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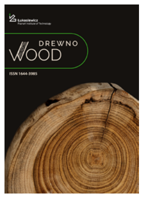

Effect of Thermal Modification and Picture Varnish Application on Color Change of Scots Pine (*Pinus Sylvestris* L.) Wood

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Scots pine is one of the important tree species used by the wood processing industry in many countries for both interior and exterior applications. It is well known that thermal treatment alters the color of wood. To protect wood from outdoor environmental conditions, certain chemicals are applied to its surface. These protective chemicals also influence the color of thermally treated wood. In this study, the color-altering effect of picture varnish (refined linseed oil), commonly used as a protective chemical in the field of painting, was investigated on both thermally treated and untreated wood materials. Scots pine (*Pinus sylvestris* L.) wood samples were subjected to thermal treatment at 212 °C for 2 h. Following this, varnish made from refined linseed oil was applied to some of these samples and some untreated samples, with the remaining untreated samples used as controls. Color and whiteness index (WI*) values were analyzed on the resulting four different materials, and the results were compared. Analysis of variance showed significant effects for the factors of heat treatment, picture varnish application, and their interaction, on WI* (‖ and ⊥), a*, L*, ho, b*, and C* values. In the non-heat-treated samples, the application of varnish resulted in reductions in WI* values in both directions and in L* values, while increases were observed in ho, b*, C*, and a* values. Additionally, the application of varnish to the heat-treated samples resulted in an increase in a* values, while reductions were observed in WI* values in both directions, as well as in ho, L*, b*, and C* values. After heat treatment, the ΔE* value for Scots pine wood was calculated as 33.63. For both heat-treated and non-heat-treated samples, varnish application resulted in negative ΔL* values and positive Δa* values. Additionally, Δb* and ΔC* values were positive in the non-heat-treated and varnished samples, while they were negative in the heat-treated and varnished samples. The protective picture varnish used in the study significantly altered the color of both thermally treated and untreated wood.

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Introduction

Wood, a material with complex biological properties, derives its characteristics from a combination of internal and external factors. Composed of cellulose and hemicellulose fibers, with lignin acting as a structural binder [Pereira et al. 2003], it is increasingly favored by consumers who prioritize environmentally friendly and health-conscious choices when selecting sustainable materials for

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use in interior design and flooring. As the use of wood-based raw materials grows, so does the need for viable wood alternatives [Yang et al. 2003].

Drying oils have been employed since ancient times as binders in paints, serving dual roles in decoration and protection. They persist today as essential raw materials in modern coating systems like alkyd paints or polyester resins. Historically, these oils were extracted from seeds of plants such as walnut, flax, or poppy. Following processes like air blowing or sieving to remove unwanted materials such as foreign seeds or stems, the seeds were finely ground into a meal and then pressed to extract the oil [van den Berg 2002].

For centuries, varnishes have been employed to safeguard and/or modify the visual appearance of diverse objects and artworks. It is documented that these liquid solutions must undergo various treatments with natural substances before being applied to items such as furniture, carriages, musical instruments, tools, and decorative pieces [Tirat et al. 2017].

Paints and varnishes have served as both decorative and protective coatings since ancient times. Early instances include the development of paints by ancient tribes, blending oils and plant-derived colors with mineral pigments – a precursor to early composite paints. These paints were employed for body adornment and to improve and waterproof animal skins. Approximately 2500 years ago, Egyptians are documented to have utilized coatings made from fossil resins and oils to finish mummy cases. While the specific use of linseed oil in their varnish production remains uncertain, historical evidence indicates their cultivation of flax plants for fabric production [Heberer 1937].

Flaxseed oil is primarily composed of a blend of triglycerides containing stearic, palmitic, linoleic, oleic, and linolenic acids. The pattern of fatty acids in the oil varies depending on the climate in which the flax plant (*Linum usitatissimum* L.) is grown [Remington 1946; Fjällström et al. 2002].

