



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

Ümit Ayata<sup>a\*</sup>   
Hüseyin Peker<sup>b</sup>   
Göksel Ulay<sup>c</sup>   
Osman Çamlıbel<sup>d</sup>   
Abdi Atılğan<sup>e</sup>

<sup>a</sup> Department of Interior Architecture and Environmental Design, Faculty of Arts and Design, Bayburt University, Bayburt, Turkey

<sup>b</sup> Department of Forest Industrial Engineering, Artvin Çoruh University, Artvin, Turkey

<sup>c</sup> Department of Furniture and Decoration, Van Yuzuncu Yil University, Van, Turkey

<sup>d</sup> Department of Interior Design, Kirikkale University, Kirikkale, Turkey

<sup>e</sup> Department of Materials Processing Technology, Afyon Kocatepe University, Afyonkarahisar, Turkey

### Article info

Received: 12 May 2025

Accepted: 14 July 2025

Published: 22 April 2026

### Keywords

blue stain

Scots pine

*Pinus sylvestris* L.

color parameters

whiteness index

glossiness

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 ( $h^\circ$ ) value, and chroma ( $C^*$ ) value], whiteness index ( $WI^*$ ) values, and glossiness measurements [at angles of  $20^\circ$ ,  $60^\circ$ , and  $85^\circ$ ] 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  $h^\circ$  value increased by 17.74%. With the blue coloration, decreases were observed in the  $20^\circ$  glossiness values measured in the  $\parallel$  and  $\perp$  directions, while increases were observed in the  $60^\circ$  and  $85^\circ$  glossiness values measured in the  $\parallel$  and  $\perp$  directions. With the blue coloration, decreases of 12.86% in the  $\perp$  direction and 29.87% in the  $\parallel$  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.

DOI: 10.53502/wood-208267

This is an open access article under the CC BY 4.0 license:

<https://creativecommons.org/licenses/by/4.0/deed.en>.

### 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

\* Corresponding author: [umitayata@yandex.com](mailto:umitayata@yandex.com)

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; Li et al. 2005; 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; Sofiatuzriyah 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<sup>3</sup>. 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 (*WT\**) 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

$\Delta a^*$ , $\Delta L^*$ , $\Delta b^*$ , and $\Delta C^*$ values [Lange, 1999]	In negative condition		Parameter	In positive case
		Bluer than reference		◀ $\Delta b^*$ ▶
	Darker than reference		◀ $\Delta L^*$ ▶	Lighter than reference
	Matte, more blurred than reference		◀ $\Delta C^*$ ▶	Clearer, brighter than reference
	Greener than reference		◀ $\Delta a^*$ ▶	Redder than reference
Criteria for $\Delta E^*$ [DIN 5033, 1979]	Color difference	$\Delta E^*$ difference	Color difference	$\Delta E^*$ 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:

