Colour Stability of Steamed Poplar Wood during Short-term Photodegradation

Endre A. Banadics, Laszlo Tolvaj,* and Denes Varga

Plantation poplar (*Populus x euramericana* cv. *Pannonia*) wood samples were steamed at 100 °C, 110 °C, and 120 °C and then irradiated by a strong UV emitter mercury lamp to test their colour stability. The colour change was evaluated and presented in a CIE Lab colour coordinate system. For the control, unsteamed poplar specimens were irradiated using the same mercury lamp. A considerable increase in colour saturation in the specimens was generated by steaming, and the saturation value further increased during the UV treatment. The lightness value of the unsteamed control specimens decreased continuously during the entire UV irradiation period. In contrast, the lightness value of the steamed samples decreased only during the first seven hours of the UV treatment and remained constant afterward. Steaming enhanced the redness stability of the poplar wood against UV irradiation. Modification of wood components during steaming at 120 °C stabilised the poplar wood redness against short-term photodegradation. Steaming slightly reduced the yellow colour sensitivity of the poplar to photodegradation.

Keywords: Steaming; Photodegradation; Colour change; Extractives

Contact information: University of Sopron, Bajcsy-Zs. u. 4. 9400 Sopron, Hungary;
** Corresponding author: tolvaj.laszlo@uni-sopron.hu*

INTRODUCTION

Poplar is a fast-growing wood species mainly cultivated in plantations. Its unattractive greyish-white colour is a strong disadvantage in appearance compared with other wood species. Steaming is an environmentally friendly colour modification method to create a warm brown wood colour. Publications related to the hydrothermal treatment of poplar are rare, but the steaming properties of black locust and beech timber have been widely investigated (Tolvaj *et al*. 2009, 2010; Milić *et al*. 2015; Geffert *et al*. 2017; Dzurenda 2018a). Varga and van der Zee (2008) studied the steam-induced alterations of the mechanical and physical properties of two European and two tropical hardwood species. Steaming proved to be a proper method to minimalize the high colour difference between the earlywood and latewood of Turkey oak (Tolvaj and Molnar 2006; Todaro *et al*. 2012; Csanady *et al*. 2015). The steaming behaviour of oak and maple wood was investigated by Dzurenda (2017, 2018b) to obtain an attractive brown colour.

The steam-induced colour change of poplar (*Populus x euramericana* cv. *Pannonia*) was investigated to obtain an attractive colour suitable for various indoor applications (Banadics and Tolvaj 2019). Steaming is a technique to turn the naturally unattractive colour of poplar wood to a pleasant brown colour. This study found that the colour saturation doubled due to the treatment, while both redness and yellowness values were increased and the lightness decreased.

Natural wood is susceptible to weathering. Sunshine is the main factor that creates wood photodegradation. The photodegradation of natural wood is an intensively studied phenomenon (Pandey 2005; Popescu *et al.* 2011; Persze and Tolvaj 2012; Denes and Lang 2013; Zivkovic *et al*. 2013; Timar *et al*. 2016; Varga *et al*. 2017). However, there is no research regarding the photodegradation behaviour of steamed wood.

This study investigated the colour stability of steamed poplar wood. The goal was to find out whether the attractive brown colour of steamed poplar wood needs protection against the discoloration effects of photodegradation.

EXPERIMENTAL

Plantation poplar timber (*Populus x euramericana* cv. *Pannonia*) was used for sample preparation with dimensions of 15 × 25 × 160 mm (W × H × L). The initial moisture content of the samples was between 9 to 10% before steaming. The steaming was carried out in an autoclave to retain the pressure. The water bath under the samples maintained 100% relative humidity within the autoclave. The chosen steaming temperatures were 100 °C, 110 °C, and 120 °C, and the steaming time was 5 days. The details of steaming process can be found in a previous work (Banadics and Tolvaj 2019). Four specimens featuring a visually homogenous surface colour were chosen for light irradiation after each steaming process.