Exposing wood to temperatures exceeding 150 °C alters its physical and chemical properties. Above 200 °C, wood undergoes notable transformations such as decreased swelling and shrinkage, enhanced resistance to decay, darkening of color, loss of extractives, lower moisture equilibrium, and improved thermal insulation capabilities [Viitaniemi et al. 1994].

It has been reported in the literature that heat treatment causes color changes on the surfaces of wood materials [Ayadi et al. 2003; Brischke et al. 2007; Tuong and Li 2010; Matsuo et al. 2011; Cao et al. 2022].

Following heat treatment, alterations in wood color can be assessed using the CIE standard color measurement method established by the International Commission on Illumination (CIE). This method relies on three fundamental parameters: a^* (red–green index), L^* (lightness index), and b^* (yellow–blue index), which are used to derive the saturation difference ΔC^* and the color difference index ΔE^*. These metrics are crucial for characterizing the extent of color change in processed wood. Moreover, the treatment process itself serves as a critical factor influencing these color transformations, which can vary significantly across different wood species [Cao et al. 2022].

Scots pine wood is regarded as a highly important species by the wood processing industry in numerous countries, being utilized extensively in both indoor and outdoor settings. Furthermore, thermal treatment applications have advanced and are currently maintained as an effective wood preservation method in the wood industry.

Scots pine (*Pinus sylvestris* L.) is geographically widely distributed. Pure stands are found in northeastern Anatolia, while throughout northern Anatolia it grows mixed with other trees. The wood is easy to work with, with moderate qualities in terms of ability to hold screws, nails, and adhesives. It is primarily used as structural timber, and finds applications in carpentry, joinery, furniture-making, basketry, and box construction [Hammond et al. 1969].

The thermal conductivity value of Scots pine (*Pinus sylvestris* L.) wood is reported as 0.132 W/m.K [Çavuş et al. 2019]. Measurements after combustion experiments yielded an O_2 content of 19.15%, a CO content of 224.68 ppm, an NO content of 8.31 ppm, and a chimney temperature of 125.73 °C [Çalım 2013]. Additionally, the wood's composition includes lignin at 25.34%, hemicellulose at 75.35%, alcohol solubility at 4.90%, α-cellulose at 53.14%, cold water solubility at 2.19%, and hot water solubility at 3.22% [Çetin 2009]. Mechanical properties include a tangential compression strength of 22.39 N/mm^2, a parallel-to-fiber compression resistance of 48.93 N/mm^2, a modulus of elasticity of 10057 N/mm^2, a bending strength of 95.61 N/mm^2, and a radial Brinell hardness value of 24.23 N/mm^2 [Pelit 2014]. Additionally, Kamperidou et al. [2014] reported the bending strength as 81.39 N/mm^2, the modulus of elasticity as 9532.13 N/mm^2, the impact bending strength as 2.75 J/cm^2, and the compression strength as 50.49 N/mm^2. Decay resistance percentages are reported as 60.79% for *Postia placenta* [Arslan 2017], 25.48% for *Coniophora puteana*, and 23.04% for *Pleurotus ostreatus* [Ayata et al. 2017]. These results were obtained from studies on untreated Scots pine wood.

This study examines the impact of picture varnish (refined linseed oil) and thermal modification on specific surface properties of Scots pine (*Pinus sylvestris* L.) wood. There is no previous study in the literature on the application of picture varnish to wood surfaces after thermal treatment. The color of wood is known to undergo significant changes due to thermal treatment. In an effort to protect wood from outdoor environmental impacts, various surface-applied chemicals are used. Such protective chemicals also play a role in modifying the color of thermally treated wood. This study investigates the color-changing effects of picture varnish (refined linseed oil), a preservation product commonly employed in artistic applications, on thermally treated and untreated wood. This study was conducted to fill the aforementioned research gap.

Materials and methods

1. Wood material

Scots pine (*Pinus sylvestris* L.) wood served as the principal experimental material in this study. The specimens, measuring 100 mm x 100 mm x 20 mm and of premium quality, were obtained from a commercial supplier. Subsequently, the materials underwent air-conditioning procedures as per the ISO 554 [1976] standard. The sapwood portions of the wood were used in the study.

