Original scientific paper
Received: 13.8.2025
Accepted: 27.8.2026
UDC: 674.032.475.4:535.653.3

COLOR VARIATION OF PINE HEARTWOOD AND SAPWOOD IN THE COLOR SPACE CIE L*A*B*

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ABSTRACT

The color of pine wood represents an important aesthetic and technological parameter that influences its use in furniture making and interior applications. The aim of this study was to determine the color of pine sapwood and heartwood in the color space CIE L*a*b* at 10% moisture content and to analyze the natural color variability. Measurements on samples from the Štiavnické vrchy locality showed that the lightness (L*) of sapwood averaged 78.5 ± 2.5, while heartwood had a value of 63.8 ± 3.6. On the red color coordinate (a*), values were 9.2 ± 1.6 for sapwood and 11.5 ± 1.8 for heartwood, while the yellow color (b*) was at levels of 19.5 ± 1.8 and 19.9 ± 1.6, respectively. The total color difference ΔE* was approximately 14.9, confirming a significant color heterogeneity between sapwood and heartwood. These results are crucial for optimizing the processing and application of pine wood in design and manufacturing.

Keywords: pine wood, sapwood, heartwood, wood color, color space CIE L*a*b*.

1. INTRODUCTION

Pine wood (genus *Pinus*) is among the most widely used coniferous woods in Europe and worldwide. It is known for its good technical properties, such as strength, workability, and a favourable price-performance ratio. However, the color of pine wood can vary significantly depending on the age of the tree, the part of the stem (sapwood vs. heartwood), the drying method, and the geographical and ecological origin. This color heterogeneity can cause problems in manufacturing processes where uniform appearance is required, such as in furniture, flooring, or panel production.

Wood color is an important aesthetic and technological property that influences its market acceptance, usability in specific applications, and the perceived value of final products. Consumers and designers often prefer materials with uniform color and minimal visual deviations. Consequently, color homogeneity becomes a key criterion when selecting wood species for interior and furniture purposes. Nevertheless, wood as a natural material exhibits significant intra- and interspecies color variability, which results from a combination of anatomical, physiological, and environmental factors. Wood color is one of the main criteria for assessing its quality, affecting how customers perceive wood products, especially in furniture, decorative products, veneers, and flooring; therefore, precise color matching of different samples is necessary (Torres *et al.* 2010). According to Abrahão (2005), color uniformity is extremely important in wood quality assessment because it determines the final appearance of the wooden product.

Color expression often involves a subjective experience dependent on the available light source, surface properties, and the individual observer's eye. To study color changes, it is necessary to measure color objectively. Objective color measurement is performed instrumentally, corresponding to visual evaluation, using spectrophotometers or colorimeters, and is numerically defined based on a standardized colorimetric calculation developed by the International Commission on Illumination (CIE) (Barański *et al.* 2017, 2020).

During processing, wood undergoes mechanical treatment such as drying or thermal modification, both of which significantly influence changes in its natural color and chemical composition (Gonzalez de Cademartori *et al.* 2013; Gonçalez *et al.* 2014; Barcík *et al.* 2015). Significant changes in wood structure occur when temperatures exceed 180 °C, while carbonization begins at 250 °C (Kačíková and Kačík 2011).

Instrumental methods for determining colorimetric parameters and color differences are in compliance with ISO standards. These standards include definitions of basic terms, requirements for colorimetric systems, fundamentals of colorimetric calculation, and guidelines for proper instrumental color measurement (Kazimierska 2014). Colorimetric measurement is valuable for quality control of wood and for evaluating the color of final wood products (Klement and Huráková 2015). The mechanism of wood color and its changes is a complex process influenced by various factors (Kudra *et al.* 2003; McCurdy *et al.* 2005; McDonald *et al.* 2010).

The aim of this study is to determine the color of dry pine sapwood and heartwood at moisture content w = 10% in the color space CIE L*a*b* and to analyze the natural color variability of pine wood.

