Color Properties of Tannin-Treated Wood

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The color-changing effect of tannin, which is a sustainable and environmentally friendly material used in wood preservation, was studied on varnished and un-varnished wood samples. For this purpose, walnut tannin was applied on samples prepared from Scots pine (*Pinus sylvestris* L.) and walnut (*Juglans regia* L.) wood in accordance with ISO 3129 (2019) standard with a brush, and then samples were coated with polyurethane varnish and water-based varnish according to ASTM D3023-98 (2017) principles. Color changes were determined according to ASTM D2244-21 (2021). The obtained data indicated that the highest value in the red color tone (*a**) was observed in Scots pine+tannin+polyurethane varnish (PU) (14.4) and the lowest was in Scots pine+control+unvarnished (Uvr) (6.5). The highest value for the yellow color tone (*b**) was observed in Scots pine+tannin+PU (34.1), the lowest was in walnut+control+Uvr (14.4), and the highest color lightness value (*L**) was obtained in Scots pine+control+Uvr (77.0), and the lowest was obtained in walnut+tannin+PU (18.9). The tannin application, which darkened the wood surface, increased the *a** and *b** values in both wood types while decreasing the color lightness values 60% to 70%. Tannin application caused a noticeable decrease in total color changes in Scots pine.

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INTRODUCTION

Wood's color and pattern alternatives, anatomical structure, physical and chemical properties, and the fact that it is an environmentally friendly, renewable, and sustainable resource, have made it an indispensable material. However, wood wears away, depending on various conditions and it degrades due to physical, mechanical, chemical, and biological factors. Various modification methods including drying, painting, surface coatings, and herbal extracts are used to protect wood material from these negative factors. Today, it has become a sought-after feature for these wood preservatives that they do not cause any environmental and health concerns (EPA; Sandberg *et al*. 2017; Broda 2020).

Tannins protect plants against sunlight, insects, fungi, and bacteria (Pizzi 2008; Tondi *et al*. 2012; Koopmann *et al*. 2020). Tannins are also widely used in the leather industry, cosmetics, medical applications, food industry, adhesive making, and wood preservation (Pizzi 2008; Zelinka and Stone 2011; Tondi *et al*. 2013; Shirmohammadli *et al*. 2018).

Tomak *et al*. (2018) exposed Scots pine wood to artificial weathering conditions for 15 to 12 h with water-based transparent and opaque coatings containing valex, mimosa, and pine tannins. Tannin-containing samples, which had been exposed under outdoor weather conditions, showed higher stability in terms of color lightness (Δ*L**) values than the reference (covered only with varnish) and control samples. Reference and control samples showed similar values in terms of changes in red (Δ*a*) and yellow color (Δ*b*) values. The reference samples showed the highest Δ*a* and Δ*b* values.

Keskin and Atar (2007) studied the yellow color tone values of Eastern beech, European oak, Scots pine, Eastern spruce, and Uludag fir samples impregnated with Timbercare Aqua (Tc), after coating them with Sayerlack parquet (Sp) varnish, Sayerlack interior (Si) varnish, and Sayerlack exterior varnish. As a result, the yellow color tone values were highest in pine (34.4) and lowest in Eastern beech (26.5). For wood material-impregnation-varnish interaction, the yellow color tone value was observed as highest in Eastern spruce+Tc+Sp (42.1) and lowest in Eastern beech+Tc+Si (21.5).

Tondi *et al*. (2013) exposed Scots pine and European beech samples that were treated with tannin to outdoor weather conditions and measured their color values. Dark coloration was observed more in tannin samples that were not left in the open air. It was also observed that the tannin led to surface roughness and decreased color lightness in samples exposed to outdoor weather conditions. Non-treated samples that were left outdoors turned gray.

Oberhofnerová *et al*. (2017) studied the color changes of 4 softwood trees (spruce, Scots pine, Douglas fir, and larch) and 5 hardwood trees (oak, black acacia, maple, poplar, and alder) during 12 months of natural weathering. The depth of color change was relatively similar among softwoods but much more diverse in hardwoods. Redness (Δ*a**) and yellowness (Δ*b**) values also showed similarities, initially increasing and then decreasing. The Δ*a** change was parallel to the change of chromophore groups and the Δ*b** change was parallel to the lignin degradation. While wood's high content of extractive material accelerates the processes in color change, its low content leads photo-degradation as a slow but continuous change.

Yalinkilic (2013) studied the color lightness (*L**), red color tone (*a**), and yellow color tone (*b**) of beech, oak, Scots pine, poplar, and fir tree samples that were varnished and heat-treated. According to the obtained results, the *L** value was highest in 165 °C + 2 h heat treated + water-based varnished + Scots pine samples, and lowest was in 175 °C+ 2 h heat treated + synthetic varnished beech samples (15.4). The *a** value was highest in 165 °C+2 h heat treated + synthetic varnished+Scots pine samples (82.48), lowest in 175 °C+2 h heat treated + synthetic varnished + Scots pine samples (43.82). The highest *b** value was in 165 °C + 2 h heat treated + water-based varnished + Scots pine samples (111.4), and the lowest was in 175 °C + 2 h heat treated + synthetic varnish + beech samples (27.67).

Cakıcıer (1994) stated that the varnish type is significant in the change occurring in the color of water-soluble wood paints caused by solvent-based varnishes used on wood material surface and the type of wood is insignificant.