2. Varnish

Picture varnish (refined linseed oil from the class of drying oils) was purchased in liquid form.

3. Thermal treatment

In the ThermoWood method, the thermal treatment of freshly cut or air-dried wood consists of three main stages. The first stage involves an increase in furnace temperature and drying at high temperatures. The furnace temperature is initially raised quickly to 100 °C using heat and steam, and then gradually increased to 130 °C for high-temperature drying. During this stage, the moisture content of the wood is reduced almost to 0% over a period of 14 to 30 h. The second stage is the thermal treatment phase, where the furnace temperature is increased to the desired treatment temperature, typically between 185 and 215 °C, over a period of 6 to 8 h. In this study, the samples were treated for 2 h at 212 °C. Steam is introduced into the furnace to prevent damage to the wood. The final stage is cooling and conditioning, during which the temperature of the wood is reduced to 50–60 °C using a water spraying system. The process continues until the moisture content of the wood reaches between 4% and 6%. The cooling and conditioning stages take between 24 and 30 h, depending on the width and thickness of the wood. The total process duration for ThermoWood is approximately 50 to 80 h [Aytin 2013].

4. Application of varnish to wood surfaces

Using a brush, picture varnish (refined linseed oil) was applied in a single layer to both untreated (control) and thermally treated wood.

5. Color parameter and whiteness index (WI^*) measurements

The BDY-1 Whiteness Meter was employed to measure the whiteness index (WI^*) in both parallel and perpendicular directions relative to the wood fibers. The assessment was carried out in accordance with ASTM E313-15e1 [2015]. Color changes in the samples were measured using a CS-10 device (CHN Spec, China) with a CIE 10° standard observer and a CIE D65 light source, utilizing an 8/d (8°/diffuse illumination) configuration as specified in ASTM D 2244-3 [2007]. The analysis was performed using the CIELAB color model, and total color variation was calculated using the relevant formulas:

$$\Delta a^* = [a^*_{\text{treated sample}}] - [a^*_{\text{untreated sample}}] \tag{1}$$

$$\Delta L^* = [L^*_{\text{treated sample}}] - [L^*_{\text{untreated sample}}] \tag{2}$$

$$\Delta b^* = [b^*_{\text{treated sample}}] - [b^*_{\text{untreated sample}}] \tag{3}$$

$$\Delta E^* = [(\Delta L^*)^2 + (\Delta b^*)^2 + (\Delta a^*)^2]^{1/2} \tag{4}$$

$$C^* = [(a^*)^2 + (b^*)^2]^{1/2} \tag{5}$$

$$\Delta C^* = [C^*_{\text{treated sample}}] - [C^*_{\text{untreated sample}}] \tag{6}$$

$$h^o = \arctan\,[b^*/a^*] \tag{7}$$

$$\Delta H^* = [(\Delta E^*)^2 - (\Delta L^*)^2 - (\Delta C^*)^2]^{1/2} \tag{8}$$

ΔH^*: Signifies variations in hue angle or shading.
Δa^*: Positive values indicate a more pronounced red tone than the reference, whereas negative values indicate a greener hue.
ΔL^*: Positive values indicate a lighter shade than the reference, while negative values indicate a darker shade.
Δb^*: Positive values indicate a shift toward increased yellowness compared with the reference, while negative values indicate increased blueness [Lange 1999].
ΔC^*: Represents changes in chroma or saturation. Positive values of ΔC^* indicate increased vibrancy and luminance relative to the reference, while samples with negative values exhibit lower vividness and distinctiveness than the reference.

The total color change values (ΔE^*) were interpreted according to the criteria specified by Barański et al. [2017] as listed in Table 1.

