ACTA FACULTATIS XYLOLOGIAE ZVOLEN, 65(1): 35−43, 2023
Zvolen, Technical University in Zvolen
DOI: 10.17423/afx.2023.65.1.03

THE EFFECT OF SUNLIGHT ON THE COLOR CHANGE OF STEAMED BIRCH WOOD

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ABSTRACT

The differences in color changes of native and steamed birch wood saturated with water steam at a temperature of t = 135 °C for a period of τ = 7.5 hours caused by the long-term exposure of sunlight to the surface of the wood in interiors for 48 months are presented in the paper. The deep brown-red color of the steamed birch wood lightened and acquired a brown shade due to the UV components of sunlight during the 48-month exposure. The degree of lightening of the color of steamed birch wood in the color space CIE L*a*b* is quantified by an increase in the values of the lightness coordinate from L_0^* = 59.8 to L_{48}^* = 66.5 and the yellow color chromatic coordinate from b_0^* = 19.2 to b_{48}^* = 24.0. On the contrary, the light white-brown color of the native birch wood darkened due to the effect of the UV components of sunlight and acquired a brown-pink color with a yellow tint. The degree of darkening and browning is quantified by a decrease in the values on the lightness coordinate from L_0^* = 81.1 to L_{48}^* = 68.2 and an increase in the values on the chromatic coordinates: red color a_0^* = 7.2 to a_{48}^* = 13.1 and yellow color from b_0^* = 20.0 to b_{48}^* = 25.9. The comparison of the color changes of native and steamed birch wood through the total color difference ΔE* under the influence of daily sunlight shows that the surface of steamed wood shows 45.8% smaller changes than native wood. The lower value of the total color difference of steamed wood points to the fact that steaming wood with saturated water steam has a positive effect on color stability and partial resistance to the initiation of photolytic reactions caused by UV + VIS wavelengths of sunlight.

Keywords: birch wood; steaming; saturated water steam; natural aging; wood color.

INTRODUCTION

The color of the wood is a basic physical-optical property that belongs to the group of macroscopic signs on the basis of which the individual wood of individual trees differs from one another in appearance. The color of the wood is created 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 thereby create the color of the wood surface perceived by the human vision.

Wood with 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 and Gryc, 2012).

Solar radiation is electromagnetic radiation with wavelengths in the range from 100 to 3000 nm Hrvoľ and 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 effects 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.

UV+VIS components of solar radiation (daylight) initiate wood photodegradation processes when impacting on the wood surface (photolytic and photo-oxidation reactions with lignin, polysaccharides and wood accessory substances), and carbohydrates absorb 5–20% and 2% of the accessory substance (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, CO_2, H_2) (Hon, 2001; Persze and Tolvaj, 2012; Baar and Gryc, 2012; Denes and Lang, 2013; Geffertova *et al.*, 2018; Liu *et al.*, 2019).

The aim of the paper is to compare the influence of solar radiation on the color change of the surface of birch wood steaming with saturated water steam at a temperature of $t = 135 \pm 2.5$ °C with the color change of the surface of native birch wood dazzled under the same conditions. The influence of solar radiation on the change of color is analyzed through changes in the lightness coordinates L* and chromatic coordinates: the red color a* and yellow color b* in the color space CIE L*a*b* and the size of the total color difference ΔE* on individual surfaces.

MATERIAL AND METHODS

The 32 × 60 × 600 mm blanks made from birch wood had a moisture content of $w_p = 61.4 \pm 5.2\%$ and were divided into 2 groups. The blanks of the first group were not steaming before drying. The blanks of the second group were steamed with saturated water steam in order to modify the color of the birch wood. Steaming of wood was carried out in a pressure autoclave APDZ 240 (Himmasch AD, Haskovo, Bulgaria) installed at Sundermann s.r.o. Banská Štiavnica (Slovakia). The mode of steaming birch wood with saturated water steam is shown in Fig. 1. and the technological parameters of the steaming mode are shown in Table 1.

