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INFLUENCE OF COMPONENTS (UV + VIS) OF SOLAR RADIATION ON THE COLOR CHANGE OF UNSTEAMED AND STEAMED BEECH WOOD

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ABSTRACT

The paper presents the differences of color changes of unsteamed and steamed beech wood with saturated water steam with temperature $t = 135\text{ °C}$ for $\tau = 7.5\text{ h}$ caused by long-term exposure of sunlight to the surface of wood in interiors for 36 months. Light white-gray color with a yellow tinge of native beech wood with values on the coordinates of the color space CIE $L^*a^*b^*$ ($L^* = 76.6$, $a^* = 7.8$, $b^* = 19.8$) darkened due to sunlight and the wood turned pale-brown color with a touch of yellow ($L^* = 71.3$, $a^* = 12.2$, $b^* = 26.8$). The degree of darkening and browning is quantified by the value of the total color difference $\Delta E^* = 13.0$. The deep brown-red color of steamed beech ($L^* = 55.3$, $a^* = 14.5$, $b^* = 23.5$) brightened during exposure due to sunlight and the wood surface took on a pale brown hue ($L^* = 77.6$, $a^* = 14.1$, $b^* = 27.8$). The degree of lightening of the color of steamed beech wood in the color space CIE $L^*a^*b^*$ is quantified by the value of the total color difference $\Delta E^* = 7.1$. A comparison of the color changes of native and steamed beech wood through the total color difference ΔE^* due to daylight shows that the surface of steamed beech wood shows 52.2% smaller changes than unsteamed beech wood. The lower value of the total color difference of steamed beech wood indicates the fact that changes in beech wood chromophores caused by steaming steam have a positive effect on color aging due to natural aging and partial resistance of steamed beech to the initiation of photochemical reactions caused wavelengths UV+VIS sunlight.

Key words: beech wood, color space CIE $L^*a^*b^*$, UV + VIS radiation, color change.

INTRODUCTION

The color of wood is a basic physical-optical property, which belongs to the group of macroscopic features on the basis of which the wood of individual woody plants differs visually. The color of the wood is formed by chromophores, i.e., functional groups of the type: $>C=O$, $-CH=CH-CH=CH-$, $-CH=CH-$, aromatic nuclei found in the chemical components of wood (lignin and extractive substances such as dyes, tannins, resins and others), which they absorb some components of the electromagnetic radiation of daylight and thus create the color of the wood surface perceived by human vision.

Wood exposed to long-term exposure to sunlight changes color on its surface. The surface of the wood darkens and mostly yellows and browns. This fact is also referred to in the professional literature as natural aging *Hon (2001)*, *Reinprecht (2008)*, *Baar – Gryc (2011)*.

Solar radiation is electromagnetic radiation with wavelengths in the range from 100 to 3000 nm *Hrvol' – Tomlain (1997)*, which consists of ultraviolet radiation, visible radiation (light) and infrared radiation. Ultraviolet radiation (UV) with wavelengths of 100 – 380 nm makes up about 2 % of the daylight spectrum. According to the effect of UV radiation on biological materials and their ef-

fects on these materials, UV radiation is divided into: UV-A radiation with a wavelength of 320 – 380 nm, UV-B radiation with a wavelength of 280 – 320 nm and UV-C radiation with a wavelength below 280 nm. The spectrum of UV radiation falls on the Earth's surface from solar radiation, which is made up of 90-99% UV-A radiation and 1-10% UV-B radiation. The most dangerous UV-C radiation is completely absorbed by the atmosphere. The visible light spectrum, referred to as VIS with wavelengths from 380 to 780 nm, represents approximately 49 % of the daylight spectrum. The rest consists of infrared IR radiation with wavelengths of 780 – 3000 nm. The wavelengths of visible and infrared radiation are absorbed or reflected by the wood surface. The reflected wavelengths of the visible spectrum allow a person to perceive its color when looking at a given object. The absorbed wavelengths of infrared solar radiation change to heat on the surface.

Components UV + VIS of solar radiation (daylight) initiate wood photodegradation processes when impacting on wood surface (photolytic and photooxidation reactions with lignin, polysaccharides and wood accessory substances), carbohydrates absorb 5 – 20 % and 2 % of the accessory substance *Kuo – Hu (1991), Gandelová et al. (2009)*. These reactions cleave both lignin macromolecules with the simultaneous formation of phenolic hydroperoxides, free radicals, carbonyl and carboxyl groups, as well as polysaccharides into polysaccharides with a lower degree of polymerization to form carbonyl, carboxyl groups and gaseous products (CO, CO₂, H₂) *Hon (2001), Baar – Gryc (2011), Persze – Tolvaj (2012), Denes – Lang (2013), Gefferová et al. (2018)*.