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

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

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

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

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

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

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

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

The change in chroma ( $\Delta C^*$ ) reflects the difference in saturation, while  $\Delta H^*$  indicates the shift in hue or shade. Explanations of these parameters [Lange 1999] and interpretation criteria for  $\Delta E^*$  [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 ( $WT^*$ ) 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		1.40	70.77	75.93	1.91
	Sample with blue rot	64.86	↓11.43	1.49	62.80	66.58	2.30
$a^*$	Normal test sample	8.03		0.39	7.60	8.84	4.82
	Sample with blue rot	1.61	↓79.95	0.09	1.40	1.75	5.70
$b^*$	Normal test sample	24.22		1.03	23.10	26.02	4.25
	Sample with blue rot	17.23	↓28.86	0.39	16.58	17.80	2.23
$C^*$	Normal test sample	25.68		1.14	24.30	27.44	4.42
	Sample with blue rot	17.27	↓32.75	0.40	16.60	17.87	2.29
$h^\circ$	Normal test sample	71.77		0.29	71.20	72.24	0.41
	Sample with blue rot	84.50	↑17.74	0.24	84.12	84.83	0.28
$\perp 20^\circ$	Normal test sample	0.68		0.08	0.60	0.80	11.12
	Sample with blue rot	0.62	↓8.82	0.04	0.60	0.70	6.52
$\perp 60^\circ$	Normal test sample	2.84		0.12	2.60	3.00	4.33
	Sample with blue rot	3.57	↑25.70	0.23	3.00	3.80	6.56
$\perp 85^\circ$	Normal test sample	0.10		0.00	0.10	0.10	0.00
	Sample with blue rot	0.29	↑190.00	0.14	0.10	0.50	48.92
$\parallel 20^\circ$	Normal test sample	0.73		0.05	0.70	0.80	6.44
	Sample with blue rot	0.67	↓8.22	0.05	0.60	0.70	6.75
$\parallel 60^\circ$	Normal test sample	3.56		0.09	3.50	3.70	2.64
	Sample with blue rot	4.16	↑16.85	0.09	4.10	4.30	2.23
$\parallel 85^\circ$	Normal test sample	0.56		0.08	0.50	0.70	13.76
	Sample with blue rot	1.52	↑171.43	0.38	0.50	1.90	25.32
$\perp WT^*$	Normal test sample	32.36		0.68	31.00	33.60	2.10
	Sample with blue rot	28.20	↓12.86	0.51	27.00	28.80	1.82
$\parallel WT^*$	Normal test sample	22.23		1.07	21.00	23.70	4.81
	Sample with blue rot	15.59	↓29.87	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 lightness ( $L^*$ ) 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  $h^\circ$  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  $\perp$  direction and by 8.22% from 0.73 to 0.67 in the  $\parallel$  direction. At 60° glossiness values, increases of 16.85% in the  $\parallel$  direction and 25.70% in the  $\perp$  direction were found. In addition, at 85° glossiness values, increases of 171.43% in the  $\parallel$  direction and 190.00% in the  $\perp$  direction were found. (Table 2).

It was also determined that  $WT^*$  values decreased by 12.86% from 32.36 to 28.20 in the  $\perp$  direction and by 29.87% from 22.23 to 15.59 in the  $\parallel$  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  $\Delta L^*$  value was found to be -8.37, the  $\Delta C^*$  value -8.36, the  $\Delta a^*$  value -6.42, the  $\Delta H^*$  value 4.40, and the  $\Delta b^*$  value -6.99. Based on the information provided in Table 1,

since the  $\Delta b^*$  value is negative, the sample is classified as “bluer than reference” (Table 3).

The negative  $\Delta L^*$  value indicates “darker than reference,” the negative  $\Delta C^*$  value suggests “matte, more blurred than reference,” and the negative  $\Delta a^*$  value indicates “greener than reference.” In addition, the  $\Delta E^*$  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  $\Delta E^*$  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
$h^\circ$	71.77	▶		◀	$h^\circ$	84.50
$\perp 20^\circ$	0.60	▶		◀	$\perp 20^\circ$	0.60
$\perp 60^\circ$	2.70	▶		◀	$\perp 60^\circ$	3.50
$\perp 85^\circ$	0.10	▶		◀	$\perp 85^\circ$	0.10
$\parallel 20^\circ$	0.70	▶		◀	$\parallel 20^\circ$	0.60
$\parallel 60^\circ$	3.50	▶		◀	$\parallel 60^\circ$	4.10
$\parallel 85^\circ$	0.50	▶		◀	$\parallel 85^\circ$	1.50
$\perp WT^*$	31.60	▶		◀	$\perp WT^*$	27.30
$\parallel WT^*$	21.20	▶		◀	$\parallel WT^*$	15.10
$\Delta L^* \rightarrow$	-8.37			$\Delta C^* \rightarrow$	-8.40	
$\Delta a^* \rightarrow$	-6.42		$\Delta H^* \rightarrow$	4.40		
$\Delta b^* \rightarrow$	-6.99		$\Delta E^* \rightarrow$	12.65		
Color Change Criteria [DIN 5033, 1979] for $\Delta E^* \rightarrow$ Very strong (> 12.0)						

