https://doi.org/10.22320/s0718221x/2026.14

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Axial variation of color and Shore D hardness in *Cedrus libani* wood

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Abstract:
This study examines the limited understanding of axial variation in color and hardness properties of *Cedrus libani* wood. In this context, the variation in color parameters and Shore D hardness across heart, heartwood, and sapwood sections was systematically investigated. Wood disc samples obtained from different axial positions of a 102-year-old tree were used to evaluate color properties, including lightness (L*), redness (a*), and yellowness (b*), together with hardness values. A total of 480 measurements were conducted across the three anatomical sections. The results demonstrated that both color and hardness properties vary systematically along the axial direction of the tree. Sapwood exhibited higher lightness values, whereas heart and heartwood showed comparatively lower L* values. Redness was more pronounced in heartwood and heart sections, while yellowness values were relatively similar across sections, with slightly higher values observed in the heart. In terms of mechanical properties, Shore D hardness increased from sapwood toward the center of the tree, reaching its maximum in the heart section. Additionally, axial differences were evident, with upper sections displaying higher hardness values compared to lower sections. These findings provide new insights into the axial variation of physical and mechanical properties in *Cedrus libani* wood, contributing to a better understanding of its material behavior. This knowledge is important for optimizing utilization strategies and improving performance-based classification of wood depending on its position within the tree.

Keywords: Axial variation, *Cedrus libani*, radial variation, Shore D hardness, wood properties, wood color

Received: 22.10.2024
Accepted: 06.04.2026

Introduction

Türkiye forestland has many valuable timber tree species. *Cedrus libani* is significant from historical, cultural, aesthetic, scientific and economic perspectives. Also, *Cedrus libani* is an important timber species widely used in structural and engineered wood products. Its physical properties, particularly color and hardness, are critical for both aesthetic and mechanical performance (Özkan et al., 2025). It is presently found primarily in the Taurus Mountains of Türkiye (Boydak 2007).

Additionally, *Cedrus libani* forests cover an area of approximately 417,189 hectares, with a current timber volume of approximately 27.4 million m³ (Brooks et al. 2008). The Burdur-Bucak region is one of the most important areas where pure and natural cedar trees grow. Its unique location at the intersection of the Mediterranean and the Mediterranean transition zone, along with its distinctive climate and ecological characteristics, make this region an ideal habitat for the growth of the Lebanese cedar (Özçelik et al. 2023). Typically, it can reach a height of 35 m, and the diameter at breast height (DBH) is 1.3 m (Husch et al. 2002, Van Laar and Akça 2007). The specific gravity of wood in natural stands is 640 kg/m³ (Koman and Feher 2015, Saranpää 2003). The Lebanese cedar is a highly sought-after material for lumber and engineered wood products. It is characterized by medium density and a yellowish color, which are properties that influence its industrial value. However, it can vary from light yellow to light brownish-yellow, and growth rings are sometimes distinguishable by dark bands (Güleç et al. 2022, Pijut 2000). Furthermore, it is known that wood properties such as color and hardness are influenced by the anatomical location within the tree. To date, many studies have focused on the influence of growth conditions on lebanon cedar tree properties across Türkiye, given its general importance. However, the intra-tree variation of color parameters and hardness in *Cedrus libani* wood has not been quantitatively characterized. Wood color has always attracted much interest, given its close relationship with commercial value (İmal *et al.* 2024). Large-scale research on wood properties for a given species requires significant investments to collect samples and perform laboratory measurements. This reality has always been an impediment to research in this field. Most studies focus on a few sites and consequently, the scope of results is often narrow.

Previous studies on other species have shown a relationship between wood color and density. However, there appear to be few studies examining such relationships in *Cedrus libani*. Since environmental differences can influence wood properties, wood color, and tree growth, a relationship between these variables can be expected depending on the environment. Very few studies have been conducted on softwood and hardwood trees in temperate climates, and the results vary depending on the species. For example, while there is no evidence that the heartwood color of the eastern American black walnut (*Juglans nigra* L.) is genetically controlled, significant differences in wood color have been observed among families of sessile oak (*Quercus petraea* (Matt.) Liebl.). In another study, a significant negative correlation was reported between wood density and color (lightness) in the eastern black walnut (*Juglans nigra* L.) (Rink and Phelps 1989).

Anatomical differences within a tree, including variations in growth ring structure and tissue organization, can influence both optical properties and mechanical strength. In various tree species, it has been reported that growth ring width, earlywood width, latewood width, cell count, latewood radial cell diameter, and cell wall thickness decrease with latitude. However, no significant changes were observed in tracheid length or latewood proportion. Townshend et al. (2015) reported that longer fiber length is associated with more productive ecosystems that support faster growth. Additionally, anatomical differences within the tree, including variations in growth ring structure and tissue organization, can influence both optical properties and mechanical strength. However, spatial variation in the wood properties of the *Cedrus libani* has rarely been investigated, and existing results are often inconsistent. Furthermore, wood color has not been sufficiently studied as a functional trait of plants. Observations of other species indicate that there are differences among tree species and planting regions. If there is genetic variation in wood color, tree breeding programs can help respond to potential changes in market preferences. Additionally, genetic correlation estimates are necessary to assess whether selection based on tree growth and/or other commercially important traits significantly affects wood color. Therefore, analyzing traits within a single tree provides a controlled framework to distinguish structural and spatial effects from external variability, thereby eliminating the confounding influence of environmental factors and evaluating axial and radial variability.