The aim of work is to compare the effect of solar radiation on the surface of thermally treated beech wood with saturated steam (steaming) and unsteamed beech wood.

Through changes in the coordinates L^* , a^* , b^* in the color space CIE $L^*a^*b^*$ and the total color difference ΔE^* , changes are evaluated color of native and steamed beech wood caused by UV+VIS components of sunlight (daylight) are evaluated.

MATERIALS AND METHODS

Blanks with dimensions 32 × 60 × 600 mm made of beech wood had a moisture content $w_p = 56.4 \pm 4.2$ % and were divided into 2 groups. The first group blanks were not thermally steamed prior to drying. The blanks of the second group were steamed with saturated water steam at a temperature of $t = 135 \pm 2.5$ °C for 9 hours in order to modify the color of beech wood to a brown-red color. Steaming was performed in an APDZ 240 pressure autoclave (Himmasch AD, Haskovo, Bulgaria) installed at Sundermann Ltd. (Banská Štiavnica, Slovakia).

Unsteamed and steamed beech blanks were dried by a low-temperature drying mode preserving the original wood color to a moisture content $w_k = 12 \pm 0.5$ % in a convection hot air dryer KWC [9].

Samples of the following dimensions were produced from native and steamed beech wood blanks: 20 × 50 × 400 mm. The planed surface of unsteamed and steamed beech wood samples was exposed to daylight for a long time at an angle of 45° in the northern temperate zone – Slovakia (Central Europe) – locality for 36 months. The temperature and relative humidity of the indoor air during the exposure was $t = 20 \pm 2.5$ °C, $\varphi = 50 \pm 10$ %.

The surface color of beech samples before and during the exposure was evaluated in the color space CIE $L^*a^*b^*$ at monthly intervals using a colorimeter Color reader CR-10 (Konica Minolta, Japan) was measured. A D65 light source was used and the diameter of the optical scanning aperture was 8 mm.

The total color difference ΔE^* of the beech wood surface change during the 36-month exposure to sunlight was determined

$$\Delta E^* = \sqrt{(L_{36}^* - L_0^*)^2 + (a_{36}^* - a_0^*)^2 + (b_{36}^* - b_0^*)^2} \quad (1)$$

Where: L_0^*, a_0^*, b_0^* the coordinates of the color space CIE $L^*a^*b^*$ on the surface of the dried, milled beech wood before exposure,

$L_{36}^*, a_{36}^*, b_{36}^*$ the coordinates of the color space CIE $L^*a^*b^*$ on the surface of the dried, milled beech wood after exposure.

RESULTS AND DISCUSSION

Beech wood, according to *Makoviny (2010), Klement et al. (2010)*, has a light white-brown-yellow color. In the steaming

according to the following ISO 11 664-4 equation:

process with a steam-air mixture at atmospheric pressure, or thermal treatment of beech wood with saturated water steam, as reported by the works: *Trebula (1986), Deliiski (1991), Tolvaj et al. (2009), Dzurenda (2014)*, depending on the temperature and length of the thermal treatment process, the wood darkens and acquires shades from pale pink-yellow color shade to brown-red color.

The color of unsteamed and steamed beech wood at a moisture content of $w = 12\%$ on the planed surface before and after 36 months of dazzling is shown in Fig. 1.



Figure 1: View of beech wood: (left) unsteamed before and after exposure, (right) thermally treated before and after exposure

In Table 1 shows the coordinates of the color space CIE $L^*a^*b^*$ of unsteamed and steamed beech wood at a moisture content of

$w = 12\%$ on the planed surface before and after 36 months of dazzling.

Table 1: Coordinate values of color space CIE $L^*a^*b^*$ of unsteamed and steamed beech wood

Beech wood	Unsteamed beech wood			Steamed beech wood		
	Coordinates of color space CIE $L^*a^*b^*$					
	L^*	a^*	b^*	L^*	a^*	b^*
Before exposure	76.6 ± 1.7	7.8 ± 1.5	19.8 ± 1.7	55.3 ± 1.6	14.5 ± 1.0	23.5 ± 0.8
After exposure	71.3 ± 0.9	12.2 ± 0.6	26.8 ± 0.9	57.6 ± 0.9	14.1 ± 0.8	27.5 ± 0.6

From the comparison of wood colors in Fig. 1 and the presented values on the coordinates L^* , a^* , b^* of unsteamed and steamed beech wood in Table 1 shows that while the surface of the unsteamed beech wood darkened and browned, the brown-red color on the steamed wood lightened.