Yalinkilic and Sonmez (2015) studied the red color tone-changing effect of water-based varnishes on different wood materials that were colored brown with water-soluble wood dyes. For this purpose, samples prepared from oriental beech (*Fagus orientalis* Lipsky), sessile oak (*Quercus petraea* Liebl.), and Scots pine (*Pinus sylvestris* L.) wood in accordance with the principles of ISO 3129 (2019) were colored with aniline, ready-mix, and chemically painted according to ASTM E1347-97 (2005); afterwards, they were coated with one and two-component water-based varnishes according to ASTM D3023-98 (2017) principles.

Color changes were determined with respect to ASTM D2244-21 (2021). According to the research results, the highest change in red color tone was obtained in ready-mix dyed oak samples with a one-component varnish application, and the lowest was in chemically dyed Scots pine with a two-component varnish application.

Colakoglu (2006) studied the effect of synthetic, acrylic, water-based, and polyurethane varnishes on the yellow color tone of beech and oak wood materials impregnated with Imersol-Aqua with the CIELab color measurement system. As a result of the research, it was stated that varnishes increase the yellow color tone in oak and Eastern beech.

Yalinkilic (2021) examined the yellow tone-changing effect of water-based varnishes on wood material colored brown with water-soluble color pigments. For this purpose, samples, which were prepared from oriental beech (*Fagus orientalis* Lipsky), sessile oak (*Quercus petraea* Liebl.), Scots pine (*Pinus sylvestris* L.) were colored with aniline, the ready-mix mixture, and chemical paint according to ASTM E1347-97 (2005), then they were coated with one and two-component varnishes according to ASTM D3023-98 (2017). The color change was determined with respect to ASTM D2244-21 (2021). Regarding the research results, the highest change in yellow tone was found in ready-mix dyed beech with a two-component varnish application, and the lowest was found in aniline-dyed Scots pine with a one-component varnish application.

Arıcan (2019) studied the color changes occurring in Scots pine coated with tannin-added varnishes, which were obtained from valex, mimosa, and red pine bark, after the accelerated aging test. At the end of the experiment, the colors of the samples, which were treated with tannin-added transparent surface applications, darkened, and the red color increased after the accelerated outdoor test. This situation decreased the ΔL^* value and increased the Δa^* value.

Yazıcı (2019) conducted color measurements on Scots pine, to which mimosa, valex, and red pine tannin+cerium oxide and nano zinc oxide (ZnO) added varnish was applied at different concentrations (3%, 1%, 0.5%, and 0.1%) after an accelerated outdoor test. According to the obtained results, the surfaces of those treated with tannin + ZnO became darker. In high concentration samples, the samples coated with tannin +nano ZnO started to take on a lighter color at the end of the aging test when compared with the beginning hours of the test. In all tannin + ZnO combinations, more changes were detected in ΔL^*, Δa^*, Δb^*, and ΔE^* values as the concentrations were increased.

Yalçın *et al*. (2017) subjected beech wood samples, which were impregnated with 5% and 10% concentrations of mimosa and quebracho tannin and 4.5% Tanalith-E, to accelerated weather conditions and studied the color changes. The average color change values in tannin impregnated samples were higher than in unimpregnated, control and Tanalith-E impregnated samples.

This study tried to determine the color changes caused by walnut tannin, a natural preservative, on the unvarnished wood surface and the color changing effects of varnishes on tannin-applied wood. It was aimed to determine the quality and sustainability of the tannin so that the results of this research create economic value and can be used by businesses in the surface applications of wood types commonly used in furniture and woodworking in Türkiye.

EXPERIMENTAL

Scots pine (*Pinus sylvestris* L.) and walnut (*Juglans regia* L.) samples provided from the Eastern Black Sea Region in Türkiye, were obtained with completely randomized methods, from timbers, which do not show color differences, have smooth fibers, and do not contain twigs and knots, in accordance with ISO 3129 (2019).

Samples were prepared from the sapwood part of randomly selected first class material that had uniform fiber, did not have knots or cracks, had no color and density difference, and the annual rings were upright to surface. Samples were cut to (11 × 11 × 1.2) cm^3. After samples that were taken into their final sizes (10 × 10 × 1) cm^3 were sanded with 80 and 100 sandpapers following the first wetting, which is the first stage of the polishing process. Before the re-sanding process, which is the last stage of the polishing process, the final wetting was done and the pieces were sanded with 120 sandpaper. Dust was cleaned off the sanded surfaces using a soft bristle brush and vacuum and they were prepared for tannin application and varnishing before surface treatment.

The sanded test pieces, which were prepared according to the standards, were first kept in the air conditioning device at 18 to 22 °C and 60% to 70% relative humidity until they reached a constant weight and were brought to the desired equilibrium humidity of 10% to 14%.

Walnut shell powder, which is obtained by drying the green shells of the walnut and produced for commercial purposes, was supplied from AR-TU KIMYA Acorn and Valex Factory in Salihli District of Manisa. Walnut tannin was prepared as 10 g/L in line with the recommendations of the manufacturer (ARTU 2022).

Natural wood preservative tannin solution of the appropriate viscosity (10% concentration), which was prepared in accordance with the manufacturer's recommendations, was applied to the test pieces with a medium-hard brush in 3 layers, parallel to the fibers, perpendicular to the fibers and again parallel to the fibers.

Water-based varnish (WB) and polyurethane varnish (PU) were used in this study. They were obtained through market purchase. While PU is a two-component and chemically reactive type of varnish; WB is diluted with water-based solvents and resins.