This study focused on *Cedrus libani* growing naturally in Türkiye and investigated the spatial variation of cedar wood properties at different heights of the same tree. To analyze within-tree variation in a controlled and detailed manner, only samples from a single cedar tree were used. This method minimizes the influence of exogenous variables such as environmental conditions, age differences and inter-individual genetic variation, allowing a more accurate assessment of natural variation in the vertical and radial directions along the stem. This preliminary study was designed to test the validity of the measurement methods used and to provide a basis for more extensive future research involving multiple trees and various variables.

Material and methods

The tree species used in this study is *Cedrus libani*, which grows in the Mediterranean region of Türkiye, specifically at an elevation of 1464 m in the Burdur-Bucak forest area. The sample tree was selected for *Cedrus libani* from the Burdur-Bucak Forest Enterprise in Türkiye on lands owned by the General Directorate of Forestry. A map of the study area, where the *Cedrus libani* used in the study is located is shown in Figure 1.

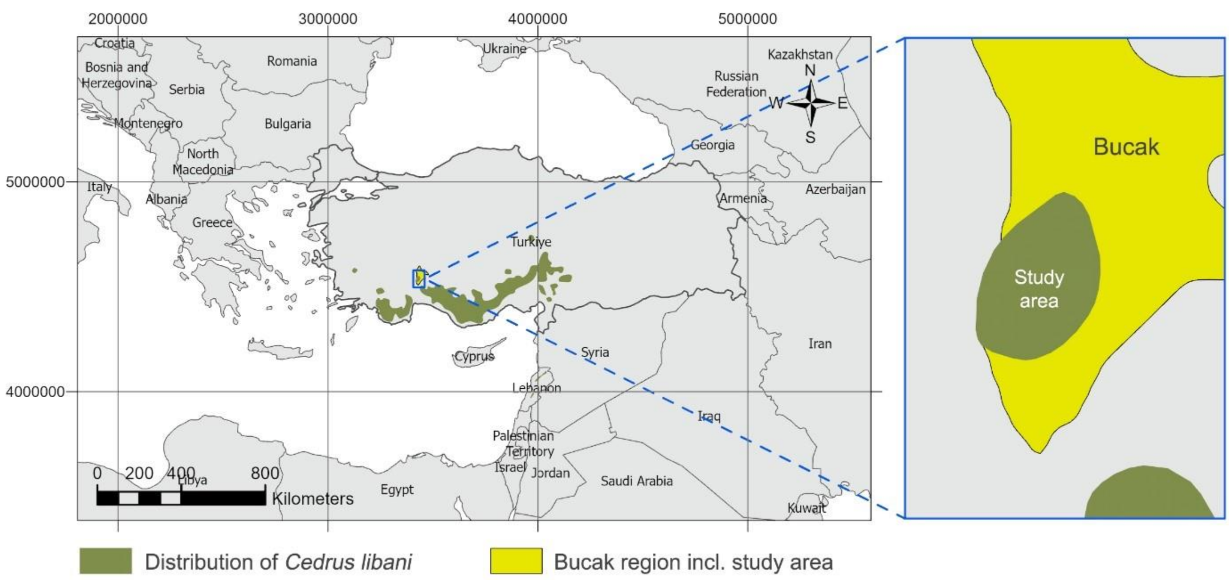

Figure 1: Map of the study area

The selected *Cedrus libani* tree was cut from the point closest to the ground. The first section was taken from a height of 0,30 m above the ground. Then, sections were taken from 1,30 m and at intervals of 2 m, such as 3,30 m; 5,30 m and 7,30 m as commonly used in many forestry models and analyses. The tree is 102 years old and is 14,8 meters total tree height. Since the tree height is 14,8 m, the last section was taken from a height of 13,55 m. Additionally, to obtain accurate results, the age of the tree and the annual ring counts were determined via the WinDENDRO program (Instruments 2012). An example disc image is provided in Figure 2 for reference in the use of the program.

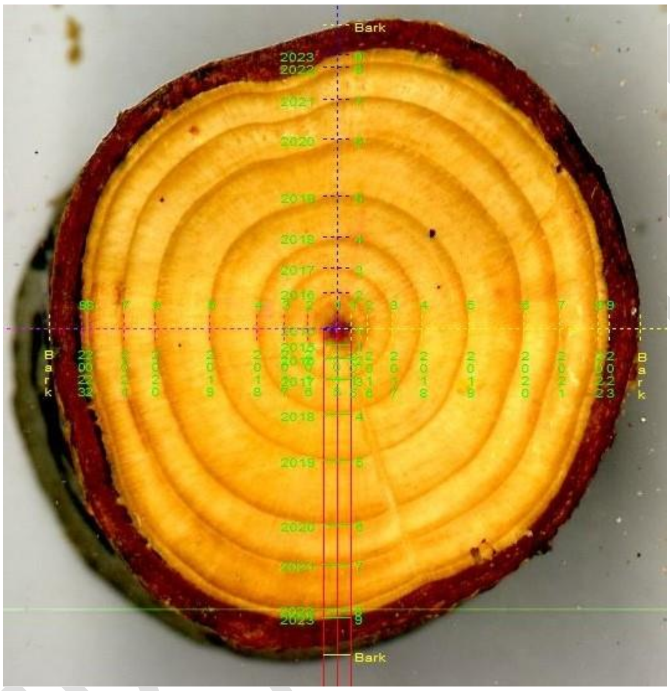

Figure 2: Reference disc image from the WinDENDRO program.