The courses of the measured values of beech wood color on the coordinates: L^* , a^* , b^* of the color space CIE $L^*a^*b^*$ in individual months, during 36 months of dazzling by the sunlight of daylight are shown in Fig. 2 and Fig. 3.

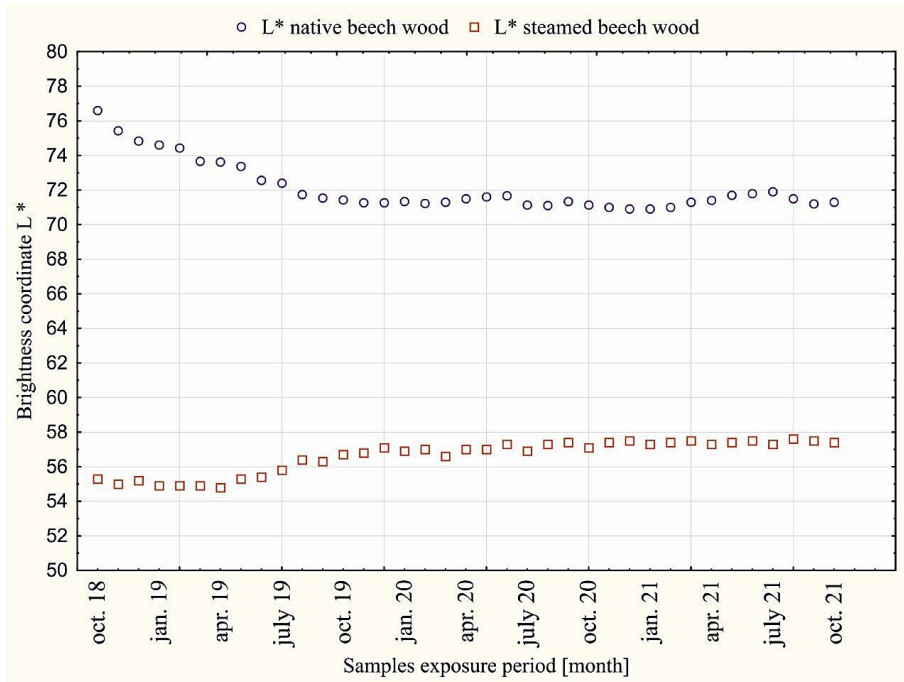


Figure 2: Values on the L^* coordinate of dazzled native and steamed beech wood over a period of 36 months (October 2019 to October 2021).