The steamed specimens were subjected to photodegradation together with the thermally untreated control (Nat) samples. A strong UV light emitter mercury vapour lamp provided the light irradiation. The UV radiation was 80% of the total emissions (31% UV-A, 24% UV-B, and 25% UV-C). The total electric power of the applied double mercury lamps was 800 W, and the distance between the samples and the light source was 64 cm. An irradiation chamber set for 70 °C ensured ambient temperature conditions. The total irradiation time was 90 h. The irradiation was interrupted after 7, 16, 36, 60, and 90 h to measure the colour change. Colour measurements were carried out with a colorimeter (Konica-Minolta 2600d, Tokyo, Japan). The CIE L^*, a^*, and b^* colour coordinates were calculated by applying the D_{65} illuminant and 10° standard observer with a test-window diameter of 8 mm. The colour of ten randomly chosen locations were measured on each specimen before and after UV irradiation.

RESULTS AND DISCUSSION

The steaming generated large colour changes in the poplar specimens. These changes are represented in Figs. 1 through 3. The data points belonging to the zero-irradiation time represents the colour modification effect of steaming at the applied steaming temperatures. The average initial colour coordinates of the natural poplar specimens were starting points of the line named “Nat”. The lightness value of the poplar decreased with an increased steam temperature (Fig. 1). The initial lightness decrease was 31% after 5 days of steaming at 120 °C. Additionally, steaming generated a notable redness value increase (Fig. 2). The redness coordinate was 3.9 times higher after 5 days of steaming at 120 °C than the initial value. The yellow colour coordinate (b^*) also increased after steaming (Fig. 3). The yellowness value was 1.7 times higher after 5 days of steaming at 120 °C than the initial value. The increases of both red and yellow (a^* and b^*) colour coordinates demonstrated that the saturation of the steamed specimen was much higher than that of the unsteamed (natural) poplar wood, thus providing an important result of the steaming process.

The lightness of the investigated samples decreased intensively during steaming while the subsequent photodegradation generated only a relatively small lightness decrease (Fig. 1). The lightness value of the unsteamed (Nat) specimens decreased considerably during the first 10 h of UV irradiation. After this period, the decrease was moderate but continuous. The lightness value of the steamed samples decreased slightly during the first 7 h of UV irradiation and remained almost constant afterward. The results demonstrated that the steamed poplar wood was less sensitive to the darkening effect of photodegradation than the untreated poplar.

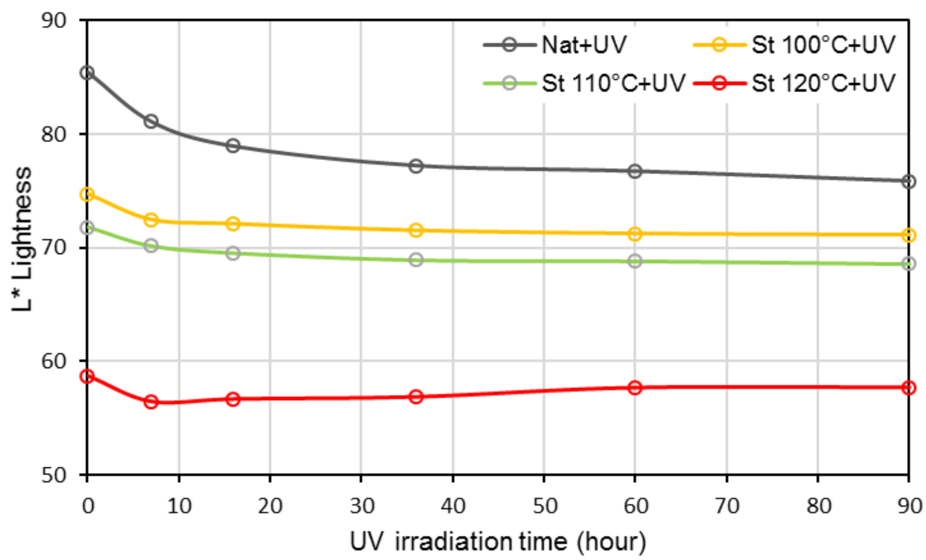

Fig. 1. Lightness change of untreated (Nat) and steamed (St) poplar samples caused by UV light irradiation

The red colour coordinate value considerably increased during the 5 days of steaming, as shown by the data points at the zero-irradiation time in Fig. 2. The average initial redness coordinate of the natural specimens was 2.7 units. The steaming at 120 °C increased this value to 10.3 units. The high redness value remained intact during the UV treatment. In contrast, the redness values of the other steamed and unsteamed samples increased continuously during the UV irradiation. The red colour coordinate increase was more intensive for the natural specimens than for the steamed (at 100 °C and 110 °C) specimens. These results indicate that the applied steam treatment enhanced the redness stability of the poplar wood against UV irradiation. The chemical modification of the hemicelluloses and extractives during steaming at 120 °C stabilised the redness of the poplar wood against short-term photodegradation.