All wood samples were conditioned for 6 months at 12 % equilibrium moisture content in an air conditioning chamber at 20 ± 2 °C and 65 ± 5% relative humidity. This conditioning process was carried out to minimize moisture variations due to the hygroscopic properties of the wood material and to obtain comparable results for all specimens. Then, color and hardness analyses were conducted on the heart, heartwood and sapwood sections of the discs obtained from various heights of the tree. Eight different sections were taken from specified tree. In forestry research, diameter at breast height (DBH), measured at 1,30 meters above ground level, is one of the most readily available and reliable tree parameters. Therefore, it serves as a key variable in numerous modeling studies, including those aimed at estimating tree age, height, volume and other structural characteristics. Thus, considering their standard use in dendrochronological and biometric analyses, the disc in section 7, corresponding to a height of 1,30 meters, was chosen as a reference section as a control for the analyses. The general characteristics of the obtained discs and their cross-sectional heights are presented in Table 1. The sampling structure presented in Table 1 shows the axial positions of eight growth rings collected along the trunk of a single *Cedrus libani* tree, at heights ranging from 0.3 m to 13.55 m. Each disk corresponds to a specific axial level and contains information regarding annual ring characteristics. Measurements for each disk were performed separately for three anatomical sections: heartwood, sapwood, and heart. Color parameters (L*, a*, b*) and Shore D hardness were measured along these sections. Thus, the experimental design is based on the combination of axial position (disk level) and anatomical section, which enables the evaluation of variations in wood properties within the tree.

Table 1: General characteristics of Lebanon cedar trees used in the study.

Disc numbers	Disc height (m)	Annual rings (total)	Annual rings (per cm≅)
1	13,55	11	2
2	11,3	31	2
3	9,3	45	2
4	7,3	64	2
5	5,3	66	2
6	3,3	80	3
7 (control)	1,3	90	3
8	0,3	98	3

Color measurements

The color measurements of the wood discs are calculated automatically for the disc samples via the Commission Internationale d'Eclairage (CIE Lab* 1976) standard, which focuses on brightness/darkness (L*), redness/greenness (a*), yellowness/blueness (b*) and total color differences (ΔE_{ab}) via the following Equation 1, Equation 2, Equation 3 and Equation 4 (Hach Lange 2023).

$$L = f\left(\frac{Y}{Yn}\right) - 16 \qquad (1)$$

$$a = 500\left[f\left(\frac{X}{Xn}\right) - f\left(\frac{Y}{Yn}\right)\right] \qquad (2)$$

$$b = 200\ [f\left(\frac{Y}{Yn}\right) - f\left(\frac{Z}{Zn}\right) \qquad (3)$$

$$\Delta E_{ab} = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2} \qquad (4)$$

In the Equations, L represents the degree of brightness/darkness (a value between 0 and 100, where a lower number indicates greater darkness; 0 denotes black, while 100 represents perfect whiteness), an indicates the degree of redness (a+) or greenness (a-) and b denotes the degree of yellowness (b+) or blueness (b-). ΔE describes the total color difference as a combination of these factors. All calculations indicated in the above equations were automatically measured via an X-Rite 962 (Grand Rapids, Michigan) spectrophotometer with a 2 °C observer angle and standard light illumination (D65) at 6500 Kelvin (Kaytanlıoğlu *et al.* 2023, Şahin *et al.* 2023). Color measurements were made for each of the heart, heartwood and sapwood parts of the discs separately for 10 repetitions. Tables and graphs were prepared by averaging these data. A total of 240 measurements were taken on the whole tree for 8 discs, separately for the heart, heartwood and sapwood sections for each disc of the cedar tree.

Hue calculations

According to the CIE standard, a color can be described via Lab* values, as well as the hue angle (h°), which indicates the determination of primary color families such as red, blue and green for the measured object. The location of the measured value in color space (hue angle) can be used to describe the color of many objects (Hach Lange 2023). Hue calculations were performed via the following Equation 5:

$$h_{ab} = a\tan 2\left(b, a\right) \qquad (5)$$

Chroma calculations

Chroma is a term that expresses the saturation or vividness of a color. In color theory, chroma indicates how far a color is from gray; in other words, it specifies how intense and vibrant the pure form of a color is. Chroma calculations were performed via Equation 6 (Şahin *et al.* 2023).

$$C = \sqrt{a^2 + b^2} \qquad (6)$$

Hardness measurements

A Shore Hardness (Scale D) device (TH-210, Time Technology, China) was used to measure the hardness properties of wood disc samples. The tests were conducted in accordance with ASTM D2240 (2010) standards. This test allows for the measurement of initial hardness and indentation hardness after a specified period. The surface hardness of the wood samples was performed on the surface according to the anatomical regions of the wood. The three anatomical regions on each section were measured on the heart, heartwood and sapwood. A total of 10 measurements were taken from these regions in each cross-section sample and 240 measurements were made for a total of 8 discs when all samples were considered.