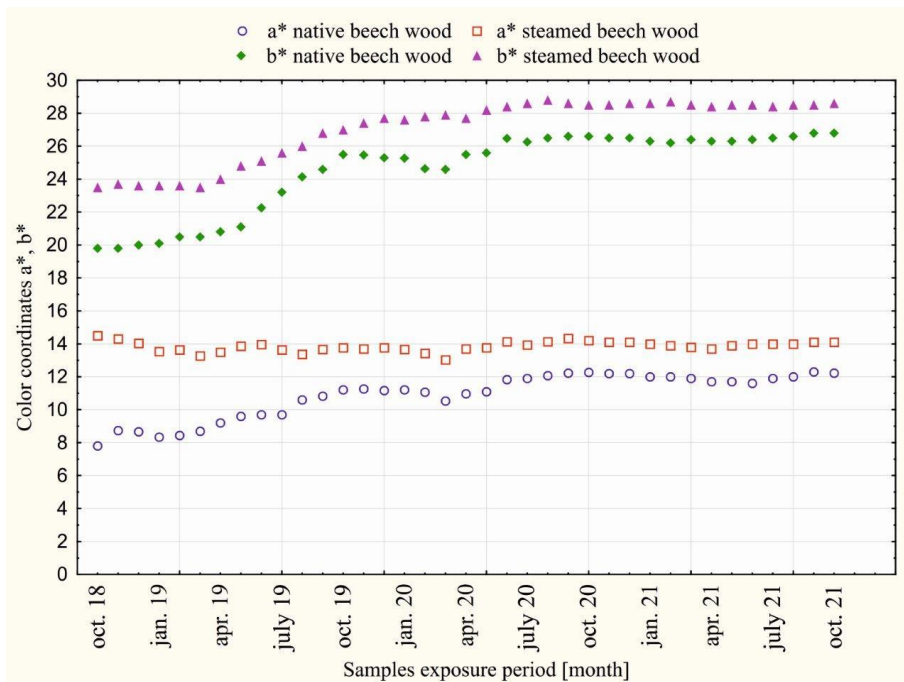


Figure 3: Values on chromatic coordinates of red color a^* and yellow color b^* of dazzling native and steamed beech wood over a period 36 months (October 2019 to October 2021).

The course of the measured values on the light coordinate L^* and the chromatic coordinates of the color a^* and the yellow color b^* in Fig. 3 and Fig. 4 during 36 months of dazzling is not fluent. The fluctuations are attributed to the influence of the intensity of solar radiation during the individual seasons, causing photochemical reactions of UV radiation with wood.

The highest intensity of solar radiation in Slovakia is in the summer months of June and July, when it reaches a value of 5.9 to

6.0 kWh/m² per day. During the autumn, the intensity of sunlight decreases and is lowest during the winter. In December, the intensity of solar radiation is the weakest with an approximate value of 1.7 kWh/m² per day *Hrvol' – Tomlain (1997)*.

In Fig. 3 show the magnitudes of changes in the average values of ΔL^* , Δa^* and Δb^* in individual seasons during the exposure.

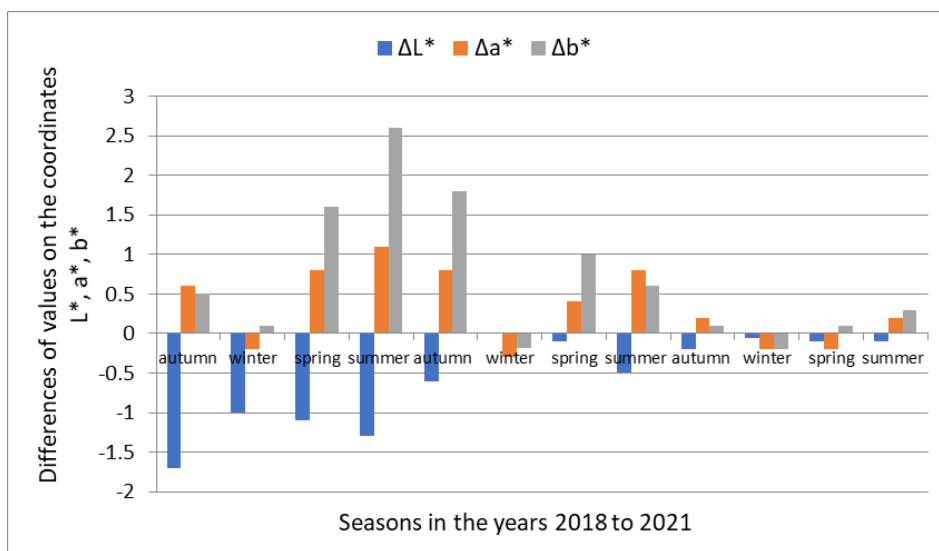


Figure 3: The magnitudes of changes in the ΔL^* , Δa^* , Δb^* values in the color space CIE $L^*a^*b^*$ native beech wood during the 36-month exposure to sunlight, depending on the season

The darkening and browning of unsteamed beech wood numerically documents the shift on the brightness coordinate L^* from the value $L_0^* = 76.6$ to $L_{36}^* = 71.3$ i.e. by the value $\Delta L^* = -5.3$ and changes in chromatic coordinates: red color a^* from $a_0^* = 7.8$ to $a_{36}^* = 12.2$ i.e. by the value $\Delta a^* = +4.4$ and the yellow color b^* from the value $b_0^* = 19.8$ to $b_{36}^* = 26.8$ i.e. by the value $\Delta b^* = +10.0$. The largest darkening of unsteamed beech wood occurred during the first year of dazzling, when changes in the brightness coordinate ΔL^* reached 76.9 % of the total change in brightness of beech wood caused by daylight, in the second year it is 16.8 and in the third year 6.3 %. The browning of unsteamed