Varnishing was carried out in the form of industrial application according to ASTM D3023-98 (2017) principles and suggestions from manufacturers. Varnishes were applied to samples with medium brushes. The varnish amount was determined by acting on the suggestions of manufacturers for 2 coats that are required to be spread. Therefore, it was weighed using a 0.01 analytical precision balance in a way that there were 120 g/m^2 in PU glossy varnish and WB glossy. A total of 2 coats of PU and WB were applied to the surfaces of samples and samples were left to dry for three weeks. After drying, they were kept in the air-conditioning cabinet at 23 ± 2 °C and 50 ± 5% relative humidity for 16 h before the experiments (ASTM D3924-16 2019).

The ColorStriker colorimeter was used for measuring (ColorStriker 2024). Color measurements were made according to ASTM D2244-21 (2021). Today, the $L^*a^*b^*$ color space (CIELab) is one of the most popular color spaces for measuring object color and is commonly used in all fields. It is one of the uniform color spaces identified by CIE in 1976. In this color space, L^* specifies lightness, such that an L^* value of zero means a perfect black, whereas an L^* value of 100 means a perfect white. The a^* and b^* terms are the chromaticity coordinates. The CIE L*a*b* color space is shown in Fig. 1 (Konica Minolta Inc 2007).

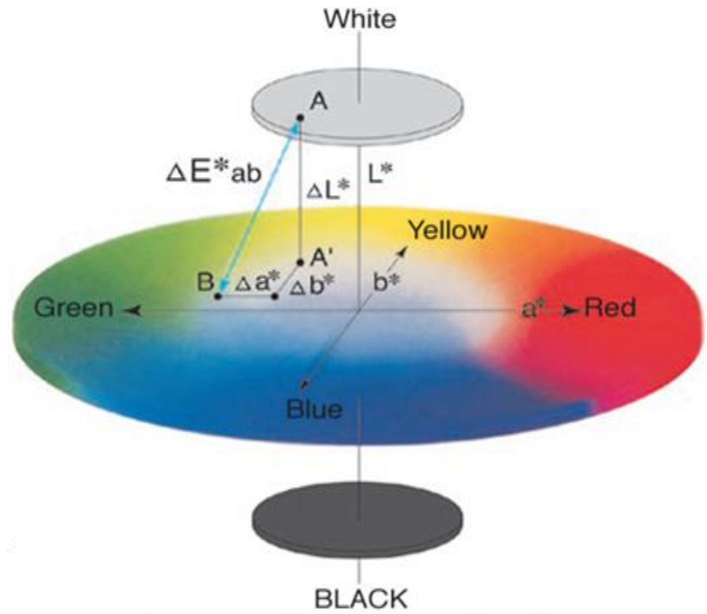

Fig. 1. CIE L*a*b* color space

In the research, (2 × 3 × 2 × 1 × 10) = 120 samples in total were prepared for the surface experiments, including 2 wood species, 3 varnish types, 2 process types, one color measurement treatment, and the number of samples were 10 for each.

The software MS Excel 2010 (Microsoft Corp., Redmond, WA, USA) was used for data evaluation and MSTATC statistical package program was utilized for statistical analysis, and multiple analyzes of variance (ANOVA) were conducted between all groups. If the factor effects were significant with a margin of error of $p \leq 0.05$, comparisons were carried out using the Duncan test.

RESULTS AND DISCUSSION

Variance analysis regarding the effects of wood type, tannin, and varnish applications on red color tone (*a**) is given in Table 1.

Table 1. Variance Analysis Belonging to Red (*a**) Color Tone Change

Source	Degrees of Freedom	Sum of Squares	Mean Squares	F- value	Sig.
Wood Type (A)	1	0.184	0.184	0.075	0.785
Process Type (B)	1	162.541	162.541	66.355	0.000*
Varnish Type (C)	2	422.405	211.203	86.220	0.000*
Interaction (AB)	1	56.472	56.472	23.054	0.000*
Interaction (AC)	2	42.002	21.001	8.573	0.000*
Interaction (BC)	2	16.145	8.073	3.295	0.041*
Interaction (ABC)	2	2.936	1.468	0.599	0.551
Error	108	264.553	2.450		
Total	119	967.238			

*: Statistically significant difference $\alpha \leq 0.05$

In the multiple variance analysis, which was conducted to determine the source of the differences, while process type, varnish type, wood type-process type, wood type-varnish type, and process-varnish type were significant, other factors were statistically insignificant. Duncan test comparisons for the wood, process, and varnish values are given in Table 2.

Table 2. Duncan Test Comparisons of Wood, Process, and Varnish Type (*a**)

Source		Means	HG	95% Confidence Interval		Std. Error
				Lower Limit	Upper Limit	
Wood type	Scotch pine	10.65	A	10.2	11.0	0.202
	Walnut	10.72*	A	10.3	11.1	
Process Type	Control	9.52	B	9.12	9.92	0.202
	Tannin	11.85*	A	11.5	12.25	
Varnish Type	WB	11.26	B	10.76	11.75	0.247
	PU	12.64*	A	12.15	13.13	
	Uvr	8.16	C	7.66	8.60	

*: The highest increase in red color tone among groups

The fact that no significant differences were observed between the woods in Table 1 may be due to the fact that they show approximately the same values. When Table 2 is studied, the highest red color tone changes were found in tannin samples concerning the process type, and in polyurethane varnish with regard to the varnish type. The lowest red color tone change was determined in Scots pine, tannin-free, and unvarnished samples. Both varnish and tannin applications increased the red color values. Duncan test comparisons for the wood-process, wood-varnish, and process-varnish interactions are given in Table 3.