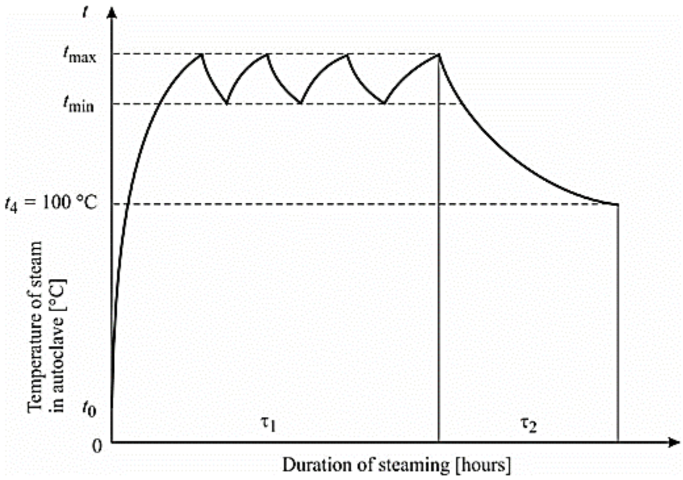

Fig. 1 Mode of colour modification of birch wood with saturated water steam.

Tab. 1 Mode of colour modification of birch wood with saturated water steam.

Mode	Temperature of saturated water steam [°C]			Time of operation [hours]		
	t_{min}	t_{max}	t_4	τ_1 -phase I	τ_2-phase II	Total time
Mode	132.5	137.5	100	6.0	1.0	7.5

Native and steamed birch blanks were dried using a low-temperature drying mode preserving the original color of the wood to a moisture content of $w_k = 12 \pm 0.5\%$ in a conventional hot air dryer: KC 1/50 (SUSAR s.r.o.) (Dzurenda, 2021).

Samples with dimensions: 20 × 50 × 400 mm were made from native and steamed birch wood blanks. The planed surface of samples of native and steamed birch wood was exposed to sunlight for a long time at an angle of 45° in the area of the northern temperate zone – location Slovakia (Central Europe) for a period of 48 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 average density of incident solar radiation on the territory of Slovakia represents a value of 1100 kWh/m^2 per year. During the year, the intensity of solar radiation changes. The highest intensity of solar radiation is in the summer months of June and July when it reaches a value of 5.9 to 6.0 kWh/m^2 per day. During autumn, the intensity of solar radiation decreases and is lowest during the winter period. In December, the intensity of solar radiation is the weakest, with an approximate value of 1.7 kWh/m^2 per day.

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

The total color difference ΔE* of the color change of the surface of birch wood during 48 months of exposure to sunlight was determined according to the following equation of ISO 11 664-4:

$$\Delta E^* = \sqrt{\left(L_2^* - L_1^*\right)^2 + \left(a_2^* - a_1^*\right)^2 + \left(b_2^* - b_1^*\right)^2} \quad (1)$$

Where: L^*_1, a^*_1, b^*_1 – values of the coordinates of the color space CIE L*a*b* on the surface of dried, milled birch wood before exposure,

L^*_2, a^*_2, b^*_2 – values of coordinates color space CIE L*a*b* on the surface of dried, milled birch wood during exposure.

The measured values on the lightness coordinate L* and the chromatic coordinates a*, b*, as well as the calculated values of the total color differences ΔE* during the monitored exposure periods were statistically and graphically evaluated using the EXCEL and STATISTICA 12 programs (V12.0 SP2, USA).

RESULTS AND DISCUSSION

In the color space CIE L*a*b*, the dark-brown color of the steamed wood of *Betula pendula Roth*, in a dry state, on a planed surface (Fig. 2), is described by the values of the coordinates: L* = 59.8 ± 1,2; a* = 12.5 ± 0.8; b* = 19.2 ± 0.9. The light white-brown color of birch wood, after drying on a planed surface, has the following color coordinate values: L* = 81.1 ± 1.7; a* = 7.2 ± 0.8; b* = 20.0 ± 1.0.

The stated values for the lightness coordinates L* and the chromatic coordinates of red color a* and yellow color b* of the color space CIE L*a*b* of native birch wood are similar to those reported by the authors: Babiak *et al.* (2004); Meints *et al.* (2017).

Due to the influence of sunlight, the color of the steamed birch wood lightened and took on a brown shade (Fig. 2), and the color of the native birch wood faded and turned brown. Color coordinates of steamed wood after exposure are: L* = 66.5 ± 1.1; a* = 11.4 ± 0.9; b* = 24.1 ± 1.3 and of native birch wood after exposure are: L* = 68.0 ± 1.2; a* = 12.8 ± 0.6; b* = 25.3 ± 0.9.

