figure 14.

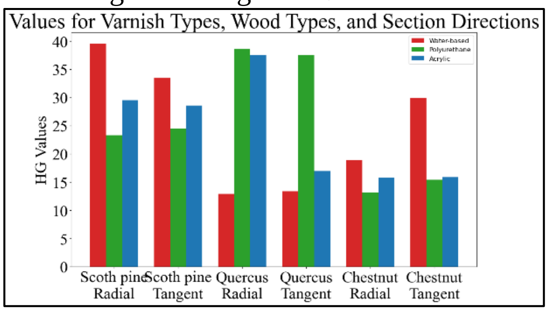

Figure 14. Duncan test results, ΔE* values at wood type-section direction-varnish type level.

Duncan test results at the level of age period, section direction, varnish type are given in Figure 15.

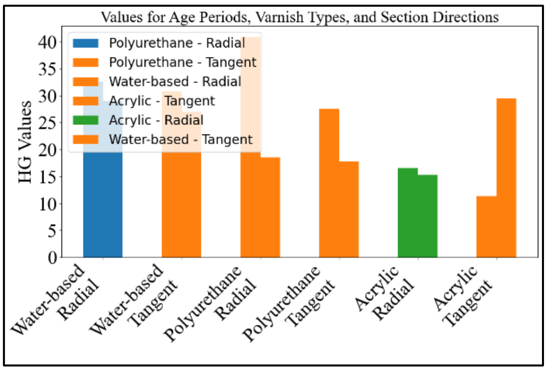

Figure 15. Duncan test results at age period-section direction-varnish type level.

Duncan's test results for wood type, age period, section direction, varnish type ΔE* are shown in Figure 16.

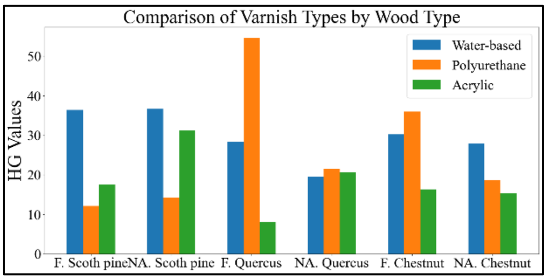

Figure 16. Duncan test results at wood type-age period-section direction-varnish type level.

Total color change ΔE Duncan's test homogeneity groups wood type, age period, cross-section direction, varnish type values are given in Table 6.

Table 6. Total color change ΔE Duncan's test homogeneity groups wood type, age period, cross-section direction, varnish type values

Wood Type/ Age Period	Type of Varnish /Cross-Section											
	Water-based				Polyurethane				Acrylic			
	Radial		Tangential		Radial		Tangential		Radial		Tangential	
	$\bar{x}$	*HG*	$\bar{x}$	*HG*	$\bar{x}$	*HG*	$\bar{x}$	*HG*	$\bar{x}$	*HG*	$\bar{x}$	*HG*
Fresh Scotch pine	38.10	E	34.69	F	12.64	Q	11.60	R	28.09	JK	7.136	T
NA. Scotch pine	41.07	D	32.20	G	13.15	Q	15.25	OP	9.747	S	52.78	C
Fresh Oak	28.95	IJ	27.72	K	55.26	A*	53.90	B	6.066	U**	10.04	S
NA. Oak	17.78	N	21.24	LM	21.95	L	21.18	LM	20.33	M	20.88	M
Fresh Chestnut	30.73	H	29.70	I	54.72	AB	17.23	N	15.66	OP	16.98	N
NA. Chestnut	28.38	JK	27.50	K	20.41	M	16.80	N	15.84	O	14.81	P

NA. Natural aged; LSD ± 0.9106; *HG: Homogenity Group*

This table provides insights into the performance of different wood types under various varnish types and cross-sectional orientations, radial and tangential. For Fresh scotch pine, it excels with water-based varnish, displaying the highest homogeneity group (HG) values in both radial (38.10 HG) and tangential (34.69 HG) sections. In contrast, its performance diminishes with acrylic varnish, especially in the tangential section (7.136 HG). NA. scotch pine performs well with water-based and polyurethane varnishes, excelling in tangential sections (32.20 HG and 15.25 HG, respectively). Fresh oak stands out under acrylic varnish, exhibiting the highest HG values in both radial (55.26 HG) and tangential (53.90 HG) sections, while its performance is suboptimal with polyurethane varnish (6.066 HG tangential). NA. Oak performs well under acrylic varnish in the tangential section (21.95 HG) and moderately under other varnish types. Fresh chestnut shows comparable performance under water-based and polyurethane varnishes, whereas acrylic varnish yields lower HG values, especially tangentially (15.66 HG). NA. Chestnut excels with water-based varnish (28.38 HG radial, 27.50 HG tangential) and displays moderate performance with polyurethane varnish, while acrylic varnish results in lower homogeneity values (15.84 HG tangential). This table aids in the informed selection of wood and varnish combinations, considering factors such as wood type, varnish type, and cross-sectional orientation.