The yellow colour coordinate changes were more uniform than the red colour coordinate alterations during UV irradiation (Fig. 3). The yellowness values of all investigated poplar wood series increased continuously through UV treatment. Nevertheless, the yellow colour of the untreated poplar specimens increased more rapidly than that of the steamed samples, while the yellowness change of the specimens steamed at 120 °C was less intensive. These results demonstrated that steaming slightly reduced the sensitivity of the yellow colour of the poplar wood to photodegradation. Similar to the other colour coordinates, the most stable wood colour in terms of redness could be reached by steaming at 120 °C, within the investigated temperature range.

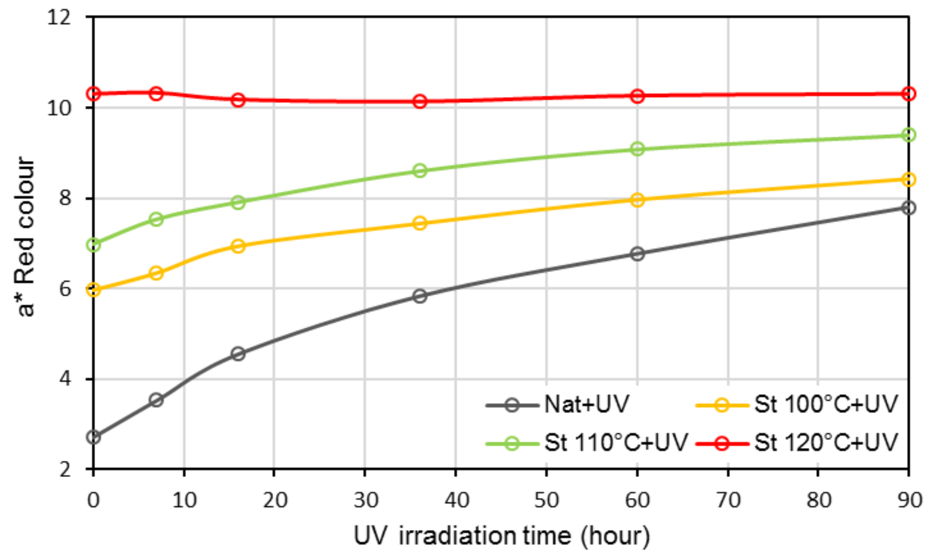

Fig. 2. Redness change of untreated (Nat) and steamed (St) poplar samples caused by UV light irradiation

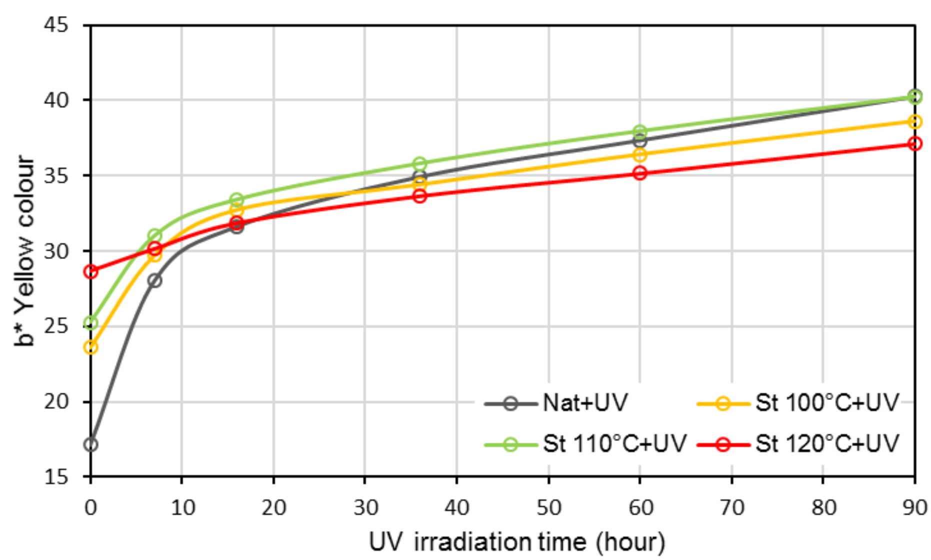

Fig. 3. Yellowness change of untreated (Nat) and steamed (St) poplar samples caused by UV light irradiation