Table 1. Color change criteria, after Barański et al. [2017]

Degree of color change	▶	ΔE* value
Invisible color change	▶	$\Delta E^* < 0.20$
Slight change of color	▶	$2.00 > \Delta E^* > 0.20$
Color change visible in high filter	▶	$3.00 > \Delta E^* > 2.00$
Color change visible with average quality of filter	▶	$6.00 > \Delta E^* > 3.00$
High color change	▶	$12.00 > \Delta E^* > 6.00$
Different color	▶	$\Delta E^* > 12.00$

6. Statistical analysis

This study employed SPSS software to calculate a range of parameters including maximum and minimum values, groups with similar characteristics, analysis of variance, percentage changes (%), standard deviations, multivariate coefficients of variation, and average outcomes.

Results and discussion

The total color differences after the treatments, calculated using the color formulas, are given in Table 2. The ΔE^* value in Scots pine wood after heat treatment was calculated as 33.63 (Table 2). The natural color of wood is determined by chromophores found in lignin and extractives. During heat treatment, the degradation of hemicelluloses generates additional chromophores in wood, leading to changes in its color [Nemeth et al. 2016].

All operations resulted in negative ΔL^* values (darker than the reference). The application of varnish to the non-heat-treated sample resulted in positive Δa^*, Δb^*, and ΔC^* values (indicating, respectively, a more reddish, more yellow, and more vivid, brighter appearance than the reference) (Table 2).

The application of varnish to the heat-treated sample resulted in a positive Δa^* value (indicating a more reddish appearance than the reference), while the Δb^* and ΔC^* values were found to be negative (indicating a more bluish and duller, more blurry appearance than the reference) (Table 2).

Interpreting the results based on the color change criteria [Barański et al. 2017], it was found that on varnish application, both heat-treated and non-heat-treated samples underwent a "high color change" ($12 > \Delta E^* > 6$). However, with heat treatment (without varnish), the samples satisfied the criterion for "different color" ($\Delta E^* > 12$). These results are shown in Table 2.

Figure 1 shows images of the experimental samples pre-thermal treatment, post-thermal treatment, without thermal treatment but with picture varnish application, and with both thermal treatment and picture varnish application.

Results of analysis of variance for the L^* parameter (Table 3) indicate significant effects for heat treatment (A), picture varnish application (B), and their interaction (AB) (Table 3).

The measurement results for the L^* parameter are provided in Table 4. A decrease of 41.99% was observed after thermal treatment. Additionally, decreases in L^* values were observed when varnish was applied, both in samples subjected to thermal treatment and in those without thermal treatment (respectively: 22.67% and 7.70%). The highest L^* values were observed in the samples without heat treatment or varnish (77.94), and

Table 2. Results for total color differences

Thermal modification	Picture varnish	ΔL* ▼	Δa* ▼	Δb* ▼	ΔC* ▼	ΔH* ▼	ΔE* ▼	Degree of color change [Barański et al. 2017]
No	Yes	–6.00	2.07	10.08	10.28	0.42	11.91	B
Yes	Yes	–10.25	1.07	–4.75	–3.47	3.40	11.34	B
Thermal modification result		–32.74	6.47	4.14	6.24	4.48	33.63	A

A: Different color ($\Delta E^* > 12$); B: High color change ($12 > \Delta E^* > 6$)

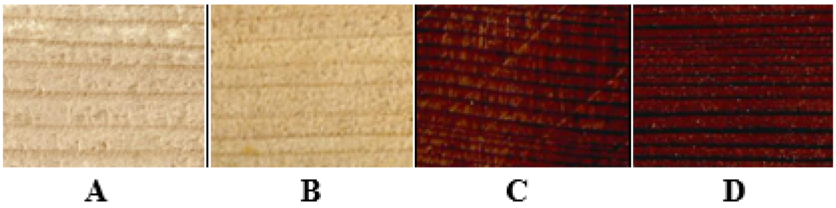

Fig. 1. Control (A), control + picture varnish (B), thermal modification (C), and thermal modification + picture varnish (D)