Results and discussion

Table 2 shows the lightness (L*) properties of the wood samples, which were collected from different heights (discs) of the same tree and three different sections in the same parts. When compared to the control sample, variability was observed in all sections and pieces (disc 7). These findings can be interpreted considering the known effects of growth variability and environmental factors on wood properties. Additionally, a continuous increase was observed from the control sample to disc 2.

However, the average lightness was 60,81 for the heart 61,85 for the heartwood and 66,65 for the sapwood. These findings suggest that the sapwood part of the tree has the greatest lightness, followed by the heartwood and heart of the cedar tree. In the case of the sampling heights of the obtained wood, the highest lightness values were found for disc 2 in all three sections: 70,94 for the heart, 71,18 for the heartwood and 69,68 for the sapwood. These values indicate lightness properties that are approximately 34,6 %, 31,5 % and 8,3 % greater than those of the control samples of heart, heartwood and sapwood, respectively. The decrease in lightness (L^*) values observed in section 1 for all wood parts is outside the general trend of increasing luminosity towards the upper parts of the tree. This variation may be associated with localized resin accumulation, variations in extractive content, or anatomical heterogeneity specific to this disc. However, these mechanisms remain speculative as they were not directly assessed. Particularly in coniferous species such as *Cedrus libani*, extractive-rich areas or blocked conduction tissues that cause a darker color in the lower part of the trunk may reduce the luminosity capacity, resulting in lower L^* values.

It should be noted that the findings presented in this study are based on axial variation observed within a single *Cedrus libani* tree. Therefore, the identified trends in color parameters and hardness should be interpreted within this specific context. While the results provide valuable insights into axial and radial variation in wood properties, they may not fully represent variability across different trees, sites, or environmental conditions. Consequently, broader generalizations should be made with caution, and further studies involving a larger number of samples are recommended to confirm these observations

Table 2: Lightness (L*) properties of samples.

Disc number	Heart	Heartwood	Sapwood
1	64,44 (±1,31)	67,88 (±1,16)	67,58 (±1,23)
2	70,94 (±0,23)	71,18 (±1,19)	69,68 (±0,98)
3	64,17 (±1,11)	65,08 (±1,77)	65,74 (±1,49)
4	62,95 (±1,26)	61,48 (±2,51)	66,93 (±2,07)
5	59,54 (±1,56)	61,33 (±1,23)	66,32 (±2,37)
6	59,58 (±0,54)	59,04 (±2,48)	66,75 (±1,28)
7 (control)	52,69 (±2,25)	54,13 (±3,27)	64,35 (±2,72)
8	52,15 (±0,97)	54,66 (±4,09)	65,85 (±1,38)
Average	60,81 (±5,87)	61,85 (±5,63)	66,65 (±1,46)

Table 3 shows the redness-greenness (a*) properties of the wood samples. The average a* values for heart, heartwood and sapwood were found to be 7,26; 7,44 and 6,50 respectively. However, the lowest a* values for all the measured samples were found with disc 2. The results presented above indicate that the color of the wood samples has become less red or greener. The highest a* values were found in different discs: disc 6 for heartwood (11.27), disc 7 for sapwood (9.70), and disc 1 for green wood (9.48). Regarding the redness-greenness (a*) parameter, the lower values observed in cross-section 2 compared to cross-section 1 may be associated with the presence of a transition zone where the boundary between heartwood and sapwood is not clearly defined. In such transition zones, the concentration of extractive substances such as phenolic compounds, which are effective in the formation of red hues, may be lower, leading to lower a* values. Furthermore, the decrease in a* values observed in section 8 in all wood sections compared to the control disk, section 7, can be explained. Since section 8 is closest to the lowest point of the tree, it may contain tissues that are structurally older but less metabolically active. In this case, the level of lignification may be high and the diversity of extractives low. This may contribute to reduced color saturation. It is also assumed that increased moisture content or mineral accumulation in this region, possibly due to its proximity to the root system, may influence wood color. However, these factors were not directly measured in this study and should be considered as speculative explanations.

Table 3: Redness-greenness (a*) properties of samples.

Disc number	Heart	Heartwood	Sapwood
1	7,07 (±0,96)	8,30 (±2,75)	9,48 (±2,60)
2	2,29 (±1,60)	4,03 (±0,93)	4,49 (±0,76)
3	4,53 (±1,08)	4,06 (±2,50)	6,15 (±2,42)
4	5,85 (±1,85)	9,48 (±2,95)	7,88 (±2,77)
5	7,85 (±1,49)	7,45 (±2,34)	5,21 (±2,69)
6	11,27 (±0,38)	9,03 (±1,25)	5,84 (±1,86)
7 (control)	10,23 (±1,14)	9,70 (±1,26)	6,94 (±1,82)
8	8,99 (±1,18)	7,43 (±2,51)	6,01 (±2,35)
Average	7,26 (±2,79)	7,44 (±2,11)	6,50 (±1,48)

Table 4 shows the yellowness-blueness (b*) properties of the wood samples. The average b* values for heart, heartwood and sapwood were 33,82, 32,45 and 30,54, respectively. It ranged from 31,37 (disc 2) to 36,89 (disc 6) for the heart, 29,66 (disc 1) to 36,82 (disc 8) and 28,51 (disc 7) to 33,57 (disc 8), in that order. This indicates a 5,52-value difference for heart samples, a 7,16 value for heartwood samples and a 4,49 value for sapwood samples.