Table 3. Duncan Test Comparisons of Wood-Process, Wood-Varnish, and Process-Varnish Interactions (a*)

Source			Means	HG	95% Confidence Interval		Std. Error
					Lower Limit	Upper Limit	
Wood type / Process Type	Scotch Pine	Control	8.8	D	8.2	9.4	0.286
		Tannin	12.5*	A	11.9	13.1	
	Walnut	Control	10.2	C	9.7	10.8	
		Tannin	11.2	B	10.6	11.7	
Wood type / Varnish Type	Scotch Pine	WB	10.4	B	9.7	11.0	0.35
		PU	12.8*	A	12.2	13.5	
		Uvr	8.7	C	8.0	9.38	
	Walnut	WB	12.1	A	11.4	12.8	
		PU	12.4	A	11.7	13.1	
		Uvr	7.6	D	6.9	8.3	
Process Type / Varnish Type	Control	WB	10.05	C	9.4	10.7	0.35
		PU	11.95	B	11.2	12.6	
		Uvr	6.60	D	5.9	7.3	
	Tannin	WB	12.5	AB	11.8	13.1	
		PU	13.3*	A	12.6	14.0	
		Uvr	9.8	C	9.05	10.4	

*: The highest increase in red color tone among groups

When Table 3 is analyzed; for the wood-process interaction values, tannin caused the highest change in red color tone in Scots pine wood with a value of 12.5, and the control samples caused the lowest difference with a value of 8.8. While tannin caused the highest change in red color tone in walnut wood with a value of 11.2, control samples had the lowest value of 10.2. According to these results, the highest red color tone change was obtained in the tannin-treated Scots pine samples and the lowest was in the Scots pine control samples. Tannin application led to an increase in the red color values of both trees.

For the wood-varnish interaction, PU caused the highest change in red color tone in Scots pine wood with a value of 12.8, while unvarnished samples had the lowest change with a value of 8.7. While PU caused the highest change in red color tone in walnut wood with a value of 12.4, unvarnished samples had the lowest change in red color tone with a value of 7.6. According to these results, the highest red color tone change was obtained in PU-applied Scots pine and the lowest was in unvarnished walnut samples. While varnish application led to an increase in the red color tone values of both trees, the highest increase was observed in PU samples.

For the process-varnish interaction, PU caused the highest change in red color tone in the control samples with a value of 12.0, while unvarnished samples had the lowest change with a value of 6.6. In tannin samples, PU caused the highest change in red color tone with a value of 13.3, while unvarnished samples had the lowest change in red color tone with a value of 9.8. The difference between WB control samples and unvarnished tannin samples was statistically insignificant. With regard to these results, the highest red color tone change was obtained in the PU-varnished tannin samples, and the lowest was in the unvarnished control samples. Varnish application led to a higher increase in the red color values of tannin samples when compared with control samples. Wood-process-varnish interactions are shown in Fig. 2.

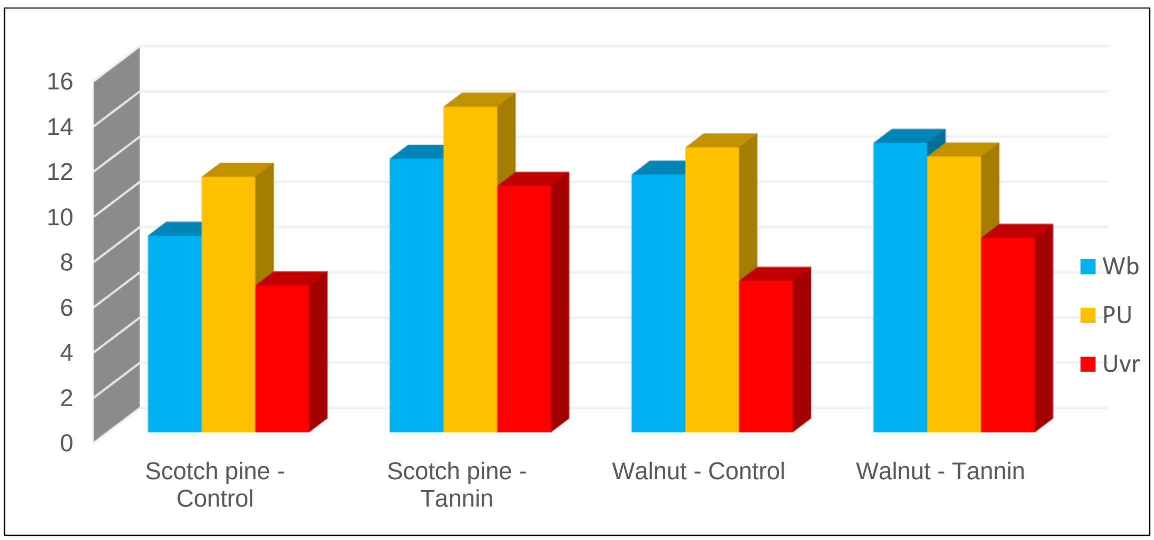

Fig. 2. Red color (a^*) variation for wood-process-varnish interaction

The highest red color tone change was observed in PU-varnished tannin Scots pine samples, the lowest values were approximately equal in unvarnished Scots pine and walnut control samples. Variance analysis regarding the effects of wood type, tannin, and varnish applications on yellow color tone (b^*) is given in Table 4.

