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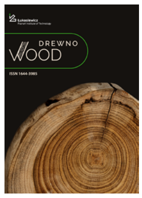

Analysis of the Impact of Blue Stain on the Color, Glossiness, and Whiteness Properties of Scots Pine Lumber

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It is known that blue stain causes a loss of price value for Scots pine wood in the wood trade due to the visual defects it creates. In this study, color parameters [red color tone (a*), lightness (L*) value, yellow (b*) color tone, tone angle (h°) value, and chroma (C*) value], whiteness index (WI*) values, and glossiness measurements [at angles of 20°, 60°, and 85°] were compared in Scots pine (*Pinus sylvestris* L.) wood with normal and blue rot conditions. According to the color parameters obtained, it was determined that the L* value decreased by 11.43%, a* by 79.95%, b* by 28.86%, and C* by 32.75%, while the h° value increased by 17.74%. With the blue coloration, decreases were observed in the 20° glossiness values measured in the ‖ and ⊥ directions, while increases were observed in the 60° and 85° glossiness values measured in the ‖ and ⊥ directions. With the blue coloration, decreases of 12.86% in the ⊥ direction and 29.87% in the ‖ direction in the WI* values were observed. According to these results, it was determined that the wood material with the blue coloration disease had a darker color.

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Introduction

Wood is an important construction material, but its widespread use is hindered by its susceptibility to biological decay and deterioration [Myronycheva et al. 2025]. Wood color changes are mainly caused by fungi that produce pigments [Zink and Fengel 1989; Humar et al. 2008].

Some fungi cause only color changes in wood, while others also lead to structural degradation over time. Blue stain is commonly found in coniferous trees like Scots pine (*Pinus sylvestris* L.), but can also appear in broadleaf trees, though less frequently [Millers et al. 2017].

Blue stain is caused by dark-colored fungal hyphae that penetrate the sapwood and create visible discoloration [Scheffer 1973; Das 2005]. Blue stain fungi do not affect the mechanical strength of wood, but they significantly reduce its aesthetic value [Şanıvar and Zorlu 1980].

Blue stain reduces the aesthetic quality of wood, appearing during harvesting when fungal spores enter

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the wood through cuts, branch pruning, or trunk damage [Szewczyk et al. 2020]. It is primarily caused by fungi from the *Ophiostoma* and *Ceratocystis* genera, which produce a bluish-gray discoloration as their melanized hyphae colonize the sapwood [Harrington 2005].

Wood with intact bark is less affected by blue stain fungi than wood with bark defects. These fungi enter the heartwood through damaged bark, causing infection. Blue stain appears as wedge-shaped streaks on the trunk, and in some cases it can spread throughout the entire heartwood, even becoming visible from the round end of the wood. Stacked timber is more susceptible to infection, as the fungi spread rapidly once settled [Millers et al. 2017].

Although blue-stained pine does not exhibit a significant decrease in physical strength, it is advisable for aesthetic reasons that any such wood be painted. It is not recommended for use with natural-colored varnishing or on the exterior parts of buildings [Şanıvar and Zorlu 1980].

Blue stain can appear at any stage during production, storage, or transportation, or even in the finished product when the necessary conditions (humidity, air, and temperature) are met. It can also appear in standing trees or logs. Blue stain, also known as heartwood stain, is the most economically important discoloration, affecting both hardwood and softwood species. While the heartwood may have inherent resistance to the fungus causing the stain, its presence significantly reduces the saleability and price of the timber due to the altered appearance. A natural finish cannot be applied to blue-stained timber, making it less appealing to most consumers [Shupe et al. 2008].

Blue stain fungi have been reported to have no significant impact on the durability of wood. Furthermore, they have been reported to alter the wood's visual characteristics and lead to significant reductions in lumber prices [Savory et al. 1965]. *Ophiostoma clavatum* was identified as a key fungal associate of *Ips acuminatus*, which invaded *Pinus sylvestris* L. in Sweden [Mathiesen 1951; Linnakoski et al. 2016].