The color of native and steamed birch wood before and after exposure to daylight glare is shown in Fig. 2.

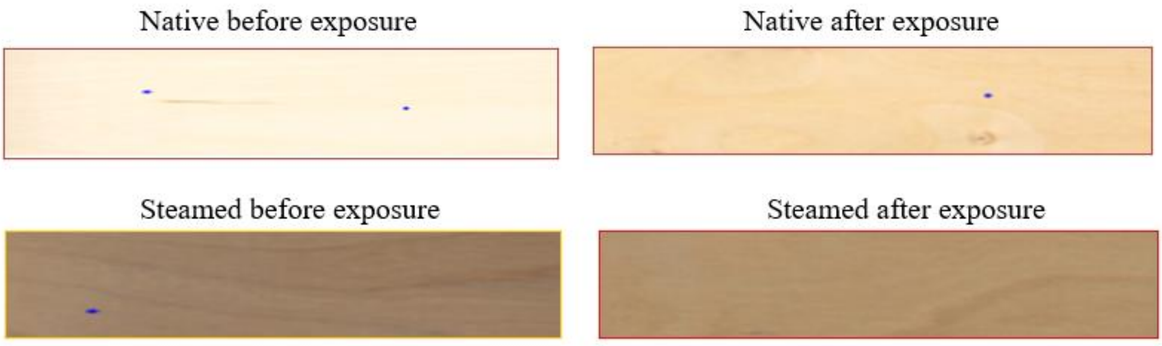

Fig. 2 View of the birch wood before and after 48 months exposure.

The course of the measured values of the color of birch wood on the coordinates: L*, a*, b* of the color space CIE L*a*b* in individual months, during 48 months of glare from solar radiation of daylight, are shown in Fig. 3 and Fig. 4.

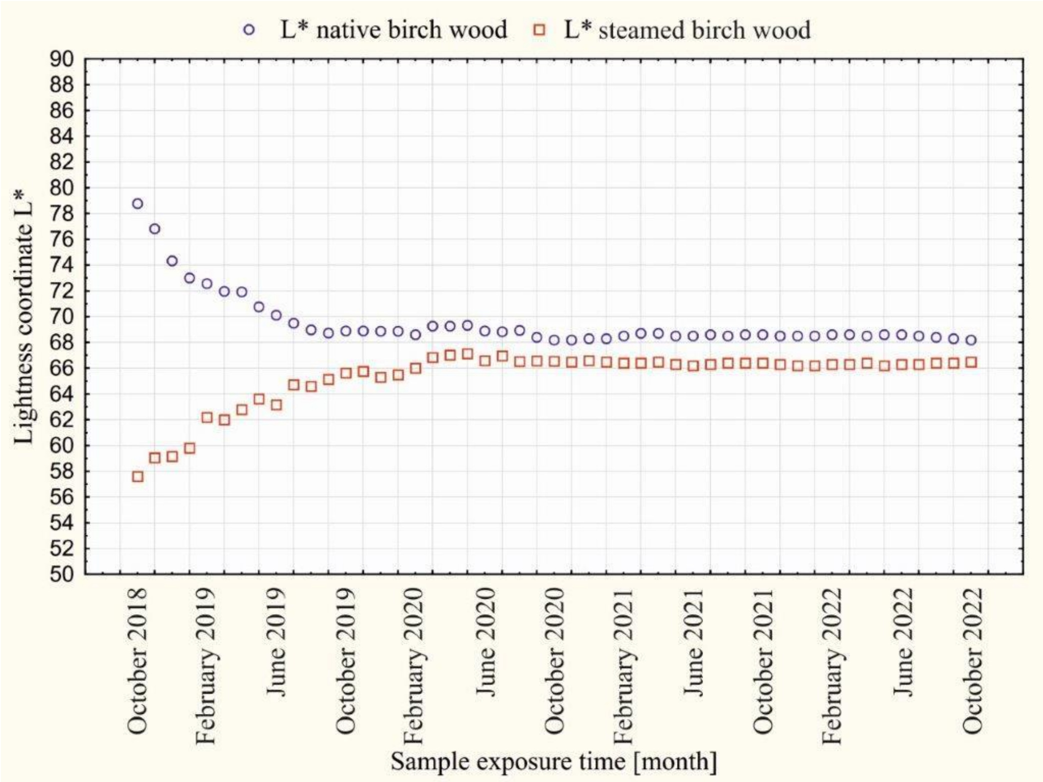

Fig. 3. Values on the lightness coordinate L* of dazzled native and steamed birch wood over a period of 48 months (October 2018 to October 2022).