Table 4: Yellowness-blueness (b*) properties of samples.

Disc number	Heart	Heartwood	Sapwood
1	31,62 (±1,78)	29,66 (±1,45)	30,48 (±1,09)
2	31,37 (±0,94)	30,36 (±0,86)	30,97 (±1,08)
3	33,87 (±0,28)	32,22 (±2,27)	30,73 (±2,60)
4	35,08 (±0,18)	30,58 (±2,84)	29,11 (±2,14)
5	32,12 (±2,33)	31,74 (±2,70)	29,43 (±2,51)
6	36,89 (±1,25)	36,50 (±1,42)	31,51 (±1,47)
7 (control)	34,58 (±0,93)	31,73 (±1,90)	28,51 (±1,86)
8	35,04 (±1,68)	36,82 (±2,61)	33,57 (±1,96)
Average	33,82 (±1,83)	32,45 (±2,55)	30,54 (±1,49)

Figure 3 shows the total color difference properties (ΔE) of the heart**,** heartwood and sapwood samples. There were distinct color differences, especially between the sapwood, heartwood and heart of the same wood samples. The color difference was found to be in the range of ΔE= 1,43 (disc 8) to ΔE= 20,16 (disc 2) for the heart**,** in the range of ΔE= 5,60 (disc 8) to ΔE= 18,02 (disc 2) for the heartwood and instead of 2. ΔE= 2,74 (disc 3) to ΔE= 6,36 (disc 2) for sapwood. Notably, the lowest and highest color differences were observed in the same discs for the heart and heartwood samples (disc 8 for the lowest and disc 2 for the highest ΔE values). In the sapwood section, the highest color difference value (ΔE = 6,36) was found in disc 2.

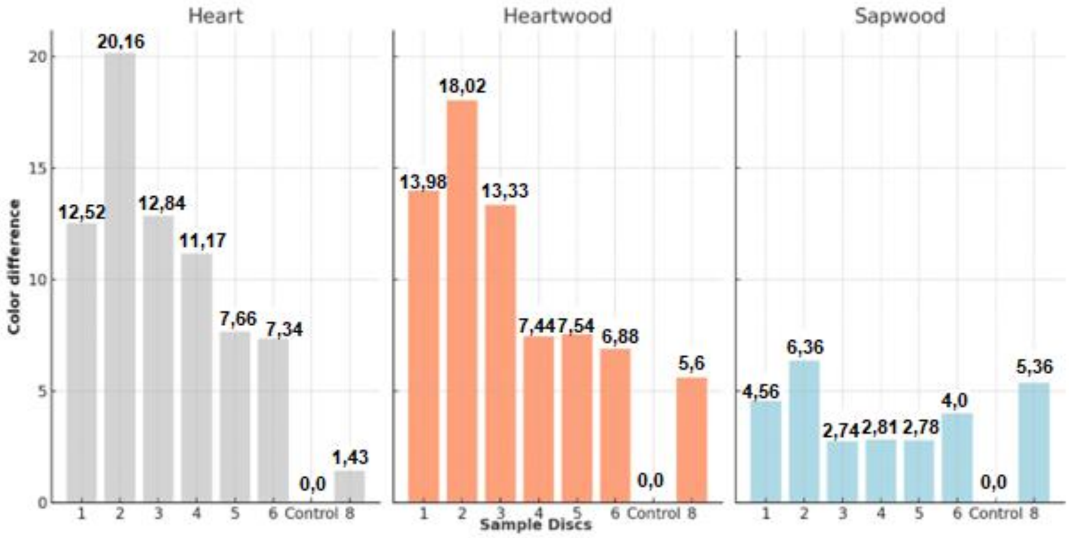

Figure 3: Total color difference properties (ΔE) of the samples.

Figure 4 shows the chroma (saturation) properties of three different parts of wood. It was found to range from 31,45 (disc 2) to 38,57 (disc 6) for the heart parts of wood ($C_{Average}$= 34,68)**.** Similar values were also calculated for heartwood, which was found to be in the range of 30,62 (disc 2) to 37,60 (disc 6) ($C_{Average}$= 33,36). Notably, only marginal average value differences were found between wood parts; the highest average value of $C_{Average}$= 34,68, was found for the heart and the lowest value of $C_{Average}$= 31,26, was found for the sapwood, which was only 3,42 different. Although some variation has been found not only in similar parts of wood but also in different parts of wood at measured heights, differentiating those variations easily via the human eye is difficult.