Table 4. Variance Analysis of Yellow (*b**) Color Tone Change

Source	Degrees of Freedom	Sum of Squares	Mean Squares	F- value	Sig.
Wood Type (A)	1	2179.928	2179.928	687.519	0.000*
Process Type (B)	1	15.109	15.109	4.765	0.031*
Varnish Type (C)	2	1451.781	725.891	228.936	0.000*
Interaction (AB)	1	.804	0.804	0.253	0.616
Interaction (AC)	2	131.844	65.922	20.791	0.000*
Interaction (BC)	2	12.205	6.103	1.925	0.151
Interaction (ABC)	2	47.777	23.889	7.534	0.001*
Error	108	342.437	3.171		
Total	119	4181.885			

*: Statistically significant difference $\alpha \leq 0.05$

In the multiple variance analysis performed to determine the source of the differences, wood type-process type and process type-varnish type were insignificant, while other factors were statistically significant. Duncan test comparisons for the wood, process, and varnish are given in Table 5.

Table 5. Duncan Test Comparisons of Wood, Process, and Varnish Type (*b**)

Source		Means	HG	95% Confidence Interval		Std. Error
				Lower Limit	Upper Limit	
Wood Type	Scotch pine	28.98*	A	28.52	29.43	0.230
	Walnut	20.45	B	19.90	20.91	
Process Type	Control	24.36	B	23.90	24.80	0.230
	Tannin	25.07*	A	24.60	25.52	
Varnish Type	WB	26.20	B	25.65	26.80	0.282
	PU	28.02*	A	27.47	28.60	
	Uvr	19.90	C	19.35	20.50	

*: The highest increase in yellow color tone among groups

Table 6. Duncan Test Comparisons of Wood-Process, Wood-Varnish, and Process-Varnish Interactions (*b**)

Source			Means	HG	95% Confidence Interval		Std. Error
					Lower Limit	Upper Limit	
Wood type / Process Type	Scotch pine	Control	28.5	A	27.9	29.2	0.325
		Tannin	29.4*	A	28.8	30.1	
	Walnut	Control	20.2	B	19.5	20.8	
		Tannin	20.7	B	20.1	21.4	
Wood type / Varnish Type	Scotch pine	WB	29.27	B	28.49	30.06	0.398
		PU	33.64*	A	32.85	34.40	
		Uvr	24.00	C	23.22	24.80	
	Walnut	WB	23.14	CD	22.35	23.90	
		PU	22.41	D	21.62	23.20	
		Uvr	15.80	E	15.02	16.60	
Process Type / Varnish Type	Control	WB	25.6	C	24.8	26.4	0.398
		PU	28.1*	A	27.3	28.9	
		Uvr	19.3	E	18.5	20.1	
	Tannin	WB	26.8	B	26.0	27.6	
		PU	27.9	A	27.1	28.7	
		Uvr	20.5	D	19.7	21.3	

*: The highest increase in yellow color tone among groups

When Table 5 is studied, the highest yellow color tone change was found in Scots pine for the wood type, tannin samples for the process type, and polyurethane varnish for the varnish type, the lowest yellow color tone change was detected in tannin-free and unvarnished walnut samples. Both varnish and tannin applications increased the yellow color values. Duncan test comparisons for the wood-process, wood-varnish, and process-varnish interactions are given in Table 6.

When Table 6 is studied, for the wood-process interaction, tannin caused the highest change in yellow color tone in Scots pine wood with a value of 29.4, while control samples had the lowest difference with a value of 28.5. While tannin caused the highest change in yellow color tone in walnut wood with a value of 20.7, control samples had the lowest change with a value of 20.2. According to these results, the highest yellow color tone change was obtained in tannin-treated Scots pine samples and the lowest was in walnut control samples. Tannin application caused an increase in the yellow color values of both woods.

For the wood-varnish interactions, the PU-varnish caused the highest change in yellow color tone in Scots pine wood with a value of 33.6, while unvarnished samples had the lowest change with a value of 24.0. While WB-varnish caused the highest change in yellow color tone in walnut wood with a value of 23.1, unvarnished samples had the lowest change with a value of 15.8. According to these results, the highest yellow color tone change was observed in PU-varnished Scots pine and the lowest was in unvarnished walnut samples. Varnish application caused an increase in the yellow color values of both woods. Because walnuts have a coarser texture and extractive substance content, and that the tracheids of Scots pine are more homogeneous, could be reasons for the higher values (Hon *et al.* 1986; Atar 1999; Yalinkilic 2013).