The coloured data point movements on the a^*-b^* plane visualise the integrated effects of steaming and UV irradiation (Fig. 4). The dotted lines demonstrate the colour change caused by steaming, while solid lines represent the colour modification effects of the UV irradiation. The distance from the (0, 0) data point on the a^*-b^* plane gives the saturation value of the individual colour data points. Figure 4 demonstrates that both steaming and UV irradiation elevated the saturation value considerably. Steaming increased both the redness and yellowness coordinate values almost to the same direction on the a^*-b^* plane. This indicates that the rate of change of the a^* and b^* coordinate values did not change during steaming, and the values were only amplified by the rising steaming temperature. This finding suggests that the change of both the redness and yellowness values generated by steaming belonged to changes in the same chemical compounds.

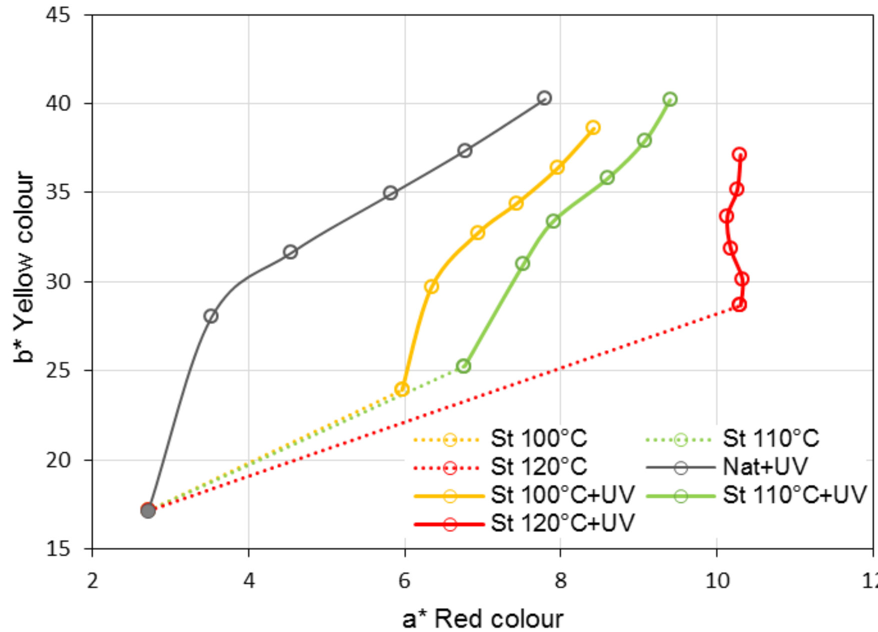

Fig. 4. The locations of colour dots on the Red Colour (*a**) - Yellow Colour (*b**) plane generated by steaming (St) and UV light irradiation

The UV radiation modified the values of *a** and *b** coordinates in different ways depending on the starting coordinate values. The greater changes were determined by the smaller initial values. Steaming at 120 °C resulted in such a high redness value that UV irradiation did not change it at all. Figure 4 demonstrates that the trend lines moved toward one redness value on the *a**-*b** plane, which means that steaming and UV irradiation modified the same chemical compounds (extractives and hemicelluloses), which determined the redness of the specimens. In contrast, the yellowness change was generated mainly by lignin degradation. Lignin was thermally stabile at the applied steaming temperatures. The vertical distances between the two ends of the solid lines show the lignin degradation rate. It shows that steaming reduced the photodegradation sensitivity of the poplar wood more effectively with rising temperatures.

CONCLUSIONS

1. Untreated and steamed poplar specimens were irradiated by strong UV emitter mercury lamps to test colour stability. The colour changes were monitored by objective colour measurements, and the colour data were presented in a CIE Lab system. Steaming generated considerable increases in colour saturation for the specimens, and the saturation value increased more during the UV treatment.
2. The lightness value of unsteamed control specimens decreased continuously during the entire UV irradiation period. In contrast, the lightness value of steamed samples

decreased only during the first seven hours of UV irradiation and remained constant afterward.