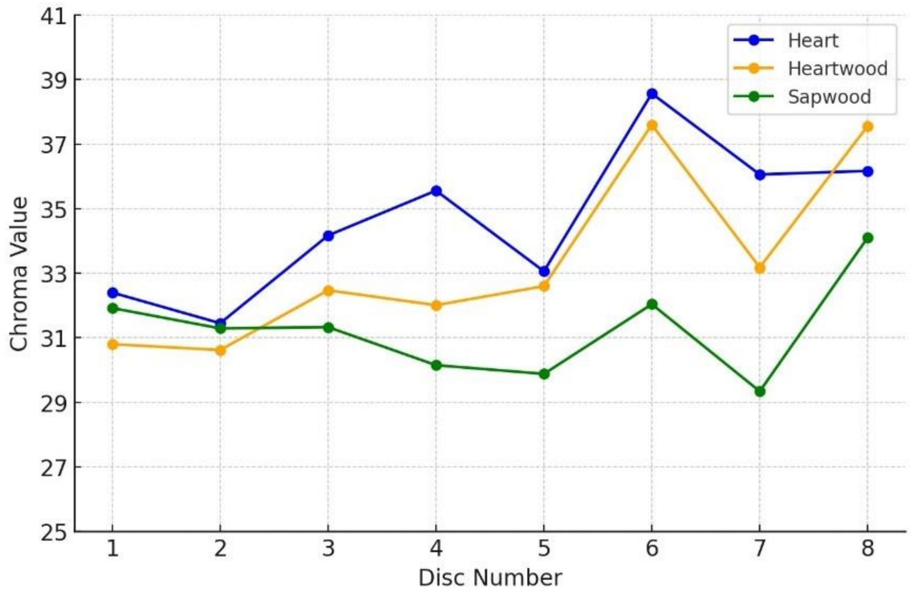

Figure 4: Chroma (purity) properties of the samples.

Figure 5 shows the hue angle (h°) values for the three anatomical regions of the wood. In the heart section, the hue angle ranged from 73,01° (disc 6) to 85,82° (disc 2), corresponding to a difference of 12,81°. For the heartwood, a difference of 9,82° was observed between the lowest value of 73° (disc 7) and the highest of 82,82° (disc 3). In the sapwood section, the hue angle varied from 74,85° (disc 4) to 81,75° (disc 2), resulting in a 6,90° difference. Despite these intra-regional variations, the average hue values across the three regions were relatively close: 78,07° for the heart, 77,11° for the heartwood, and 77,95° for the sapwood, with less than 1° difference between them. It could be suggested that although some differences exist among color properties of the same wood but at different parts, it is difficult to differentiate those variations easily by the human eye.

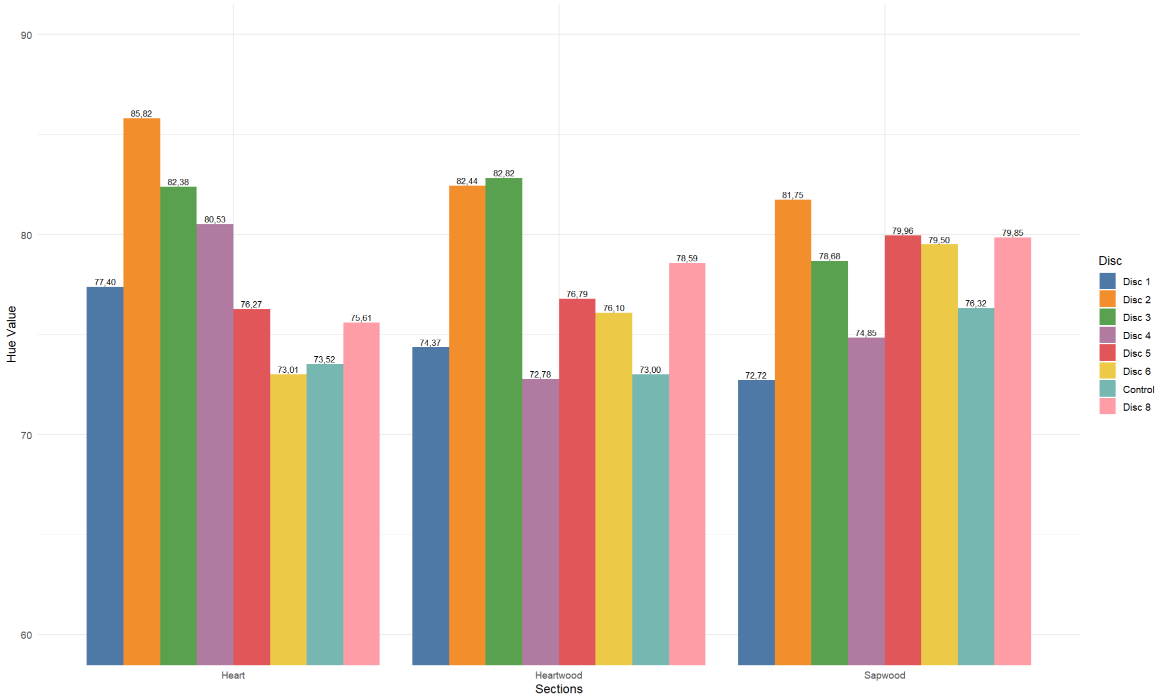

Figure 5: Total hue (angle) difference properties of the samples.