2. MATERIALS AND WORK METHODS

The color measurement of pine wood without true heartwood was performed on pine wood from the Štiavnické vrchy locality (N48.40582° E18.85389°). From this locality, 30 pine logs were selected from which center lumber with dimensions of 50×300×1000 mm was produced in a quantity of 30 pieces.

To preserve the original wood color, the lumber was dried in a climate-controlled room at a temperature of t = 20°C and relative humidity φ = 60% to a moisture content of w = 10 ± 0.5%. The bearing surfaces of the dry lumber were machined on a horizontal planar milling machine, FS 200.

The color of pine wood in the color space CIE L*a*b* was measured using a Color Reader CR-10 colorimeter (Konica Minolta, Japan). A D65 light source was used, and the diameter of the optical measuring aperture was 8 mm. The colorimeter evaluates the color of pine wood using a three-axis system (Fig. 1), measuring the coordinates of lightness (L*) and chromaticity (a*, b*) in accordance with ISO 11664-2 (2007) and ISO 11664-4 (2008). The CIELAB color system recommended by the CIE consists of two axes with parameters a* and b*, placed at right angles to each other, which define the color shade. The third axis represents the lightness L*, perpendicular to the a* b* plane.

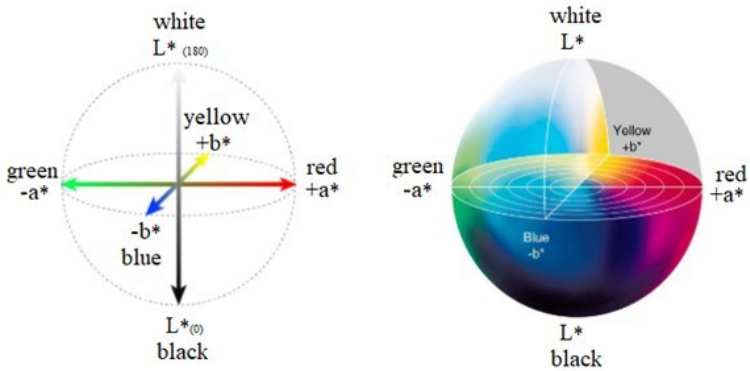


Figure 1. *Schematic of three-axis color change measurement system.*

The results of the measurements of lightness values L* and the values of the basic chromatic coordinates of red color a* and yellow color b* in the color space CIE L*a*b* are presented in the form of the mean value $\bar{x}$ and the standard deviation s_x.

$$x = \bar{x} \pm s_x\,[-] \qquad [1]$$

The degree of dispersion of the measured values is assessed (evaluated) by the coefficient of variation:

$$v_x = \frac{s_x}{\bar{x}} \cdot 100 \ [\%] \qquad [2]$$

Color differences in the CIE space can be straightforwardly determined by calculating their spatial distance, equal to the square root of the sum of the squares of differences for each of the three coordinates of the two compared colors, according to the relationship (in accordance with ISO 11664-4 (2008) and ISO 11664-6 (2022) standards,

$$\Delta E^* = \sqrt{(L_1 - L_2)^2 + (a_1 - a_2)^2 + (b_1 - b_2)^2} \quad [-] \qquad [3]$$

where ΔE* is the parameter determining the overall color change, ΔL* is the difference of the parameter determining the color change in the white-black direction, Δa* is the difference of the parameter determining the color change in the red-green direction, and Δb* is the difference of the parameter determining the color change in the yellow-blue direction.

3. RESULTS AND DISCUSSION

The color of pine wood on the cross-section is shown in Fig. 2a. Figures 2b–d show the color of pine wood on the planed surface of the lumber. According to visual evaluation, the color of pine sapwood is white with a yellowish tint, and the color of the heartwood is red-yellow with a higher resin content, which gives the wood a redder color.