Conclusions

In this study, the color change values of commonly used varnishes in the furniture and woodworking industry, namely polyurethane varnish, acrylic varnish, and water-based varnish, are measured on the surfaces of naturally aged wood materials. The evaluation of the obtained color change value data reveals the effects of different

varnish types on both fresh and naturally aged wood materials that have undergone surface treatment. The measurements are conducted using a color change device head. When the color change value data obtained are evaluated:

Before the experiment, fresh and naturally aged wood materials are sanded with 150 grit sandpaper on a calibrated sanding machine, and four coats of varnish are applied in total, two coats of filler and two coats of top coat varnish.

The experimental results indicate that water-based and acrylic varnishes had a dry film thickness of 120 µm, while polyurethane varnish had a slightly thicker dry film thickness of 130 µm. This difference in dry film thickness allows for a fair comparison of the layer thicknesses between the different varnishes.

The specific gravity values of the wood materials in a dry air state are 0.55 g/cm^3 for fresh scotch pine and 0.48 g/cm^3 for naturally aged scotch pine. New oak is 0.77 g/cm^3, and natural aged oak is 0.70 g/cm^3. Fresh chestnut is 0.62 g/cm^3, and natural aged chestnut is 0.58 g/cm^3. All of the naturally aged wood materials are found to have low specific gravities. The reason for this is thought to be the degradation of the wood material over time.

Among the wood type, oak exhibited the highest color change (ΔE), while chestnut exhibited the lowest. The color change is also more pronounced in fresh wood than in naturally aged wood materials.

In addition, it has been observed that the color change (ΔE) is more pronounced in the radial cross-sectional direction compared to the tangential direction. This variation in color change can be attributed to the reduced absorption on the surface, which is caused by the higher concentration of woody cell wall components in the radial direction. When considering the color change, it is important to take into account the orientation of the wood sample and the distribution of its cell structure.

Regarding the varnish type, acrylic varnish demonstrated the slightest color change, followed by polyurethane and water-based varnishes. Acrylic varnish is suitable for applications where a minimal color change is desired, and it is also appropriate for preserving the natural color of the wood material.

At the wood type, age period, cross-sectional direction, and varnish type levels, the highest color change (ΔE) is observed in fresh oak samples with a radial cross-sectional direction treated with polyurethane varnish. Conversely, the lowest color change (ΔE) is found in new oak samples with a radial cross-sectional direction treated with acrylic varnish.

Choosing the appropriate varnish type and applying it correctly are crucial factors that depend on the specific usage and properties of the wood material. Notably, naturally aged wood materials exhibit lower color change values (ΔE), which should be considered when deciding on the varnish type for wood treatment.

Acknowledgements

The data used in this article are prepared from Kenan KILIÇ's Master's Thesis titled " *Performance Properties of Finishing in Natural Aged Wood Material* ".

Ethics Committee Approval

N/A

Peer-review

Externally peer-reviewed.

Author Contributions

Conceptualization: K.K; Investigation: K.K, C.S.; Material and Methodology: K.K., C.S.; Supervision: K.K.; Visualization: K.K., C.S.; Writing-Original Draft: K.K.; Writing-review & Editing: K.K.; Other: All authors have read and agreed to the published version of manuscript

Conflict of Interest

The authors declare no conflicts of interest.

Funding

The authors stated that this study did not receive any financial support.

References

Anderson, E. L., Pawlak, Z., Owen, N. L. & Feist, W. C. (1991). Infrared studies of wood weathering. Part I: Softwoods. *Applied Spectroscopy*, 45(4), 641-647.

ASTM, D. (1981). 3023. Determination of Resistance of Factory Applied Coatings on Wood Products of Stain and Reagents. In *American Society for Testing and Materials* (pp. 1-5).

ASTM, D. (2001). 1005-95. Standard Test Method for Measurement of Dry-Film Thickness of Organic Coatings Using Mikrometers. In *American Society for Testing and Materials* (pp. 10-12).

ASTM, D. (2007). 2244–07 e1, Standard practice for calculation of color tolerances and color differences from instrumentally measured color coordinates, American Society for Testing and Materials. American Society for Testing and Materials, West Conshohocken, PA, 3134-97.

Ayadi, N., Lejeune, F., Charrier, F., Charrier, B. & Merlin, A. (2003). Color stability of heat-treated wood during artificial weathering. *Holz als Roh-und Werkstoff,* 61, 221-226.

Aydemir, D., & Gündüz, G. (2009). Ahşabın fiziksel, kimyasal, mekaniksel ve biyolojik özellikleri üzerine ısıyla muamelenin etkisi. *Bartın Orman Fakültesi Dergisi*, *11*(15), 71-81.

Aykaç, S. & Sofuoğlu, S. D. (2020). Bambu ağaç malzemede vernik tiplerinin yüzey özellikleri üzerine etkisinin incelenmesi. *Politeknik Dergisi*, 24(4), 1353-1363.

Budakci, M. (2006). Effect of outdoor exposure and bleaching on surface color and chemical structure of scots pine. *Progress in Organic Coatings*, *56*(1), 46-52.