Table 3. Analysis of variance results for the L* parameter

Source	Sum of squares	Degree of freedom	Mean square	F value	Sig.
Heat treatment (A)	12151.150	1	12151.150	56106.329	0.000*
Varnish application (B)	660.075	1	660.075	3047.809	0.000*
Interaction (AB)	45.008	1	45.008	207.817	0.000*
Error	7.797	36	0.217		
Total	145170.386	40			
Corrected total	12864.029	39			

*: significant

Table 4. Measured results for the L* parameter

Thermal modification	Picture varnish application	Mean	Change (%)	Homo-geneity group	Standard deviation	Minimum	Maximum	Coefficient of variation
No	No	77.94	↓7.70	A*	0.64	76.97	79.02	0.82
No	Yes	71.94		B	0.44	71.30	72.65	0.61
Yes	No	45.21	↓22.67	C	0.49	43.98	45.64	1.09
Yes	Yes	34.96		D**	0.15	34.60	35.18	0.44

Each group consisted of 10 measurements. *: highest value, **: lowest value

Table 5. Analysis of variance results for the a* parameter

Source	Sum of squares	Degree of freedom	Mean square	F value	Sig.
Heat treatment (A)	355.932	1	355.932	3535.705	0.000*
Varnish application (B)	24.524	1	24.524	243.609	0.000*
Interaction (AB)	2.500	1	2.500	24.834	0.000*
Error	3.624	36	0.101		
Total	3366.346	40			
Corrected total	386.579	39			

*: significant

the lowest in the samples with both heat treatment and varnish (34.96) (Table 4). Decreases in *L** values indicate results shifting towards 0, representing black, and away from 100, representing white.

The results of analysis of variance for the *a** parameter (Table 5) show that the effects of heat treatment (A), picture varnish application (B), and their interaction (AB) are significant.

The measurement results for the *a** parameter are given in Table 6. All Δ*a** values were determined to be positive. The lowest *a** value was found in the samples without heat treatment or picture varnish (4.62), and the highest in the samples with both heat treatment and varnish (12.15). Heat treatment produced a 140.04% increase in this parameter. In samples without heat treatment, the application of picture varnish resulted in a 44.59% increase, while in heat-treated samples the increase was 9.66% (Table 6).

Table 7 presents the results of analysis of variance for the *b** parameter, showing significant effects from heat treatment (A), picture varnish application (B), and their interaction (AB).

The measurement results for the *b** parameter are given in Table 8. Heat treatment caused a 24.07% increase in the *b** value. When picture varnish was applied to samples without heat treatment, a 58.60% increase was observed, while the application of varnish to the surface of heat-treated materials led to a 22.26% decrease. The highest *b** value was recorded for the samples without heat treatment and with picture varnish (27.28), and the lowest for the samples with both heat treatment and picture varnish (16.59) (Table 8).

Table 9 gives the results of analysis of variance for the *C** parameter, highlighting the significant effects of heat treatment (A), picture varnish application (B), and their interaction (AB).

The measured results for the *C** parameter are given in Table 10. With heat treatment, a 34.75% increase in the *C** parameter was recorded. Additionally, a 57.72% increase was observed in samples without heat treatment but with picture varnish, while a 14.43% decrease was detected in the samples with both heat treatment and picture varnish. The lowest *C** value was found in the samples without heat treatment or picture varnish (17.81), and the highest in the samples without heat treatment but with picture varnish (28.09) (Table 10).

The results of analysis of variance for the *h*° parameter (Table 11) indicate that heat treatment (A), picture varnish application (B), and their interaction (AB) had significant effects.