Table 4. Results of Variance Analysis

Variance	Test	Mean Square	df	F	Sig.	$\alpha \leq 0.05$
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 ( $h^\circ$ ) angle	4051.959	1	4051.959	56464.576	0.000*
	Glossiness at $\perp 20^\circ$	0.090	1	0.090	24.500	0.000*
	Glossiness at $\perp 60^\circ$	13.396	1	13.396	381.841	0.000*
	Glossiness at $\perp 85^\circ$	0.884	1	0.884	89.014	0.000*
	Glossiness at $\parallel 20^\circ$	0.090	1	0.090	42.080	0.000*
	Glossiness at $\parallel 60^\circ$	8.880	1	8.880	1017.632	0.000*
	Glossiness at $\parallel 85^\circ$	22.848	1	22.848	296.371	0.000*
	$WI^*$ perpendicular ( $\perp$ )	434.306	1	434.306	1199.793	0.000*
$WI^*$ parallel ( $\parallel$ )	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 ( $h^\circ$ ) angle	7.033	98	0.072		
	Glossiness at $\perp 20^\circ$	0.360	98	0.004		
	Glossiness at $\perp 60^\circ$	3.438	98	0.035		
	Glossiness at $\perp 85^\circ$	0.973	98	0.010		
	Glossiness at $\parallel 20^\circ$	0.210	98	0.002		
	Glossiness at $\parallel 60^\circ$	0.855	98	0.009		
	Glossiness at $\parallel 85^\circ$	7.555	98	0.077		
	$WI^*$ perpendicular ( $\perp$ )	35.474	98	0.362		
$WI^*$ parallel ( $\parallel$ )	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 ( $h^\circ$ ) angle	614618.384	100			
	Glossiness at $\perp 20^\circ$	42.700	100			
	Glossiness at $\perp 60^\circ$	1045.960	100			
	Glossiness at $\perp 85^\circ$	5.620	100			
	Glossiness at $\parallel 20^\circ$	49.580	100			
	Glossiness at $\parallel 60^\circ$	1501.240	100			
	Glossiness at $\parallel 85^\circ$	138.980	100			
	$WI^*$ perpendicular ( $\perp$ )	92157.620	100			
$WI^*$ parallel ( $\parallel$ )	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 ( $h^\circ$ ) angle	4058.992	99			
	Glossiness at $\perp 20^\circ$	0.450	99			
	Glossiness at $\perp 60^\circ$	16.834	99			
	Glossiness at $\perp 85^\circ$	1.856	99			
	Glossiness at $\parallel 20^\circ$	0.300	99			
	Glossiness at $\parallel 60^\circ$	9.736	99			
	Glossiness at $\parallel 85^\circ$	30.404	99			
	$WI^*$ perpendicular ( $\perp$ )	469.780	99			
$WI^*$ parallel ( $\parallel$ )	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; Sofiatuzkiyah 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,  $\Delta E^*$  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 ( $h^\circ$ ) angle, glossiness values (in all degrees and directions) and whiteness index ( $WI^*$ :  $\perp$  and  $\parallel$ ) values were obtained as significant (Table 4).

## Conclusions

This study found that the  $h^\circ$  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.

## References

- Akçay C. [2020]: Determination of decay, larvae resistance, water uptake, color, and hardness properties of wood impregnated with honeybee wax, *BioResources*. 15(4), 8339-8354. DOI: 10.15376/biores.15.4.8339-8354.
- Blanchette R. A., Wilmering A. M., Baumeister M. [1992]: The use of green-stained wood caused by the fungus *Chlorociboria* in intarsia masterpieces from the 15<sup>th</sup> century, 46(3), 225. DOI: 10.1515/hfsg.1992.46.3.225
- Budakçi M., Korkmaz M., Karal I. [2023]: Antifungal effects of staining process on wood: Hardness, gloss, and color change, *BioResources* 18(1), 302-316. DOI: 10.15376/biores.18.1.302-316
- Darma I. G. K. T. [2006]: Blue stain sebagai perusak warna kayu pinus (*Pinus merkusii* Jung et de Vriese).
- Das N.C. [2005]: Blue stain of timber and its prevention, *Forestry and Wood*, Course Title: Project Work Course No: Fwt-5114, Forestry and Wood Technology Discipline, Khulna University, Khulna.
- Gierlinger N., Jacques D., Grabner M., Wimmer R., Schwanninger M., Rozenberg P., Pâques L. E. [2004]: Colour of larch heartwood and relationships to extractives and brown-rot decay resistance. *Trees*, 18, 102-108. DOI: 10.1007/s00468-003-0290-y.
- Gorbushina A. A., Krumbein W. E., Hamman C. H., Panina L., Soukharjevski S., Wollenzien U. [1993]: Role of black fungi in color change and biodeterioration of antique marbles, *Geomicrobiology Journal* 11(3-4), 205-221. DOI: 10.1080/01490459309377952
- Harrington T. C. [2005]: Ecology and evolution of mycophagous bark beetles and their fungal partners, In F.E. Vega and M. Blackwell (Eds.), *Ecological and Evolutionary Advances in Insect-Fungal Associations* (pp. 257-291). Oxford University Press.
- Hernandez V. A., Galleguillos F., Robinson S. [2016]: Fungal pigments from spaltung fungi attenuating blue stain in *Pinus* spp. *International Biodeterioration & Biodegradation*, 107, 154-157. DOI: 10.1016/j.ibiod.2015.11.020