Earlier research has indicated that fungi influence the overall color change in wood and wood-based materials [Gorbushina et al. 1993; Gierlinger et al. 2004; Humar et al. 2008; Okino et al. 2015; Hernandez et al. 2016; Sunardi et al. 2018; Akçay 2020; Nandika et al. 2020; 2021; Wang et al. 2022; Sofiaturizkiyah and Priadi 2023; Yin et al. 2023].

This study investigated changes in color, gloss, and whiteness properties of Scots pine wood with a blue stain. It is known that blue-stained wood significantly impacts sales conditions in the wood industry.

Materials and methods

The test specimens, including both normal and blue-stain-affected Scots pine (*Pinus sylvestris* L.) wood, were cut into pieces measuring 100 mm x 100 mm x 20 mm. The experimental samples were selected from visually flawless materials (without cracks, knots, or discolorations) and were characterized by straight grain and uniform texture and density.

In the study, the wood materials were arranged into 10 samples per group. These materials were purchased from a private lumber dealer in Bayburt province. The average density of the purchased wood was determined to be approximately 590 kg/m^3. Care was taken to ensure that the samples had uniform density and color characteristics. This selection helps reveal the blue coloration. The samples were conditioned according to ISO 554 [1976] standards at 20±2°C and 65% relative humidity.

On wood materials, gloss tests were determined according to the ISO 2813 [1994] standard, whiteness index (*WI**) tests were determined according to the ASTM E313-15e1' [2015] standard, and color parameters were determined according to the ASTM S 2244-3 [2007] standard.

Table 1. Some important information about color parameters

Δa^*, ΔL^*, Δb^*, and ΔC^* values [Lange, 1999]	**In negative condition**		**Parameter**	**In positive case**
	Bluer than reference		◄ Δb^* ►	Yellower than reference
	Darker than reference		◄ ΔL^* ►	Lighter than reference
	Matte, more blurred than reference		◄ ΔC^* ►	Clearer, brighter than reference
	Greener than reference		◄ Δa^* ►	Redder than reference
Criteria for ΔE^* [DIN 5033, 1979]	**Color difference**	**ΔE* difference**	**Color difference**	**ΔE* difference**
	Not perceptible	<0.2	Very noticeable	3.0 - 6.0
	Very weak	0.2 - 0.5	Strong	6.0 - 12.0
	Weak	0.5 - 1.5	Very strong	> 12.0
	Noticeable	1.5 - 3.0		

The overall color difference results were computed using the following formulas:

$$\Delta L^* = (L^*_{\text{Sample with blue rot}}) - (L^*_{\text{Normal test sample}}) \quad (1)$$

$$\Delta C^* = (C^*_{\text{Sample with blue rot}}) - (C^*_{\text{Normal test sample}}) \quad (2)$$

$$h^o = \arctan\,(b^*/a^*) \quad (3)$$

$$\Delta E^* = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{0.5} \quad (4)$$

$$\Delta a^* = (a^*_{\text{Sample with blue rot}}) - (a^*_{\text{Normal test sample}}) \quad (5)$$

$$\Delta b^* = (b^*_{\text{Sample with blue rot}}) - (b^*_{\text{Normal test sample}}) \quad (6)$$

$$\Delta H^* = [(\Delta E^*)^2 - (\Delta L^*)^2 - (\Delta C^*)^2]^{0.5} \quad (7)$$

$$C^* = [(a^*)^2 + (b^*)^2]^{0.5} \quad (8)$$

The change in chroma (ΔC^*) reflects the difference in saturation, while ΔH^* indicates the shift in hue or shade. Explanations of these parameters [Lange 1999] and interpretation criteria for ΔE^* [DIN 5033, 1979] are presented in Table 1.

The statistical analysis was conducted using specialized statistical software, and included the calculation of mean values, homogeneity groups, standard deviations, maximum and minimum values, variance analysis, and percentage changes.

Results and discussion

Data for the color parameters, whiteness index (WI^*) values (in all directions), and glossiness values (in all degrees and directions) measured in the study are presented in Table 2.