The results of the measurements of the *h*° parameter are given in Table 12. A reduction of 16.59% was

Table 6. Measured results for the a* parameter

Thermal modification	Picture varnish application	Mean	Change (%)	Homogeneity group	Standard deviation	Minimum	Maximum	Coefficient of variation
No	No	4.62	↑44.59	D**	0.20	4.31	4.87	4.25
No	Yes	6.68		C	0.34	6.19	7.35	5.11
Yes	No	11.08	↑9.66	B	0.40	10.02	11.47	3.65
Yes	Yes	12.15		A*	0.29	11.80	12.54	2.38

Each group consisted of 10 measurements. *: highest value, **: lowest value

Table 7. Analysis of variance results for the b* parameter

Source	Sum of squares	Degree of freedom	Mean square	F value	Sig.
Heat treatment (A)	107.158	1	107.158	528.344	0.000*
Varnish application (B)	71.102	1	71.102	350.571	0.000*
Interaction (AB)	549.452	1	549.452	2709.079	0.000*
Error	7.301	36	0.203		
Total	17710.649	40			
Corrected total	735.013	39			

*: significant

observed due to the heat treatment. Additionally, the application of varnish to the non-heat-treated sample resulted in an increase of 1.63%, while its application to the heat-treated sample caused a decrease of 14.02%. The lowest *h*° value (53.79) was obtained for the heat-treated sample with varnish, and the highest (76.22) for the non-heat-treated sample with varnish (Table 12).

Table 13 presents the results of analysis of variance for the whiteness index (*WI**) measured in a perpendicular (⊥) direction relative to the fibers. These results show that heat treatment (A), picture varnish application (B), and their interaction (AB) all had significant effects.

The results of the measurements of whiteness index (*WI**) perpendicular (⊥) to the fibers are shown in Table 14. The value of this index decreased with the application of varnish (by 28.44% for non-heat-treated samples and 48.85% for heat-treated samples). The highest *WI** value in the direction perpendicular

Table 8. Measured results for the b* parameter

Thermal modification	Picture varnish application	Mean	Change (%)	Homogeneity group	Standard deviation	Minimum	Maximum	Coefficient of variation
No	No	17.20	↑58.60	C	0.43	16.61	17.96	2.49
No	Yes	27.28		A*	0.64	25.94	28.16	2.35
Yes	No	21.34	↓22.26	B	0.41	20.31	21.86	1.91
Yes	Yes	16.59		D**	0.23	16.25	17.02	1.38

Each group consisted of 10 measurements. *: highest value, **: lowest value

Table 9. Analysis of variance results for the C* parameter

Source	Sum of squares	Degree of freedom	Mean square	F value	Sig.
Heat treatment (A)	4.109	1	4.109	20.494	0.000*
Varnish application (B)	115.804	1	115.804	577.615	0.000*
Interaction (AB)	472.931	1	472.931	2358.916	0.000*
Error	7.218	36	0.200		
Total	21078.402	40			
Corrected total	600.062	39			

*: significant

Table 10. Measured results for the C* parameter

Thermal modification	Picture varnish application	Mean	Change (%)	Homogeneity group	Standard deviation	Minimum	Maximum	Coefficient of variation
No	No	17.81	↑57.72	D**	0.44	17.16	18.51	2.46
No	Yes	28.09		A*	0.57	26.97	28.92	2.03
Yes	No	24.04	↓14.43	B	0.52	22.65	24.56	2.16
Yes	Yes	20.57		C	0.12	20.42	20.76	0.60

Each group consisted of 10 measurements. *: highest value, **: lowest value

Table 11. Analysis of variance results for the h° parameter

Source	Sum of squares	Degree of freedom	Mean square	F value	Sig.
Heat treatment (A)	3039.444	1	3039.444	5097.533	0.000*
Varnish application (B)	142.582	1	142.582	239.128	0.000*
Interaction (AB)	249.400	1	249.400	418.276	0.000*
Error	21.465	36	0.596		
Total	182429.126	40			
Corrected total	3452.891	39			

*: significant

Table 12. Measured results for the h° parameter

Thermal modification	Picture varnish application	Mean	Change (%)	Homo-geneity group	Standard deviation	Minimum	Maximum	Coefficient of variation
No	No	75.00	↑1.63	B	0.53	74.46	76.11	0.71
No	Yes	76.22		A*	0.92	74.17	77.13	1.21
Yes	No	62.56	↓14.02	C	0.58	61.69	63.73	0.92
Yes	Yes	53.79		D**	0.96	52.34	55.05	1.78