- Hiller C. H., Freese F., Smith D. M.** [1972]: Relationships in black walnut heartwood between colour and other physical and anatomical characteristics. *Wood Fiber* 4: 38-42
- Humar M., Vek V., Bučar B.** [2008]: Properties of blue-stained wood. *Drvna Industrija*, 59(2), 75-79.
- Konica Minolta**, [1998]: Sensing Americas Inc, Comunicação precisa da cor. 57, p.
- Lange D. R.** [1999]: Fundamentals of Colourimetry – Application, Report No. 10e. DR Lange: New York, NY, USA.
- Linnakoski R., Jankowiak R., Villari C., Kirisits T., Solheim H., de Beer Z. W., Wingfield M. J.** [2016]: The *Ophiostoma clavatum* species complex: a newly defined group in the *Ophiostomatales* including three novel taxa. *Antonie van Leeuwenhoek*, 109, 987-1018. DOI: 10.1007/s10482-016-0700-y.
- Mathiesen A.** [1951]: Einige neue Ophiostoma-Arten in Schweden *Sven Bot Tidskr*, 45, 203-232.
- Mesquita R. R. S. D.** [2023]: Comportamento de madeiras tropicais submetidas ao intemperismo artificial e natural, Universidade De Brasília, Faculdade De Tecnologia, Departamento De Engenharia Florestal, Tese De Doutorado.
- Millers M., Magaznieks J., Gzibovska Z.** [2017]: Blue stain development of Scots pine [*Pinus sylvestris* L.] roundwood and its influencing factors. *Research for Rural Development*, 1, 120-126. DOI: 10.22616/rrd.23.2017.018.
- Moya R., Fallas R. S., Bonilla P. J., Tenorio C.** [2012]: Relationship between wood color parameters measured by the CIELab system and extractive and phenol content in *Acacia mangium* and *Vochysia guatemalensis* from fast-growth plantations. *Molecules*, 17(4), 3639-3652. DOI: 10.3390/molecules17043639.
- Myronycheva O., Kim I., Karlsson O., Kiurcheva L., Jacobsson P., Sandberg D.**, [2025]: Evaluation of the antifungal efficiency of coatings on wood. *Wood Science and Technology*, 59(1), 12. DOI: 10.1007/s00226-024-01614-6.
- Nandika D., Darmawan W., Karlinasari L., Hadi Y. S., Abdillah I. B., Hiziroglu S.** [2020]: Evaluation of color change and biodeterioration resistance of gewang (*Corypha utan* Lamk.) wood, *Applied Sciences* 10(21), 7501. DOI: 10.3390/app10217501
- Nandika D., Arinana A., Salman, A. B. A., Putri J. Y.** [2021]. Morphological and molecular features of stain fungi infecting rubberwood (*Hevea brasiliensis*). *Biodiversitas Journal of Biological Diversity*, 22(12), 5408-5416. DOI: 10.13057/biodiv/d221223
- Nelson N.D., Heather W.A.** [1972]: Wood color, basic density, and decay resistance in heartwood of fast-grown *Eucalyptus grandis* Hill ex Maiden. *Holzforschung* 26(2), 54-60 DOI: 10.1515/hfsg.1972.26.2.54.
- Octavia A., Wantini S.** [2017]: Comparison of *Aspergillus flavus* Fungus Growth In PDA Media (*Potato Dextrose Agar*) and Alternative Media from Cassava (*Manihot esculenta* Crantz). *Jurnal Analis Kesehatan*, 6(2), 625-631.
- Okino E. Y. A., Pastore T. C. M., Camargos J. A. A., Coradin V. T. R., Teixeira D. E., Santana M. A. E., Fagg C. W.** [2015]: Accelerated laboratory test of three Amazonian wood species called tauari, exposed to white- and brown-rot fungi and color response according to CIE L\* A\* B\* system, *Ciência Florestal*, 25(3), 581-593. DOI: 10.5902/1980509819609.
- Şanivar N., Zorlu İ. [1980]: Ağaçışleri Gereç Bilgisi Temel Ders Kitabı, Mesleki Ve Teknik Öğretim Kitapları, Milli Eğitim Basımevi, İstanbul, Turkey, Etüd ve Programlama dairesi yayınları No: 43, 472 sayfa.