Table 2. Measurement results for the color parameters, glossiness values and, whiteness index values (One-Way Anova)

Test	Condition of Timber	Mean	Change (%)	SD	Minimum	Maximum	COV
L^*	Normal test sample	73.23	↓11.43	1.40	70.77	75.93	1.91
	Sample with blue rot	64.86		1.49	62.80	66.58	2.30
a^*	Normal test sample	8.03	↓79.95	0.39	7.60	8.84	4.82
	Sample with blue rot	1.61		0.09	1.40	1.75	5.70
b^*	Normal test sample	24.22	↓28.86	1.03	23.10	26.02	4.25
	Sample with blue rot	17.23		0.39	16.58	17.80	2.23
C^*	Normal test sample	25.68	↓32.75	1.14	24.30	27.44	4.42
	Sample with blue rot	17.27		0.40	16.60	17.87	2.29
h^o	Normal test sample	71.77	↑17.74	0.29	71.20	72.24	0.41
	Sample with blue rot	84.50		0.24	84.12	84.83	0.28
⊥20°	Normal test sample	0.68	↓8.82	0.08	0.60	0.80	11.12
	Sample with blue rot	0.62		0.04	0.60	0.70	6.52
⊥60°	Normal test sample	2.84	↑25.70	0.12	2.60	3.00	4.33
	Sample with blue rot	3.57		0.23	3.00	3.80	6.56
⊥85°	Normal test sample	0.10	↑190.00	0.00	0.10	0.10	0.00
	Sample with blue rot	0.29		0.14	0.10	0.50	48.92
‖20°	Normal test sample	0.73	↓8.22	0.05	0.70	0.80	6.44
	Sample with blue rot	0.67		0.05	0.60	0.70	6.75
‖60°	Normal test sample	3.56	↑16.85	0.09	3.50	3.70	2.64
	Sample with blue rot	4.16		0.09	4.10	4.30	2.23
‖85°	Normal test sample	0.56	↑171.43	0.08	0.50	0.70	13.76
	Sample with blue rot	1.52		0.38	0.50	1.90	25.32
⊥WI^*	Normal test sample	32.36	↓12.86	0.68	31.00	33.60	2.10
	Sample with blue rot	28.20		0.51	27.00	28.80	1.82
‖WI^*	Normal test sample	22.23	↓29.87	1.07	21.00	23.70	4.81
	Sample with blue rot	15.59		0.37	15.10	16.20	2.34

SD: Standard deviation, COV: Coefficient of variation, Number of measurements: 50

It was also observed that with blue rot in Scots pine wood, the lisghtness (L^*) value decreased by 11.43% from 73.23 to 64.86, the red (a^*) color tone value decreased by 79.95% from 8.03 to 1.61, the yellow (b^*) color tone value decreased by 28.86% from 24.22 to 17.23 and the chroma (C^*) value decreased by 32.75% from 25.68 to 17.27, while the h^o value increased by 17.74% from 71.77 to 84.50 (Table 2).

When the glossiness values obtained from wooden materials with and without blue rot were examined, it was observed that the data at 20 degrees decreased by 8.82% from 0.68 to 0.62 in the ⊥ direction and by 8.22% from 0.73 to 0.67 in the ‖ direction. At 60° glossiness values, increases of 16.85% in the ‖ direction and 25.70% in the ⊥ direction were found. In addition, at 85° glossiness values, increases of 171.43% in the ‖ direction and 190.00% in the ⊥ direction were found. (Table 2).

It was also determined that WI^* values decreased by 12.86% from 32.36 to 28.20 in the ⊥ direction and by 29.87% from 22.23 to 15.59 in the ‖ direction (Table 2).

The measurements obtained are an indication of the changes that occur on the optical properties of the wood material.

The photographs in Table 3 illustrate the visual appearance of normal and blue-stained Scots pine samples, showing differences in surface color and glossiness.

Color differences were calculated using the formulas given in the materials and methods section, and these results are shown in Table 3. They show that the ΔL^* value was found to be –8.37, the ΔC^* value –8.36, the Δa^* value –6.42, the ΔH^* value 4.40, and the Δb^* value –6.99. Based on the information provided in Table 1, since the Δb^* value is negative, the sample is classified as "bluer than reference" (Table 3).