Each group consisted of 10 measurements. *: highest value, **: lowest value

Table 13. Analysis of variance results for whiteness index (WI*) ⊥ values

Source	Sum of squares	Degree of freedom	Mean square	F value	Sig.
Heat treatment (A)	6919.530	1	6919.530	28349.048	0.000*
Varnish application (B)	573.806	1	573.806	2350.862	0.000*
Interaction (AB)	110.556	1	110.556	452.945	0.000*
Error	8.787	36	0.244		
Total	23179.650	40			
Corrected total	7612.680	39			

*: significant

to the fibers was found in the non-heat-treated and non-varnished sample (38.33), and the lowest in the heat-treated and varnished sample (4.45). Furthermore, a reduction of 77.30% in *WI** values in the direction perpendicular to the fibers was found to occur due to the heat treatment (Table 14).

Table 15 shows the results of analysis of variance for the whiteness index (*WI**) measured parallel (‖) to the fibers. Based on these findings, heat treatment (A), picture varnish application (B), and their interaction (AB) were found to have significant effects.

The results for whiteness index (*WI**) measured parallel (‖) to the fibers are given in Table 16. Reductions in *WI** values parallel to the fibers were observed with the application of varnish (by 39.27% for non-heat-treated samples and 56.58% for heat-treated samples).

Table 14. Results for whiteness index (WI*) measured perpendicular (⊥) to the fibers

Thermal modification	Picture varnish application	Mean	Change (%)	Homo-geneity group	Standard deviation	Minimum	Maximum	Coefficient of variation
No	No	38.33	↓28.44	A*	0.75	37.20	39.10	1.96
No	Yes	27.43		B	0.57	26.70	28.10	2.07
Yes	No	8.70	↓48.85	C	0.26	8.00	8.90	3.02
Yes	Yes	4.45		D**	0.14	4.30	4.60	3.04

Each group consisted of 10 measurements. *: highest value, **: lowest value

Table 15. Analysis of variance results for whiteness index (WI*) ‖ values

Source	Sum of squares	Degree of freedom	Mean square	F value	Sig.
Heat treatment (A)	7363.082	1	7363.082	31417.679	0.000*
Varnish application (B)	536.556	1	536.556	2289.442	0.000*
Interaction (AB)	417.962	1	417.962	1783.411	0.000*
Error	8.437	36	0.234		
Total	16919.730	40			
Corrected total	8326.038	39			

*: significant

Table 16. Results for whiteness index (WI*) measured parallel (‖) to the fibers

Thermal modification	Picture varnish application	Mean	Change (%)	Homo-geneity group	Standard deviation	Minimum	Maximum	Coefficient of variation
No	No	35.12	↓39.27	A*	0.48	34.30	35.50	1.37
No	Yes	21.33		B	0.83	20.50	22.50	3.91
Yes	No	1.52	↓56.58	C	0.08	1.40	1.60	5.19
Yes	Yes	0.66		D**	0.05	0.60	0.70	7.82

Each group consisted of 10 measurements. *: highest value, **: lowest value

The highest WI^* value in this direction was found in the non-heat-treated and non-varnished sample (35.12), and the lowest in the heat-treated and varnished sample (0.66). Additionally, a reduction of 95.67% in the WI^* value in the direction parallel to the fibers was found to occur due to the heat treatment (Table 16).

Conclusions

1. After the heat treatment, the ΔE^* value for Scots pine wood was calculated as 33.63.
2. In the heat-treated samples, applying varnish led to an increase in a^* values, but to a decrease in WI^* values in both directions, as well as decreases in h^o, L^*, b^*, and C^* values.
3. For both non-heat-treated and heat-treated samples, the varnish treatment resulted in negative ΔL^* values and positive Δa^* values.
4. Moreover, the Δb^* and ΔC^* values were positive for the non-heat-treated and varnished samples, but negative for the heat-treated and varnished samples.

Conflict of interest

The author(s) declare(s) that there is no conflict of interest concerning the publication of this article.

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