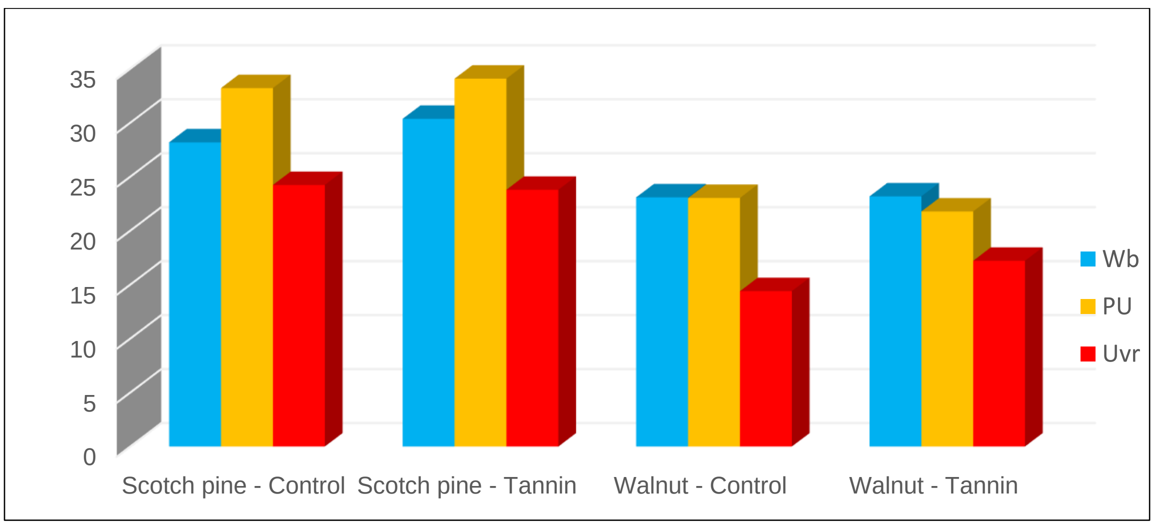

Fig. 3. Yellow color tone (*b**) variation for wood-process-varnish interaction

For the process-varnish interactions, the PU-varnish caused the highest change in yellow color tone in the control samples with a value of 28.1, while unvarnished samples had the lowest change with a value of 19.3. In tannin samples, the PU-varnish caused the highest change in yellow color tone with a value of 27.9, while unvarnished samples had the lowest change in yellow color tone with a value of 20.5. The difference between PU-varnished control and tannin samples was statistically insignificant. According to these results, the highest yellow color tone changes were obtained approximately equally in the PU-varnished control and tannin samples, and the lowest value was obtained in the unvarnished control samples. While varnish application caused an increase in the yellow color tone values of the control and tannin samples, the highest increase was observed in PU varnish. Wood-process-varnish interactions are shown in Fig. 3.

The highest yellow color tone change was observed in PU-varnished tannin Scots pine samples, and the lowest was observed in unvarnished walnut control samples. Variance analysis regarding the effects of wood type, tannin, and varnish applications on color lightness (*L**) is given in Table 7.

Table 7. Variance Analysis for Changes in Color Lightness (*L**)

Source	Degrees of Freedom	Sum of Squares	Mean Squares	F- value	Sig.
Wood Type (A)	1	18833.342	18833.342	1155.445	0.000*
Process Type (B)	1	8895.680	8895.680	545.759	0.000*
Varnish Type (C)	2	5694.297	2847.149	174.675	0.000*
Interaction (AB)	1	844.026	844.026	51.782	0.000*
Interaction (AC)	2	535.219	267.610	16.418	0.000*
Interaction (BC)	2	72.017	36.009	2.209	0.115
Interaction (ABC)	2	126.964	63.482	3.895	0.023*
Error	108	1760.362	3.868		
Total	119	36761.907			

*: Statistically significant difference $\alpha \leq 0.05$

In the multiple variance analysis conducted to determine the source of the differences, the process type and varnish type were insignificant, while other factors were statistically significant. The Duncan test comparisons for the wood, process, and varnish values are given in Table 8.

Table 8. Duncan Test Comparisons of Wood, Process, and Varnish Type (*L**)

Source		Means	HG	95% Confidence Interval		Std. Error
				Lower Limit	Upper Limit	
Wood type	Scotch pine	56.64*	A	55.60	57.67	0.521
	Walnut	31.59	B	30.55	32.62	
Process Type	Control	52.72*	A	51.70	53.80	0.521
	Tannin	35.50	B	34.47	36.54	
Varnish Type	WB	38.64	B	37.38	39.91	0.638
	PU	39.87	B	38.61	41.14	
	Uvr	53.83*	A	52.56	55.09	

*: The highest increase in color lightness

When Table 8 is examined, the highest color lightness was found in Scots pine for the wood types, control samples for the process types, and unvarnished samples for the varnish types, the lowest color lightness value was observed in walnut, tannin, and water-based varnished samples. The color lightness of WB and PU varnishes was approximately equal. Both varnish and tannin applications caused a decrease in color lightness. Duncan test comparisons for the wood-process, wood-varnish, and process-varnish interactions are given in Table 9.

Table 9. Duncan Test Comparisons of Wood-Process, Wood-Varnish, and Process-Varnish Interactions (*L**)

Source			Means	HG	95% Confidence Interval		Std. Error
					Lower Limit	Upper Limit	
Wood Type / Process Type	Scotch pine	Control	67.90*	A	66.44	69.36	0.737
		Tannin	45.38	B	43.92	46.84	
	Walnut	Control	37.54	C	36.08	39.00	
		Tannin	25.63	D	24.17	27.09	
Wood Type / Varnish Type	Scotch pine	WB	52.13	B	50.34	53.92	0.903
		PU	54.37	B	52.58	56.16	
		Uvr	63.43*	A	61.64	65.20	
	Walnut	WB	25.15	D	23.36	26.94	
		PU	25.37	D	23.59	27.16	
		Uvr	44.23	C	42.44	46.02	
Process Type / Varnish Type	Control	WB	46.3	BC	44.5	48.0	0.903
		PU	48.6	B	46.8	50.4	
		Uvr	63.3*	A	61.5	65.1	
	Tannin	WB	31.0	D	29.2	32.8	
		PU	31.1	D	29.4	32.9	
		Uvr	44.3	C	42.5	46.1	

*: The highest increase in color lightness

When Table 9 is studied, for the wood-process interaction, the change in color lightness value of Scots pine wood was highest in control samples with a value of 67.9, while the lowest was in tannin samples with a value of 45.4. The change in color lightness value of walnut wood was highest in the control samples with a value of 37.5, while the lowest was in the tannin samples with a value of 25.6. Concerning these results, the highest change in color lightness value was obtained in Scots pine control samples and the lowest was in tannin-walnut samples. Tannin application caused a decrease in the color lightness values of both trees.