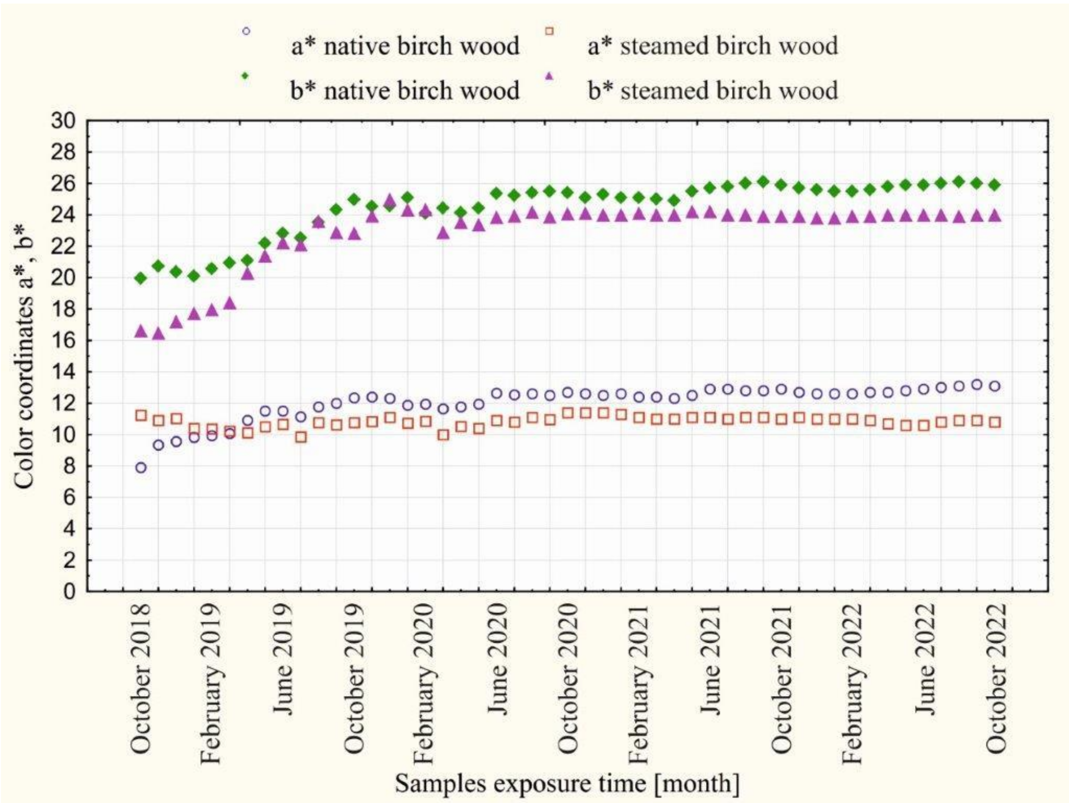

Fig. 4. Values on the chromatic coordinates of red color a* and yellow color b* of glazed native and steamed birch wood during 48 months (October 2018 to October 2022).