The negative ΔL^* value indicates "darker than reference," the negative ΔC^* value suggests "matte, more blurred than reference," and the negative Δa^* value indicates "greener than reference." In addition, the ΔE^* value calculated using the formulas was found to be 12.65. When this result is compared with the color change criteria [DIN 5033, 1979], it is seen that it corresponds to the "very strong (> 12.0)" criterion (Table 3).

It has been reported in the literature that the b^* value is transformed into a smaller molecular structure than that of cell wall structures such as lignin, cellulose and hemicellulose, and that the L^* and a^* parameters are affected by the phenol structure of the extractive substances of wood [Gierlinger et al. 2004; Moya et al. 2012; Sunardi et al. 2018].

In a study conducted by Akçay [2020], it was reported that changes in color parameters were obtained in Scots pine wood exposed to Trametes versicolor and *Neolentinus lepideus* fungi (decrease in a^* parameter and increase in b^* and L^* parameters). In these changes, the ΔE^* value was calculated as 18.70 for *Trametes* versicolor and 15.63 for *Neolentinus lepideus*.

In a study conducted by Gierlinger et al. [2004], after investigating the conditions between the extractive substances of the larch heartwood and brown rot, it was reported that the a^* parameter found to be high in the wood used in the study was related to the high value of decay and the high phenolic structure.

Several factors have been reported to influence the development of blue staining. These factors include the

Table 3. Summary of the results of the experimental samples used in the study

Image of Normal Test Samples				Image of Test Samples with Blue Rot		
L^*	73.73	►		◄	L^*	64.86
a^*	8.03	►		◄	a^*	1.61
b^*	24.22	►		◄	b^*	17.23
C^*	25.68	►		◄	C^*	17.17
h^o	71.77	►		◄	h^o	84.50
⊥20°	0.60	►		◄	⊥20°	0.60
⊥60°	2.70	►		◄	⊥60°	3.50
⊥85°	0.10	►		◄	⊥85°	0.10
‖20°	0.70	►		◄	‖20°	0.60
‖60°	3.50	►		◄	‖60°	4.10
‖85°	0.50	►		◄	‖85°	1.50
⊥WI^*	31.60	►		◄	⊥WI^*	27.30
‖WI^*	21.20	►		◄	‖WI^*	15.10
	ΔL^* →		-8.37	ΔC^* →		-8.40
	Δa^* →		-6.42	ΔH^* →		4.40
	Δb^* →		-6.99	ΔE^* →		12.65
Color Change Criteria [DIN 5033, 1979] for ΔE^* → Very strong (> 12.0)						