beech wood is described by changes in the chromatic coordinates: red a^* and yellow b^* . The change in the red coordinate in the first year of exposure was 57.5 % of the total change Δa^* , in the second year of dazzling 42.5 % and in the third year oscillated around $a^* = 12$. In the yellow coordinate the change Δb^* in the first year of dazzling was 57.7 % of the total value of the change in Δb^* beech wood, 38.7 % in the second year and 3.6 % in the third year. The changes in the red a^* and yellow b^* coordinates of the color space CIE $L^*a^*b^*$ in the third year, as the measurements show, are small and, in addition, the different seasons are contradictory, while in winter and spring they show a decrease in

values, so in summer in times of more intense sunlight, their growth. The darkening of wood due to solar radiation is in line with the views of experts dealing with changes in the properties of wood due to long-term exposure to sunlight, who state that the wood surface darkens and mostly yellows and browns

Reinprecht (2008), Baar – Gryc (2011), Kúdela – Kubovský (2016), Dudiak 2022, Dudiak et al. 2022.

In Fig. 4 show the magnitudes of changes in the average values of ΔL^* , Δa^* and Δb^* in individual seasons during the exposure.

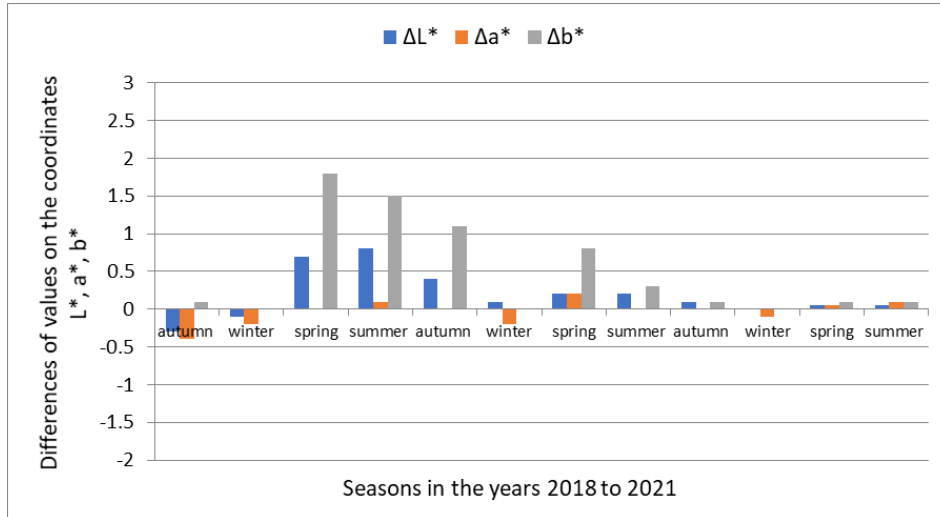


Figure 4: The magnitudes of changes in the values of ΔL^* , Δa^* , Δb^* in the color space CIE $L^*a^*b^*$ of steamed beech wood during the 36-month exposure to sunlight, depending on the season

Steamed beech wood under the influence of sunlight for 36 months compared to unsteamed wood showed the opposite character of the color change, the surface of the wood faded. Visually, this is documented in Fig. 2, as well as the shift on the brightness coordinate L^* from the value $L_0^* = 55.3$ to $L_{36}^* = 57.2$ i.e. by the value $\Delta L^* = + 1.9$, on the red coordinate a^* offset from $a_0^* = 14.5$ to $a_{36}^* = 14.1$ i.e. by the value $\Delta a^* = - 0.4$ and on the chromatic coordinate of yellow color b^* from the value $b_0^* = 19.8$ to $b_{36}^* = 25.5$ i.e. by the value $\Delta b^* = + 5.7$. On the basis of comparison of individual changes ΔL^* , Δa^* , Δb^* on the coordinates of the color space CIE $L^*a^*b^*$ of steamed beech wood caused by the action of sunlight with changes ΔL^* , Δa^* , Δb^* on the coordinates of the unmatched of beech wood caused by daylight,

it can be stated that the values expressing the magnitude of changes in steamed beech wood are smaller. The magnitude of changes in the brightness coordinates L^* and yellow b^* , similar to unsteamed beech wood, are largest in the first year of exposure. The red coordinate changes of a^* oscillated around the value of $a^* = 14.0$. In winter, at low sunlight intensity, the values on the red coordinate a^* decrease and from spring to autumn they increased at higher sunlight intensity. The rate of decline, or the increase in red coordinate values decreases over the years.