Table 5 presents a comparative analysis of the hardness changes observed across each disc from three different sections (heart, heartwood and sapwood). Disc 8 exhibited the highest hardness values, recording 48,34 for heart, 44,47 for heartwood and 42,17 for sapwood, while disc 1 displayed the lowest hardness values, measuring 30,15 for heart, 24,84 for heartwood and 23,19 for sapwood. The hardness values of the other discs also showed a consistent trend, with disc 2 recording 30,16 for heart, 25,03 for heartwood and 24,95 for sapwood and disc 3 measuring 30,94 for heart, 25,11 for heartwood and 24,49 for sapwood. Noticeably, disc 4 recorded values of 34,97 for heart, 25,75 for heartwood and 24,63 for sapwood. Disc 5 showed an increase in hardness, with values of 43,73 for heart, 31,31 for heartwood and 32,24 for sapwood.

Given that increasing disc heights tend to exert a negative influence on hardness, these results are consistent with trends reported in the literature. Additionally, it is noteworthy that the hardness values consistently followed the pattern of heart > heartwood > sapwood across all discs tested. The results obtained in this study showed that heart typically has higher hardness values compared to both heartwood and sapwood.

Table 5: Hardness properties of samples.

Disc Number	Heart	Heartwood	Sapwood
1	30,15 (±4,01)	24,84 (±1,51)	23,19 (±2,21)
2	30,16 (±2,45)	25,03 (±1,48)	24,95 (±1,98)
3	30,94 (±1,94)	25,11 (±1,15)	24,49 (±3,10)
4	34,97 (±5,09)	25,75 (±3,05)	24,63 (±3,05)
5	43,73 (±2,38)	31,31 (±3,20)	32,24 (±2,65)
6	42,98 (±2,30)	32,36 (±2,74)	32,53 (±2,05)
7	43,35 (±1,18)	35,24 (±5,60)	33,54 (±4,98)
8	48,34 (±4,64)	44,47 (±3,55)	42,17 (±4,74)

The measured values were plotted together to evaluate how hardness properties correlate to each other. The plot shape in Figure 6 demonstrates that at similar conditions, heart appeared to have higher hardness properties than heartwood and sapwood. This trend suggests higher hardness values in the heart region compared to heartwood and sapwood. This observation may be associated with structural characteristics commonly reported in the literature, such as increased density and age-related wood properties, although these factors were not directly measured in this study.

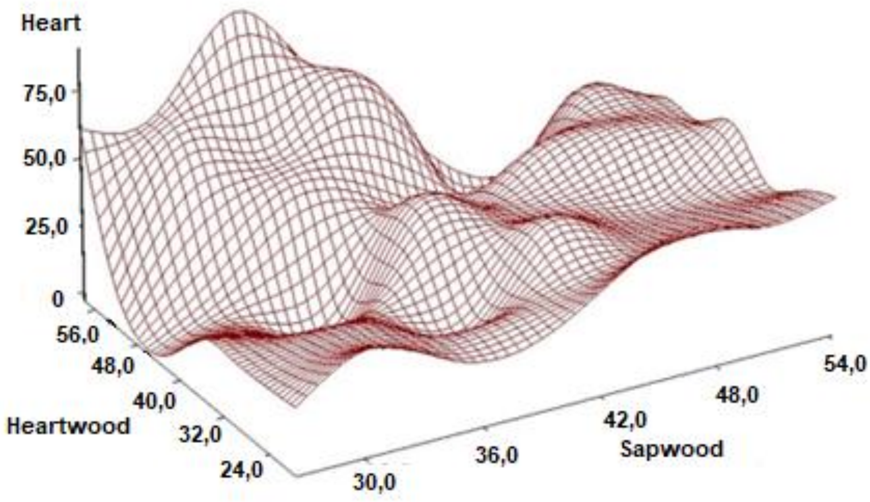

Figure 6: Relationship between the hardness properties of the samples.

Conclusions

This study provides a detailed intra-tree characterization of color and hardness properties in *Cedrus libani* wood, revealing clear axial and radial variations across heart, heartwood, and sapwood sections. The findings demonstrate that both color parameters (L*, a*, b*) and Shore D hardness are strongly influenced by wood type and sampling height, indicating a systematic variation in wood properties within the tree. From a material perspective, sapwood exhibited higher lightness, while heart and heartwood showed relatively darker and more reddish tones. In contrast, hardness values increased toward the center of the tree, with the heart section exhibiting the highest resistance. This pattern may be associated with structural characteristics reported in the literature between inner and outer wood tissues and confirms that mechanical performance appears to increase toward the inner regions of the tree. Additionally, the observed axial variation suggests that lower sections of the tree tend to develop denser and mechanically stronger wood compared to upper sections.

These results have important implications for wood performance and industrial applications. The variation in color and hardness should be considered in timber selection and processing, as different sections of the tree may be more suitable for specific end uses. For example, sapwood may be preferred in applications requiring lighter color and aesthetic uniformity, whereas heartwood and heart are more suitable for structural applications requiring higher strength and durability. Although the study is based on a single tree, it provides valuable preliminary insights into the intra-tree variation of key wood properties in *Cedrus libani*. The findings contribute to a better understanding of how anatomical position influences material behavior and highlight the need for further studies involving larger sample sizes and different growth conditions. Such research would support more efficient utilization, classification, and performance-based selection of this species in both industrial and ecological contexts.