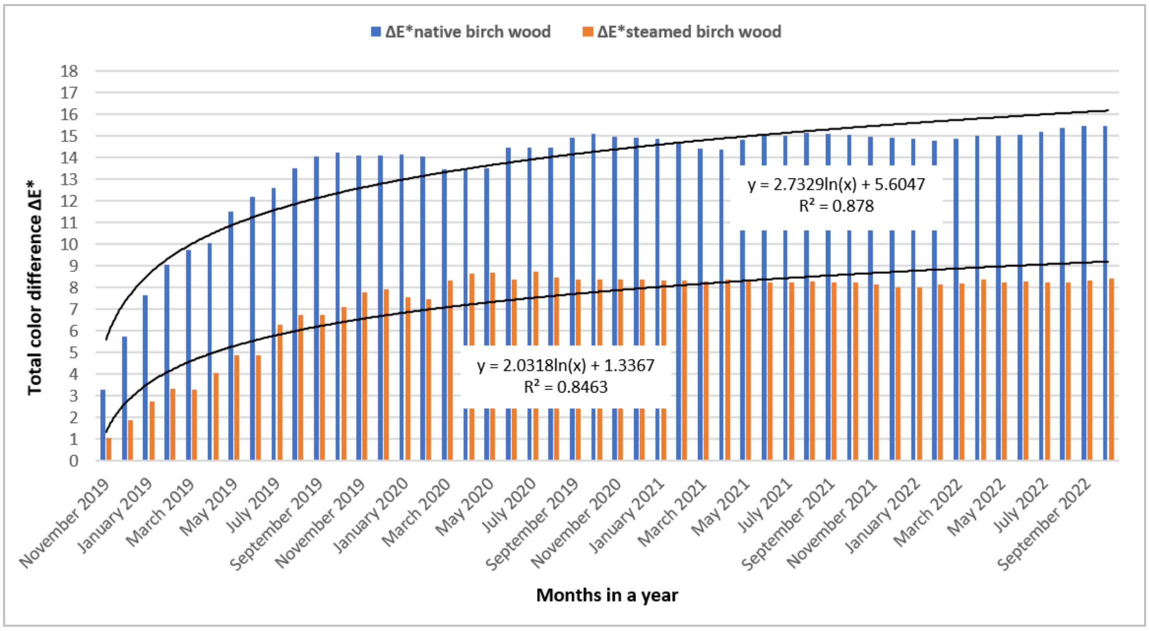

Fig. 5 Values of the total color difference ΔE* of native and steamed birch wood during 48 months of glare (October 2018 to October 2022).

The comparison of wood colors in Fig. 2 and the presented values on the coordinates L*,a*,b* of native and steamed birch wood during exposure in Fig. 3 and Fig. 4 shows that while the surface of native birch wood darkened and browned, the dark-brown color of steamed wood lightened.

The darkening and browning of native birch wood numerically documents the shift on the lightness coordinate L* from the value L_0* = 81.1 to L_{48}* = 68.2, i.e., by the value ΔL* = - 12.9 and changes in chromatic coordinates: red color a* from a_0* = 7.2 to a_{48}* = 13.1 i.e., by the value Δa* = + 5.8 and the yellow color b* from the value b_0* = 20.0 to b_{48}* = 25.9, i.e., by the value Δb* = + 5.9. The most remarkable darkening of native birch wood occurred during the first year of glare when the changes in the lightness coordinate decreased by ΔL* = 12.9 from the total change in the lightness of birch wood caused by UV+VIS radiation of daylight, whereas in other years of glare they only oscillated around the value of L * = 68 depending on the season. The browning of native beech wood is described by changes in the chromatic coordinates: the red color a* and yellow color b*. The change in the red color coordinate in the first year of insolation was Δa* = 5.1 of the total change in other years; the changes were small depending on the season. On the yellow coordinate, the change in Δb* in the first year of glazing increased by b* = 4.3 from the total value of birch wood in the other years of glazing, there were only small fluctuating changes depending on the season. Changes in the coordinates of the red a* and yellow b* color of the color space CIE L*a*b* in the third and fourth year, as determined by the measurements, are small and, moreover, opposite to individual seasons. At the same time, in the winter and spring they show a decrease in values, so in the summer, at the time of more intense sunlight, they increase. The darkening of wood due to sunlight is in accordance with the opinions of experts dealing with changes in the properties of wood due to long-term exposure to sunlight, who state that the surface of the wood darkens and mostly turns yellow and brown (Reinprecht, 2008; Chang *et al.*, 2010; Baar and Gryc, 2012; Kúdela and Kubovský, 2016; Geffertová *et al.*, 2018; Dudiak 2022).