For the wood-varnish interaction, the change in color lightness value of Scots pine wood was highest in unvarnished samples with a value of 63.4, while the lowest was in WB-varnished samples with a value of 52.1. The change in color lightness value of walnut wood was determined to be highest in unvarnished samples with a value of 44.2, while the lowest was in water-based varnished samples with a value of 25.2. Regarding these results, the highest change in color lightness value was obtained in unvarnished Scots pine samples, and the lowest was obtained in WB-varnished walnut samples. The WB and PU varnish applications caused a decrease in the color lightness values of both trees, and the difference between the values was statistically insignificant.

For the process-varnish interaction, the change in color lightness value in the control samples was highest in the unvarnished samples with a value of 63.3, while the lowest was in the WB-varnished samples with a value of 46.3. In tannin samples, the change in color lightness value was determined to be highest in unvarnished samples with a value of 44.3, while the lowest was in WB-varnished samples with a value of 31.0. The difference between WB- and PU-varnished tannin samples was statistically insignificant. With respect to these results, the highest change in color lightness value was obtained in the unvarnished control samples, and the lowest was obtained in the WB-varnished tannin samples. Tannin application caused a decrease in color lightness values when compared with unvarnished and varnished control samples. Tannin application caused a decrease in color lightness values when compared with unvarnished and varnished control samples. Wood-process-varnish interactions are shown in Fig. 4.

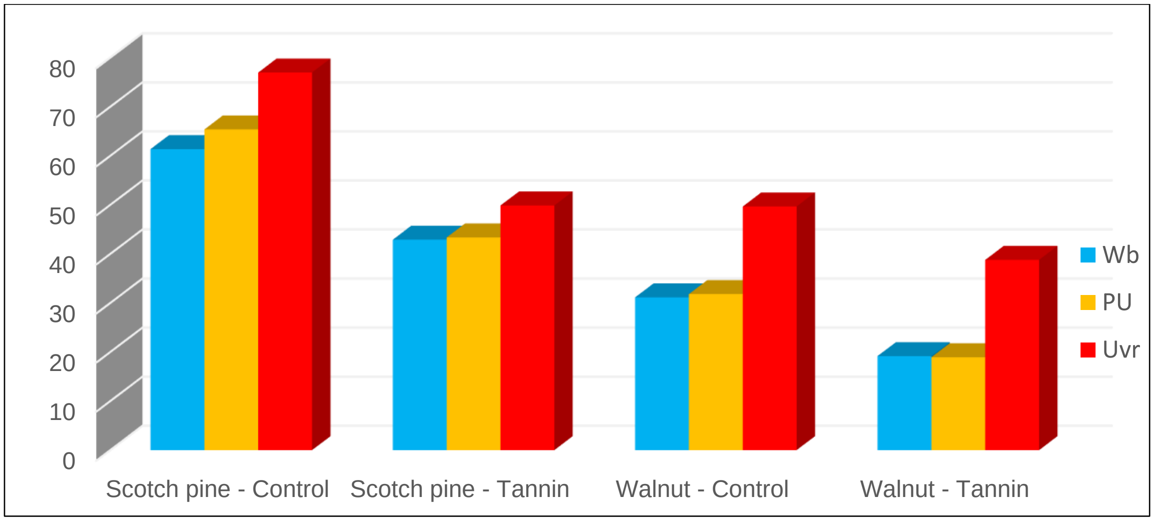

Fig. 4. Color lightness (*L**) change for the wood-process-varnish interaction

The highest change in color lightness value was obtained in unvarnished Scots pine control samples, and the lowest was in PU-varnished tannin walnut samples. Tannin application caused a decrease in color brightness in both wood types when compared with the control samples and decreased the lightness values 60% to 70%. Tannin application may have decreased the color brightness values because it causes a darker and brown coloration (Atar 1999; Tondi *et al*. 2013; Shirmohammadli *et al*. 2018). Variance analysis regarding the effects of wood type, tannin, and varnish applications on the total color changes (ΔE^*) is given in Table 10.

Table 10. Variance Analysis for Changes in total color changes (ΔE^*)

Source	Degrees of Freedom	Sum of Squares	Mean Squares	F- value	Sig.
Wood Type (A)	1	1205.904	1205.904	186.865	0.000*
Process Type (B)	1	185.258	185.258	28.707	0.000*
Varnish Type (C)	1	0.588	0.588	0.091	0.764
Interaction (AB)	1	80.240	80.240	12.434	0.001*
Interaction (AC)	1	1.502	1.502	0.233	0.631
Interaction (BC)	1	1.782	1.782	0.276	0.601
Interaction (ABC)	1	33.956	33.956	5.262	0.025*
Error	72	464.640	6.453		
Total	80	25666.533			

*: Statistically significant difference $\alpha \leq 0.05$

In the multiple variance analysis conducted to determine the source of the differences varnish type, wood type-varnish type and process type-varnish type were insignificant, while other factors were statistically significant. The Duncan test comparisons for the wood, process, and varnish values are given in Table 11.