- Savory J. G., Pawsey R. G., Lawrence, J. S.** [1965]: Prevention of blue-stain in unpeeled Scots pine logs: (With 2 Plates). *Forestry*, 38(1), 59-81. DOI: 10.1093/forestry/38.1.59.
- Scheffer T. C.** [1973]: Wood Deterioration and its Prevention, pp. 73-74.
- Shupe T., Lebow S., Ring D.** [2008]: Causes and control of wood decay, degradation & stain, Pub. (Louisiana Cooperative Extension Service) - 2703. [Baton Rouge, La.]: Louisiana State University Agricultural Center, 26 pages, 2703.
- Sofiatuzrikizyah N., Priadi T.** [2023]: The blue stain attack and its effect on the mechanical properties of five light-colour woods. In *BIO Web of Conferences* (Vol. 77, p. 01007). EDP Sciences. DOI: 10.1051/bioconf/20237701007
- Sunardi S., Istikowati W. T., Ishiguri F., Yokota S.** [2018]: FTIR spectroscopy and color change of wood for assessment and monitoring of softwood degradation by white-rot fungus *Porodaedalea pini*. In *AIP Conference Proceedings* (Vol. 2026, No. 1). AIP Publishing. DOI: 10.1063/1.5064984
- Szewczyk G., Jankowiak R., Mitka B., Bożek P., Bilański P., Kulak D., Barycza A., Kunys G.** [2020]: Development of blue stain in mechanically harvested Scots pine [*Pinus sylvestris*] logs during storage. *Canadian Journal of Forest Research*, 50(1), 42-50. DOI: 10.1139/cjfr-2019-0112.
- Wang P., Cheng S., Cao S., Cai J.** [2022]: Evaluation of color changes, wettability, and moisture sorption of heat-treated blue-stained radiata pine lumber, *BioResources* 17(3), 4952-4961. DOI: 10.15376/biores.17.3.4952-4961
- Wilcox W.W., Piirto D.D.** [1976]: Decay resistance in redwood (*Sequoia sempervirens*) heartwood as related to color and extractives. *Wood and Fiber Science* 7: 240-245
- Yin H., Ringman R., Moghaddam M. S., Tuominen M., Dédinaité A., Wälinder M., Swerin A., Bardage S.** [2023]: Susceptibility of surface-modified superhydrophobic wood and acetylated wood to mold and blue stain fungi. *Progress in organic coatings*, 182, 107628. DOI: 10.1016/j.porgcoat.2023.107628
- Zink P., Fengel D.** [1989]: Studies on the coloring matter of blue-stain fungi. *Holzforschung*, 43, 371-374.

### List of standards

**ASTM D 2244-3:2007** Standard practice for calculation or color tolerances and color, differences from instrumentally measured color coordinates. ASTM International, West Conshohocken, PA

**ASTM E313-15e1:2015** Standard practice for calculating yellowness and whiteness indices from instrumentally measured color coordinates, ASTM International, West Conshohocken, PA.

**DIN 5033:1979** Deutsche Normen. Farbmessung, Normenausschuß Farbe (FNF) im DIN Deutsches Institut für Normung eV. Beuth, Berlin März.

**EN 113:1996** Wood preservatives. Test method for determining the protective effectiveness against wood destroying basidiomycetes. Determination of the toxic values, European Committee for Standardization, Brussels, Belgium.

**ISO 2813:1994** Paints and varnishes - determination of specular gloss of non-metallic paint films at 20 degrees, 60 degrees and 85 degrees, International Organization for Standardization, Geneva, Switzerland.

**ISO 554:1976** Standard atmospheres for conditioning and/or testing, International Standardization Organization, Geneva, Switzerland.