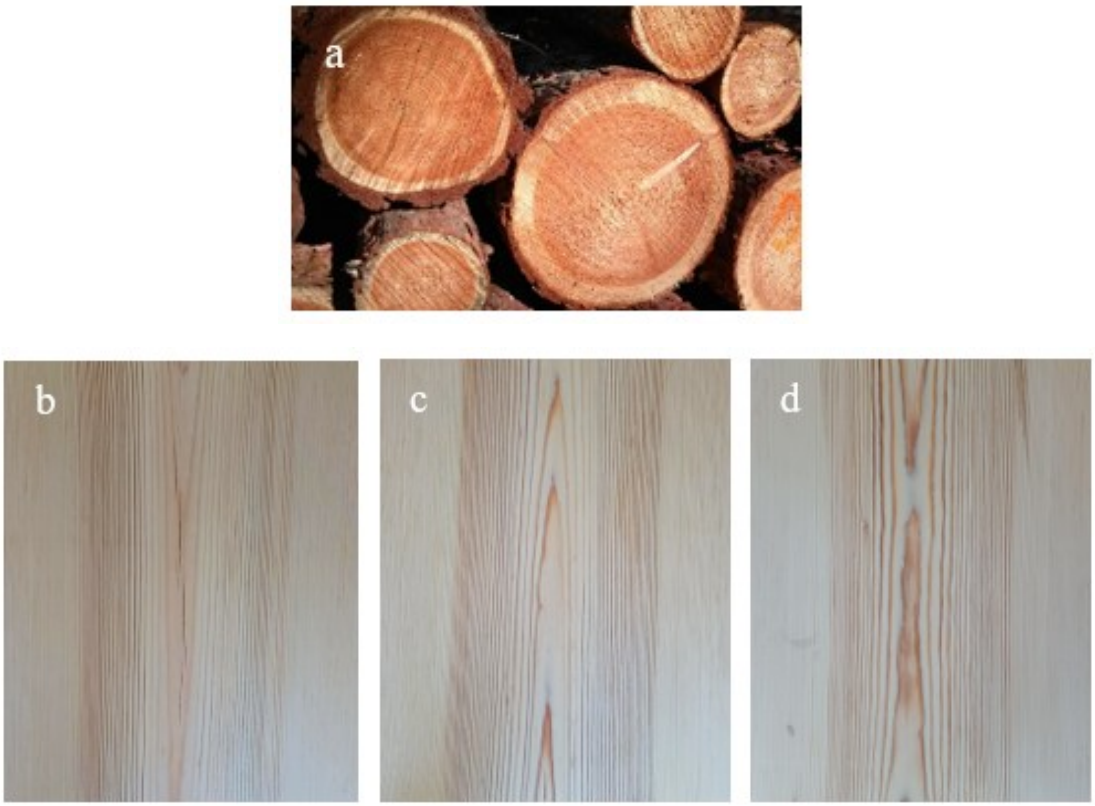


Figure 2. *Color of pine heartwood and sapwood on the cross-section of the log (a) and on the bearing surfaces of the lumber (b, c, d)*

The results of the statistical processing of the measured color values of sapwood and heartwood on the individual coordinates of the CIE Lab* color space are presented in Table 1 and Table 2.

Table 1. *Values in the CIE L*a*b* color space coordinates of pine sapwood*

Pine sapwood	Color coordinates CIE L*a*b*		
	L*	a*	b*
Number of measurements [-]	150	150	150
Measured value	78.5 ± 2.5	9.2 ± 1.6	19.5 ± 1.8
Standard deviation s_x [-]	2.5	1.6	1.8
Coefficient of variation v_x [%]	3.2	17.4	9.2

Table 2. *Values in the CIE L*a*b* color space coordinates of pine heartwood*

Pine heartwood	Color coordinates CIE L*a*b*		
	L*	a*	b*
Number of measurements [-]	150	150	150
Measured value	63.8 ± 3.6	11.5 ± 1.8	19.9 ± 1.6
Standard deviation s_x [-]	3.6	1.8	1.6
Coefficient of variation v_x [%]	5.7	15.7	8.0

The measured color values of sapwood and heartwood on the individual coordinates of the CIE Lab* color space were used to create a graphical representation for the results' visual assessment, which is shown in Fig. 3.