Steamed birch wood due to the influence of sunlight over a period of 48 months compared to native wood showed the opposite nature of the color change, the surface of the wood became pale. It is visually documented in Fig. 2, as well as a shift on the lightness coordinate L* from the value $L_0^* = 59.8$ to $L_{48}^* = 66.5$, i.e. by the value $\Delta L^* = + 6.7$, on the red color coordinate a* a shift from $a_0^* = 12.5$ to $a_{48}^* = 10.8$, i.e. by the value $\Delta a^* = - 1.7$ and on the chromatic coordinate of the yellow color b* from the value $b_0^* = 19.2$ to $b_{48}^* = 24.0$. i.e. by the value $\Delta b^* = + 4.8$. Based on the comparison of individual changes ΔL*, Δa*, Δb* on the coordinates of the color space CIE L*a*b* of steamed birch wood caused by exposure to sunlight with changes of ΔL*, Δa*, Δb* on the coordinates of native of birch wood caused by exposure, it can be concluded that the values expressing the magnitude of changes in steamed birch wood are smaller. The size of the changes in the lightness coordinate L* and the yellow color b*, similarly to native birch wood, are the largest in the first year of exposure. Changes in the red color coordinate a* oscillated around the value a* = 11.0. In winter periods, with low intensity of solar radiation, the values on the red color coordinate a* decreased from spring to autumn, while with higher intensity of solar radiation, they increased. The rate of decline, or an increase in values on the red color coordinate decreases over the years. On the basis of the above findings, it can be concluded that the functional groups of the chromophoric system of birch wood with the absorption of the spectrum of electromagnetic radiation with a wavelength of red 630-750 nm causing the reddening of steamed birch wood were strongly eliminated by steaming for the photochemical reactions of wood induced by UV radiation.

Authors Dudiak *et al.* (2022) in their work also points to the effect of lightening the surface of steamed beech wood with saturated water steam at a temperature of t = 135 °C during solar exposure for a period of 36 months. The lightening of the brown color with a reddish tinge is declared by the differences on the lightness coordinate by an increase in the values ΔL* = + 1.9, on the chromatic coordinate of the yellow color by Δb* = + 5.7 and a decrease on the red color coordinate by Δa* = - 0.4. The most significant changes in the color of the steamed beech wood surface were recorded in the first year of exposure.

The effect of UV radiation on steamed acacia wood is discussed in the work of Varga *et al.* (2021) report that while the surface of steamed acacia wood darkened slightly at the steaming temperature t = 100 °C, the surface of the acacia wood became lighter at the steaming temperature t = 120 °C.

On the change of surface color due to UV radiation of steamed maple wood saturated with water steam, the authors Dzurenda *et al.* 2022 state that while the surface of steamed maple wood at temperature t = 95 °C darkened slightly, the color of the surface of steamed maple wood at temperature t = 125 °C became lighter, which was declared by the shift of values on the lightness coordinate by ΔL* = + 3.4. In the paper, they also state that the color of the steamed maple wood surface at t = 105 °C did not change due to UV radiation.

The effect of the steaming of birch wood on the color stability and resistance to the action of sunlight is declared by the decrease in the value of the total color difference ΔE* in Fig. 5. While the change in color of native birch wood caused by sunlight expressed by the value of the total color difference over the course of 4 years is ΔE* = 15.5, the change in the total color difference of steamed birch wood in the same period is ΔE* = 8.4, which a decrease in color changes by 45.8 %. This fact points to the fact that the steaming of birch wood has a positive effect on the changes in the chromophoric system of the steamed birch wood and the partial resistance of the steamed birch wood to the initiation of photolytic reactions caused by UV + VIS wavelengths of sunlight.

CONCLUSION

The results of changes in the color of steamed birch wood saturated with water steam and native birch wood under the influence of solar radiation over a period of 48 months were presented the paper. The results of analyzes of the effect of solar radiation on steamed birch wood and native birch wood showed that:

- The surface of steamed birch wood faded from dark brown to brown due to sunlight. The mentioned change in the fading of the wood is declared by the shift on the coordinates by the following values: $\Delta L^* = + 6.7$; $\Delta a^* = - 1.7$ and $\Delta b^* = + 4.8$.
- The surface of the native birch wood darkened from a light white-brown to a pale-brown color due to sunlight. The mentioned change in the darkening of the wood is declared by the shift on the lightness coordinate by the value $\Delta L^* = - 12.9$, and by the browning shifts on the chromatic coordinates by the values: $\Delta a^* = - 5.8$ and $\Delta b^* = + 5.9$.
- The course of color changes on the surface of natural, as well as on the surface of steamed birch wood, during glare is not uniform. Significant color changes occurred during the first year of dazzle.
- A smaller change in the overall color difference of steamed birch wood points to the positive effect of treatment with saturated water steam on the wood color stability and resistance to sunlight.

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ACKNOWLEDGMENT

This experimental research was prepared within the grant project: APVV-17-0456 "Termická modifikácia dreva sýtou vodnou parou za účelom cielenej a stabilnej zmeny farby drevnej hmoty" as the result of work of author and the considerable assistance of the APVV agency.

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