Author contributions

U. Ö.: Writing original draft, methodology, conceptualization, resources, formal analysis visualization. B. K.: Writing review and editing, methodology, resources, formal analysis, investigation, visualization. O. A.: Writing review and editing, visualization, supervision, conceptualization. N. Ö.: Formal analysis, methodology, resources, investigation. Ş. K. G.: Data curation, formal analysis, methodology, visualization. C. K. Ş.: Writing review and editing, methodology, investigation, visualization.

Conflicts of interest

The authors declare there are no conflicts of interest for each author

References:

ASTM International 2010. Standard Test Method for Rubber Property. ASTM D2240. ASTM International: West Conshohocken, PA, USA.

Boydak, M. 2007. Reforestation of Lebanon cedar (*Cedrus libani* A. Rich.) in bare karstic lands by broadcast seeding in Turkey. In: Options méditerranéennes, Series A: Mediterranean Seminars 75. CIHEAM: Paris, France, pp. 33-43.

Brooks, J.R.; Jiang, L.; Ozçelik, R. 2008. Compatible stem volume and taper equations for Brutian pine, Cedar of Lebanon, and Cilicica fir in Turkey. *Forest Ecology and Management* 256(1-2): 147-151. https://doi.org/10.1016/j.foreco.2008.04.018

Güleç, M.; Kiremitci, S.A.; Olgun, A. 2022. *Cedrus libani* A. Rich. In: Novel Drug Targets with Traditional Herbal Medicines: Scientific and Clinical Evidence. Springer International Publishing: Cham, Switzerland, pp. 109-119. https://doi.org/10.1007/978-3-031-07753-1_8

Hach Lange GmbH. 2023. Objective color assessment and quality control in the chemical, pharmaceutical and cosmetic industries. Application Report No. 3.14e DOC042.52.00019. Hach Lange GmbH: Düsseldorf, Germany.

Husch, B.; Beers, T.W.; Kershaw Jr, J.A. 2002. Forest mensuration. John Wiley & Sons: New York, USA.

İmal, B.; Semerci, A.; Gonzalez-Benecke, C.A. 2024. Intraspecific variability in cold hardiness of Taurus cedar (*Cedrus libani* A. Rich.) in Türkiye. *European Journal of Forest Research* 143(2): 727-737. https://doi.org/10.1007/s10342-023-01648-8

Kaytanlioğlu, E.H.T.; Fakir, H.; Özkan, U.; Şahin, C.K. 2023. A diversity analysis of fruits of strawberry tree (*Arbutus andrachne* L.) grown in Isparta-Türkiye. *KSU Journal of Agriculture and Nature* 27(4): 749-757. https://doi.org/10.18016/ksutarimdoga.vi.1300933

Koman, S.; Feher, S. 2015. Basic density of hardwoods depending on age and site. *Wood Research* 60(6): 907-912. https://www.woodresearch.sk/wr/201506/07.pdf

Özçelik, R.; Koparan, B.; Fonseca, T.J.F.; Baş, B. 2023. Characterization of the variability of the diameter distribution of natural Taurus cedar stands in Türkiye using Johnson's Sb distribution. *Cerne* 29. e103265. https://doi.org/10.1590/01047760202329013265

Özkan, U.; Koparan, B.; Genç, Ş. K.; Şahin, C. K. 2025. Wood color variation in anatomical sections of C*edrus libani* from two mediterranean regions. *BioResources* 20(3): 7278-7292. https://doi.org/10.15376/biores.20.3.7278-7292

Pijut, P.M. 2000. Cedrus the true cedars. *Arboriculture and Urban Forestry* 26(4): 218-224. https://doi.org/10.48044/jauf.2000.026

Regent Instruments Inc. 2012. WinDENDRO: An Image Analysis System for Tree-Rings Analysis. Regent Instruments Inc.: Québec, Canada.

Rink, G.; Phelps, J.E. 1989. Variation in heartwood and sapwood properties among 10-year-old black walnut trees. *Wood and Fiber Science* 21(2): 177-182. https://wfs.swst.org/index.php/wfs/article/view/632

Şahin, C.; Kaytanlıoğlu, E.H.T.; Fakir, H.; Özkan, U. 2023. Evolution of autumn leaf coloration of Torminalis glaberrima grown in Isparta, Türkiye. *Journal of Geography* 47: 101-108. https://doi.org/10.26650/JGEOG2023-1257031

Saranpää, P. 2003. Wood density and growth. In: *Wood Quality and Its Biological Basis*. CRC Press: Boca Raton, FL, USA.

Townshend, E.; Pokharel, B.; Groot, A.; Pitt, D.; Dech, J.P. 2015. Modeling wood fiber length in black spruce (*Picea mariana* (Mill.) BSP) based on ecological land classification. *Forests* 6(10): 3369-3394. https://doi.org/10.3390/f6103369

Van Laar, A.; Akça, A. 2007. *Forest mensuration*. Springer: Dordrecht, Netherlands. https://doi.org/10.1007/978-1-4020-5991-9