Table 4. Results of Variance Analysis

Variance	Test	Mean Square	df	F	Sig.	α≤0.05
Factor	Lightness (*L**)	1750.753	1	1750.753	838.077	0.000*
	Red (*a**) colour tone	1029.640	1	1029.640	13024.646	0.000*
	Yellow (*b**) colour tone	1219.965	1	1219.965	2020.099	0.000*
	Chroma (*C**)	1765.512	1	1765.512	2441.424	0.000*
	Hue (*h*°) angle	4051.959	1	4051.959	56464.576	0.000*
	Glossiness at ⊥20°	0.090	1	0.090	24.500	0.000*
	Glossiness at ⊥60°	13.396	1	13.396	381.841	0.000*
	Glossiness at ⊥85°	0.884	1	0.884	89.014	0.000*
	Glossiness at ‖20°	0.090	1	0.090	42.080	0.000*
	Glossiness at ‖60°	8.880	1	8.880	1017.632	0.000*
	Glossiness at ‖85°	22.848	1	22.848	296.371	0.000*
	*WI** perpendicular (⊥)	434.306	1	434.306	1199.793	0.000*
	*WI** parallel (‖)	1102.904	1	1102.904	1728.972	0.000*
Error	Lightness (*L**)	204.723	98	2.089		
	Red (*a**) colour tone	7.747	98	0.079		
	Yellow (*b**) colour tone	59.184	98	0.604		
	Chroma (*C**)	70.869	98	0.723		
	Hue (*h*°) angle	7.033	98	0.072		
	Glossiness at ⊥20°	0.360	98	0.004		
	Glossiness at ⊥60°	3.438	98	0.035		
	Glossiness at ⊥85°	0.973	98	0.010		
	Glossiness at ‖20°	0.210	98	0.002		
	Glossiness at ‖60°	0.855	98	0.009		
	Glossiness at ‖85°	7.555	98	0.077		
	*WI** perpendicular (⊥)	35.474	98	0.362		
	*WI** parallel (‖)	62.514	98	0.638		
Total	Lightness (*L**)	478654.585	100			
	Red (*a**) colour tone	3356.965	100			
	Yellow (*b**) colour tone	44225.908	100			
	Chroma (*C**)	47953.943	100			
	Hue (*h*°) angle	614618.384	100			
	Glossiness at ⊥20°	42.700	100			
	Glossiness at ⊥60°	1045.960	100			
	Glossiness at ⊥85°	5.620	100			
	Glossiness at ‖20°	49.580	100			
	Glossiness at ‖60°	1501.240	100			
	Glossiness at ‖85°	138.980	100			
	*WI** perpendicular (⊥)	92157.620	100			
	*WI** parallel (‖)	36928.010	100			
Corrected Total	Lightness (*L**)	1955.476	99			
	Red (*a**) colour tone	1037.387	99			
	Yellow (*b**) colour tone	1279.149	99			
	Chroma (*C**)	1836.381	99			
	Hue (*h*°) angle	4058.992	99			
	Glossiness at ⊥20°	0.450	99			
	Glossiness at ⊥60°	16.834	99			
	Glossiness at ⊥85°	1.856	99			
	Glossiness at ‖20°	0.300	99			
	Glossiness at ‖60°	9.736	99			
	Glossiness at ‖85°	30.404	99			
	*WI** perpendicular (⊥)	469.780	99			
	*WI** parallel (‖)	1165.418	99			

***: Significant**

wood's own structure and its environmental environment. Additionally, the wood's pH level, oxygen level, and nutrient content have also been reported to influence blue staining [Darma 2006; Octavia and Wantini 2017; Sofiaturizkiyah and Priadi 2023].

In their study, Humar et al. [2008] exposed Scots pine sapwood (*Pinus sylvestris*) samples to two different types of blue spot fungi (*Sclerophoma pithyophila* and *Aureobasidium pullulans*) for 8 weeks using the EN 113 (1996) standard. Decreases in L^*, a^* and b^* values were reported in the results measured at the end of exposure, and in addition, ΔE^* values were calculated as 27.40 for *Sclerophoma pithyophila* and 15.40 for *Aureobasidium pullulans* at the end of exposure.

Blue stain fungi do not affect the mechanical properties of wood, but they have been reported to significantly impair the surface aesthetics of wood products, thereby greatly reducing their added value [Humar et al. 2008].

Color change on the wood surface generally occurs as a result of biological, chemical, and physical processes. In particular, blue stain fungi (such as *Ophiostoma* species) settle in the cell lumens and tracheids of the wood and produce dark-colored pigments similar to melanin.

Spalted wood, which features pigments created by fungal activity, has been used for hundreds of years by artisans to improve the appearance of wooden products [Blanchette et al. 1992; Hernandez et al. 2016].

The variance analysis tests performed using the data measured in the study are given in Table 4, and according to these results, it was determined that lightness (L^*), red (a^*) color tone, yellow (b^*) color tone, chroma (C^*), hue (h^o) angle, glossiness values (in all degrees and directions) and whiteness index (WI^*: ⊥ and ∥) values were obtained as significant (Table 4).

Conclusions

This study found that the h^o value, a color parameter, increased in both blue-rot-affected and non-blue-rot-affected Scots pine wood, while other color parameters and WI^* values in both directions decreased.

Decreases in gloss measurements at 20 degrees were observed, while increases in gloss values at other gloss levels (60 and 85) were observed. The results indicate that the wood's decorative appearance alters its visual quality and causes it to cool. This study confirmed that changes in the optical properties of wood with blue-rot were observed.

We recommend that different surface treatments be researched and developed to prevent these negative situations identified for this tree species selected in the study and to increase its marketability for wood processing industries.

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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