The contribution of the influence of beech wood steaming on the color fastness and resistance to the effects of sunlight declares decrease in the value of the total color difference ΔE^* in Fig. 5.

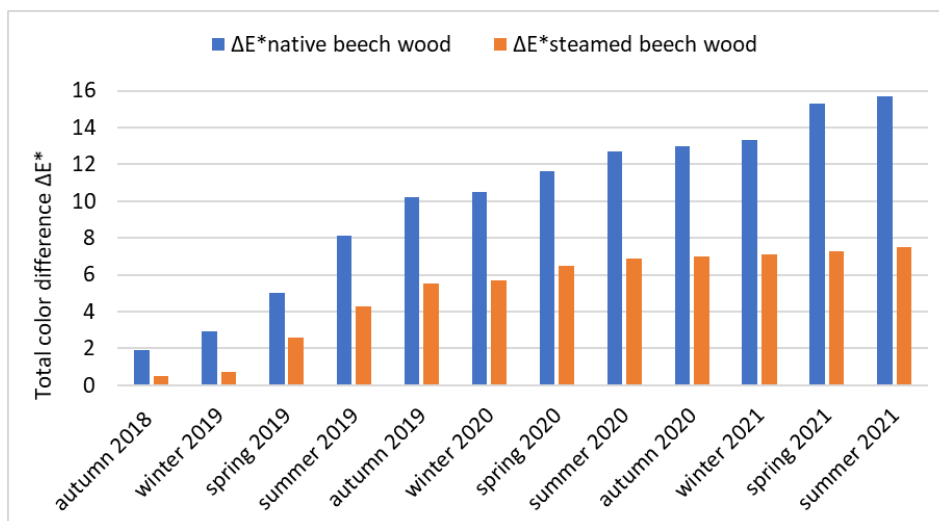


Figure 5: Values of the total color difference ΔE^* of native and steamed beech wood during 36 months of dazdling (October 2019 to October 2021).

While the change in the color of unsteamed beech wood caused by solar radiation expressed by the value of the total color difference over 3 years is $\Delta E^* = 15.7$, then the change in the total color difference of steamed beech wood in the same period is $\Delta E^* = 7.5$ which is the decrease in color changes about 52.2%. This fact points to the fact that beech wood steaming has a positive effect on changes in the chromophore system of steamed beech wood and the partial re-

sistance of steamed beech wood to the initiation of photochemical reactions induced by daylight wavelengths.

From the course of changes in the values of the total color difference presented in Fig. 5 and from the aspect of dazdling time, it can be stated that after the most intensive color change of the surface of unsteamed and steamed beech wood cca 70 % in 1 year of dazdling, the rate of color changes of wood decreases in 2 years of dazdling at 23 % and 3 years is minimal. The data in Table 2.

Table 2: Changes in the total color difference ΔE^* of steamed and unsteamed beech wood in individual years.

Period dazdling	Total color difference ΔE^* samples	
	unsteamed beech wood	steamed beech wood
1 year	10.2	5.5
2 year	3.3	1.5
3 year	1.0	0.5

CONCLUSION

The paper presents the results of the color change of the surface of unsteamed and steamed beech wood with saturated water steam in a pressure autoclave, which was been exposed to daylight interior for 36 months. The results of analyzes of the effect

of solar radiation on unsteamed and steamed beech wood showed:

1. The color surface of unsteamed beech wood changed under the influence of daylight during the exposure, the wood darkened and browned into a brown-yellow color shade. The opposite tendency, i.e.,

lightening, occurred during exposure on steamed beech wood samples.

2. The measured changes in the values at the coordinates of the color space CIE $L^*a^*b^*$ caused by solar radiation in unsteamed beech wood are: $\Delta L^* = -5.3$; $\Delta a^* = +4.4$; $\Delta b^* = +10.0$ changes were recorded also for steamed beech wood: $\Delta L^* = +1.9$; $\Delta a^* = -0.4$; $\Delta b^* = 5.7$.
3. The evaluation of the color change of beech wood in the form of the total color difference ΔE^* shows that the surface of steamed beech wood shows approximately 52.2 % less color change than the total color difference of unsteamed beech wood.
4. The decrease in the values of ΔL^* , Δa^* , Δb^* and the total color difference ΔE^* of steamed beech wood indicate a positive effect of steaming of wood on the partial resistance of steamed beech wood to the initiation of photochemical reactions induced by wavelengths daylight.

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