Bulian, F. & Graystone, J. (2009). *Wood coatings: Theory and practice*. Elsevier.
chemical structure of scots pine. *Progress in Organic Coatings*, 56(1), 46-52.
Evans, P. D., Thay, P. D. & 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(6), 411-422.
Feist, W. C. (1990). Outdoor wood weathering and protection. *Archaeological wood, properties, chemistry, and preservation. Advanced in Chemistry Series*, 225, 263-298.
Fengel, D. (1991). Aging and fossilization of wood and its components. *Wood Science and Technology*, 25(3), 153-177.
Futó, L. P. (1974). The photochemical decomposition of Wood—A method of preparation and analysis. *Holz als Roh-und Werkstoff*, 32, 303-311.
Johansson, D. (2005). *Strength and color response of solid wood to heat treatment* (Doctoral dissertation, Luleå tekniska universitet).
Kılıc, A. & Hafizoğlu, H. (2009). Açik Hava Koşullarinin Ağaç Malzemenin Kimyasal Yapisinda Meydana Getirdiği Değişimler Ve Alinacak Önlemler. *Turkish Journal of Forestry*, 8(2), 175-183.
Kılıç, K. & Söğütlü, C. (2020). Doğal yaşlanmış ağaç malzemeye uygulanan bazı verniklerin parlaklık değerlerinin belirlenmesi. *Politeknik Dergisi*, 23(4), 1423-1431.
Kılıç, K. & Söğütlü, C. (2023). Varnish adhesion strength in natural aged wood material. *Politeknik Dergisi*, 26(2), 847-854.
Kurtoğlu, A. (2000). Ağaç malzeme yüzey işlemleri. *Genel bilgiler*, 1.
Minolta, (1990). CR-231 Chromometer, version 3.0, *Cihaz Kullanma Klavuzu*.
Nelson, G. L. (1995). Coating Testing Manual, Chapter 44. *ASTM Special Technical Publication*, 513-523.
Oliver, J. R., Blakeney, A. B. & Allen, H. M. (1992). Measurement of flour color in color space parameters. *Cereal Chemistry*, 69(5), 546-551.
Özçifci, A. & Atar, M. (2002). Bazı kimyasal maddelerin karaağaç (*Ulmus campestris* Spach*)* odununun renk tonuna etkileri. *Teknoloji Dergisi*, Yıl, 5, 1-2.
Özen, R. & Sönmez, A. (1996). Dış hava şartlarının verniklerin katman sertliğine etkisi. *Doğa-Tr. J. Of Agriculture and Forestry*, 23(3).
Pelit, H. & Korkmaz, M. (2019). Kayın (*Fagus orientalis* L.) odununun yüzey özelliklerine nano-grafen katkılı su bazlı verniklerin etkisi. *Politeknik Dergisi*, 22(1), 203-212.
Rowell, R. M. (2005). *Handbook of wood chemistry and wood composites*. C.R.C. press.
Söğütlü, C. (2004). Bazı yerli ağaç türlerinin kündekâri yapımında kullanım imkânları. *Gazi Üniversitesi Fen Bilimleri Enstitüsü Doktora Tezi*, Ankara.
Söğütlü, C. & Sönmez, A. (2006). Değişik koruyucular ile işlem görmüş bazi yerli ağaçlarda uv işinlarinin renk değiştirici etkisi. *Gazi Üniversitesi Mühendislik Mimarlık Fakültesi Dergisi*, 21(1).
Söğütlü, C., Nzokou, P., Koc, I., Tutgun, R. & Döngel, N. (2016). The effects of surface roughness on varnish adhesion strength of wood materials. *Journal of Coatings Technology and Research*, 13, 863-870.
Sönmez, A. (1997). Color changing effects of varnishes on the wood surfaces. *Turkish Journal of Agriculture and Forestry*, 21(5), 507-511.
Sönmez, A. & Söğütlü, C. (2009). Biçme işleminde kesiş yönü ve daire testere diş sayısının ağaç malzeme yüzey pürüzlülüğüne etkisi. *Politeknik Dergisi*, 12(1), 55-60.
TS ISO 13061-1 (2021). Wood, Determination of Moisture Content for Physical and Mechanical Tests, TSE, Ankara.
TS ISO 13061-2 (2021). Wood, Determination of Density for Physical and Mechanical Tests, TSE, Ankara.
TS EN ISO (2012). 3251 Boyalar ve vernikler, boya, vernik ve bağlayıcılarda uçucu olmayan madde tayini", TSE Standardı, Ankara.
Uysal B., Sönmez A. & Atar M. (1999). Ağaç malzemede renk açma işlemleri ve verniklerin renk değiştirci etkileri, *Türk-Tarım ve Orman Dergisi*, 234, 852-859.
Vardanyan, V., Galstian, T. & Riedl, B. (2015). Effect of addition of cellulose nanocrystals to wood coatings on color changes and surface roughness due to accelerated weathering. *Journal of Coatings Technology and Research*, 12, 247-258