Table 11. Duncan Test Comparisons of Wood, Process, and Varnish Type (Δ*E**)

Source		Means	HG	95% Confidence Interval	
				Lower Limit	Upper Limit
Wood type	Scotch pine	13.3	AB	12.5	14.1
	Walnut	21.1*	A	20.3	21.9
Process Type	Control	18.7*	A	17.9	19.5
	Tannin	15.7	B	14.9	16.5
Varnish Type	WB	17.1	AB	16.3	17.9
	PU	17.3	AB	16.5	18.1

Std. Error: 0.402 *: The highest increase in color Δ*E**

When Table 11 is examined, the highest total color changes was found in walnut for the wood types and control samples for the process types. The fact that no significant differences were observed between the varnish type in Table 10 may be due to the fact that they show approximately the same values. Duncan test comparisons for the wood-process, wood-varnish, and process-varnish interactions are given in Table 12.

Table 12. Duncan Test Comparisons of Wood-Process, Wood-Varnish, and Process-Varnish Interactions (Δ*E**)

Source			Means	HG	95% Confidence Interval	
					Lower Limit	Upper Limit
Wood type / Process Type	Scotch pine	Control	15.9	B	14.7	15.9
		Tannin	10.8	C	9.7	10.8
	Walnut	Control	21.6*	A	20.5	21.6
		Tannin	20.6	A	19.4	20.6
Wood type / Varnish Type	Scotch pine	WB	13.1	BC	12.0	14.2
		PU	13.6	BC	12.4	14.7
	Walnut	WB	21.1	A	20.0	22.3
		PU	21.0	A	19.9	22.2
Process Type / Varnish Type	Control	WB	18.8	AB	17.7	19.9
		PU	18.7	AB	17.5	19.8
	Tannin	WB	15.5	B	14.3	16.6
		PU	15.9	B	14.8	17.1

Std. Error: 0.568 *: The highest increase in color Δ*E**

When Table 12 is studied, for the wood-process interaction, the total color changes value of walnut wood was highest in control samples with a value of 21.6, while the lowest was in tannin - Scots pine samples with a value of 10.8. For the wood-varnish and process/ Varnish Type interaction, the total color change values of varnish type showed no significant differences between the varnish type in Table 10. This may be due to the fact that they showed approximately the same values. Wood-process-varnish interactions are shown in Fig. 5.

The highest change in total color changes value was obtained in walnut+control +PU-varnished samples; the lowest was in Scots pine + tannin samples. Tannin application caused a noticeable decrease in total color changes in Scots pine when compared with the control samples and decreased the total color changes values 22% to 40% (Atar 1999; Tondi *et al*. 2013; Shirmohammadli *et al*. 2018).

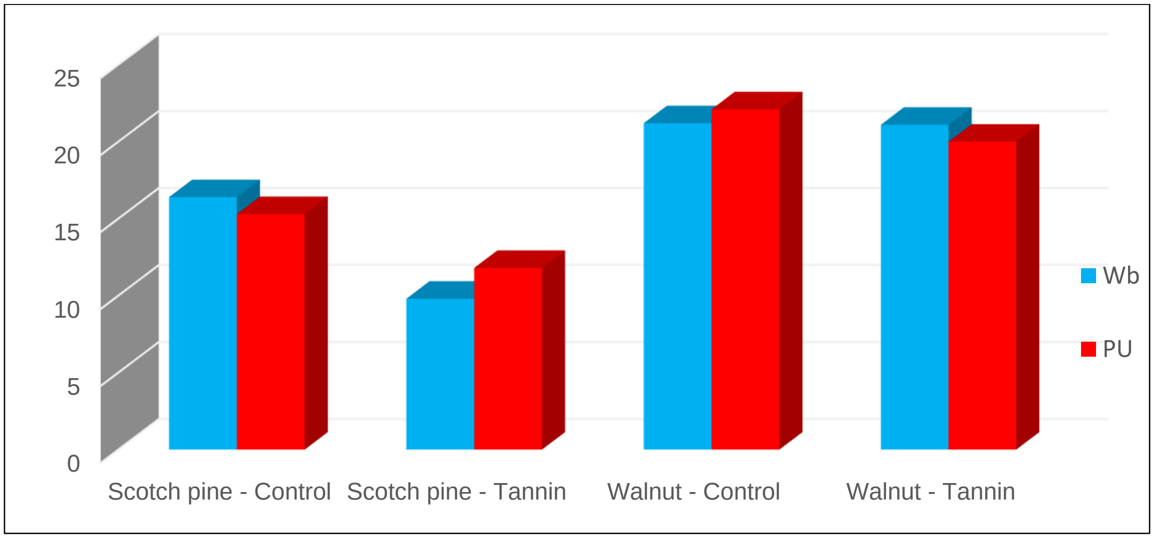

Fig. 5. Total color changes (Δ*E**) for the wood-process-varnish interaction

CONCLUSIONS

1. Tannin applications increased the red and yellow color tone values in both wood types and caused a decrease in color lightness values.
2. Varnish application caused an increase in the red and yellow color values of both trees.
3. The highest increase in red color tone was observed in PU-varnished samples.
4. While PU varnish caused the highest change in yellow color tone in Scots pine wood, WB varnish led to the highest values in walnut wood.
5. Varnish application led to a decrease in color lightness. Tannin application caused a decrease in color lightness in both tree species when compared with the control samples and decreased the lightness values 60% to 70%. Tannin application may have decreased the color lightness because it leads to a darker and brown coloration.
6. This study showed that tannin and varnish application led to significant differences in color values. The results of this research can provide data for the use of the color changing effect of tannin, which is a sustainable resource, in furniture and woodworking.

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