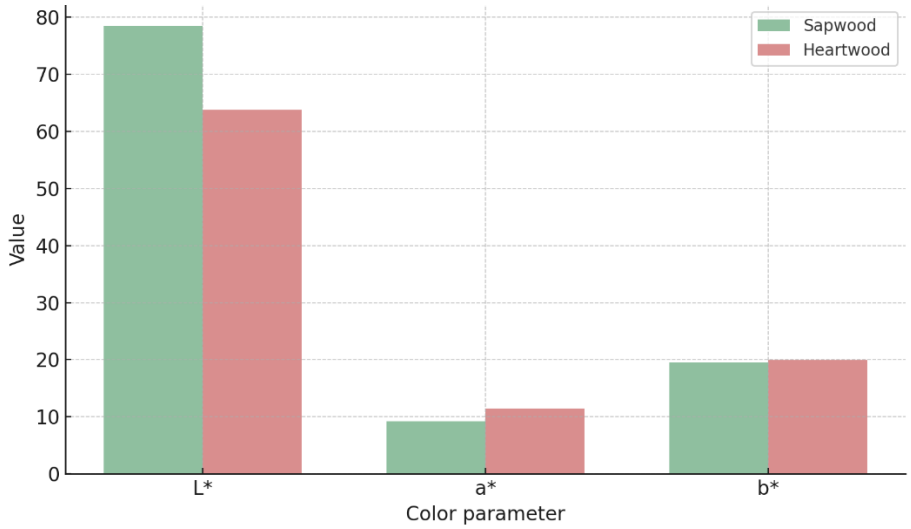


Figure 3. *Graphical representation of the measured color values of sapwood and heartwood pine wood on the coordinates of the color space CIE L*a*b**

Measurements showed that there are significant differences in the color parameters between pine heartwood and sapwood in the color space CIE L*a*b*. In lightness (L*), sapwood reached an average value of 78.5 ± 2.5, while heartwood had a value of 63.8 ± 3.6. The difference of 14.7 units means that sapwood appears visually much lighter, which is related to the lower content of colored extractives in the sapwood part.

On the red color coordinate (a*), sapwood had an average value of 9.2 ± 1.6, whereas heartwood reached 11.5 ± 1.8. The difference of 2.3 units shows that heartwood has a warmer, more reddish tone, which may be caused by a higher content of resins and color pigments in the heartwood. This parameter also had the highest relative variability, indicating significant deviations between individual samples.

On the yellow color coordinate (b*), sapwood was at 19.5 ± 1.8 and heartwood at 19.9 ± 1.6. The difference of 0.4 units is minimal and suggests that the yellow component of the color is very similar in both parts of the wood, playing no major role in visual differentiation.

To determine the overall visual distinction between sapwood and heartwood, the total color difference ΔE* was calculated. The resulting value of ΔE* ≈ 14.9 represents a very pronounced color difference, which is clearly recognizable by the naked eye even without direct side-by-side comparison of samples (Cividini et al. 2007). The high ΔE* value is mainly contributed by the difference in lightness (L*), to a lesser extent by the red tone (a*), and minimally by the yellow tone (b*).

These results confirm that the visual color heterogeneity between pine sapwood and heartwood is significant. When used in furniture making or interior cladding, these natural color differences must be considered and either avoided by selecting homogeneous material or deliberately used as a design element. It is also possible to eliminate this color heterogeneity to a single color shade by applying appropriate wood thermal modification technologies.

CONCLUSIONS

The study confirmed that the natural color variability of pine wood between sapwood and heartwood is significant and has a crucial impact on the aesthetic appearance and value of the final products. In furniture manufacturing and interior cladding, these differences must be taken into account, as they can either be eliminated by appropriate thermal modification technologies or deliberately used to create attractive designs. Precise colorimetric measurements in the CIE Lab* space represent an effective tool for quantifying and controlling color homogeneity of wood, thereby contributing to higher quality and customer satisfaction. Future research could focus on optimizing processing and surface treatments to minimize color differences or aesthetically utilize them.

ACKNOWLEDGMENTS

This paper was prepared within the grant project VEGA 1/0423/25 as the result of the work of the authors and the considerable assistance of the agencies.

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