3. Steaming enhanced the stability of the red colour of poplar wood against UV irradiation. Five days of steaming at 120 °C stabilised the "red" chemical compounds of poplar wood against short-term photodegradation.
4. Steaming slightly reduced the sensitivity of the yellow colour of the poplar to photodegradation.

ACKNOWLEDGMENTS

This research was sponsored by the OTKA K116216 "Complex analysis of the physico-mechanical and surface-physical properties of wood with low density" project. The financial supports are gratefully acknowledged.

REFERENCES CITED

Banadics, E. A., and Tolvaj, L. (2019). "Colour modification of poplar wood by steaming for brown colour," *European Journal of Wood and Wood Products* 77(4), 717-719. DOI: 10.1007/s00107-019-01397-9

Csanady, E., Magoss, E., and Tolvaj, L. (2015). *Quality of Machined Wood Surfaces,* Springer, New York. DOI: 10.1007/978-3-319-22419-0

Denes, L., and Lang, E. M. (2013). "Photodegradation of heat treated hardwood veneers," *Journal of Photochemistry and Photobiology B: Biology* 118, 9-15. DOI: 10.1016/j.jphotobiol.2012.09.017.

Dzurenda, L. (2017). "Modification of wood colour of *Acer platanoides L*. to a brown-red shade caused by thermal treatment," *Forest and Wood Technology* 98, 26-32.

Dzurenda, L. (2018a). "Colour modification of *Robinia pseudoacacia* L. during the processes of heat treatment with saturated water steam," *Acta Facultatis Xylologiae Zvolen* 60(1), 61-70. DOI:10.17423/afx.2018.60.1.07

Dzurenda, L. (2018b). "The shades of color of *Quercus robur L*. wood obtained through the processes of thermal treatment with saturated water vapour," *BioResources* 13(1), 1525-1533. DOI: 10.15376/biores.13.1.1525-1533

Geffert, A., Vybohová, E., and Geffertová, J. (2017). "Characterization of the changes of colour and some wood components on the surface of steamed beech wood," *Acta Facultatis Xylologiae Zvolen* 59(1), 49-57. DOI: 10.17423/afx.2017.59.1.05

Milić, G., Todorović, N., and Popadić, R. (2015). "Influence of steaming on drying quality and colour of beech timber," *Glasnik Šumarskog Fakulteta* 112, 83-96. DOI: 10.2298/GSF1512083M

Pandey, K. K. (2005). "Study of the effect of photo-irradiation on the surface chemistry of wood," *Polymer Degradation and Stability* 90(1), 9-20. DOI: 10.1016/j.polymdegradstab.2005.02.009

Persze, L., and Tolvaj, L. (2012). "Photodegradation of wood at elevated temperature: Colour change," *Journal of Photochemistry and Photobiology B: Biology* 108, 44-47. DOI: 10.1016/j.jphotobiol.2011.12.008

Popescu, C. M., Popescu, M. C., and Vasile, C. (2011). "Structural analysis of photodegraded lime wood by means of FT-IR and 2D IR correlation spectroscopy," *International Journal of Biological Macromolecules* 48(4), 667-675. DOI: 10.1016/j.ijbiomac.2011.02.009

Timar, M. C., Varodi, A. M., and Gurau, L. (2016). "Comparative study of photodegradation of six wood species after short-time UV exposure," *Wood Science and Technology* 50(1), 135-163. DOI: 10.1007/s00226-015-0771-3

Todaro, L., Zuccaro, L., Marra, M., Basso, B., and Scopa, A. (2012). "Steaming effects on selected wood properties of Turkey oak by spectral analysis," *Wood Science and Technology* 46(1-3), 89-100. DOI: 10.1007/s00226-010-0377-8

Tolvaj, L., and Molnár, S. (2006). "Colour homogenisation of hardwood species by steaming," *Acta Silvatica et Lignaria Hungarica* 2, 105-112.

Tolvaj, L., Nemeth, R., Varga, D., and Molnar, S. (2009). "Colour homogenisation of beech wood by steam treatment," *Drewno* 52(181), 5-17.

Tolvaj, L., Molnár, S., Németh, R., and Varga, D. (2010). "Colour modification of black locust depending on the steaming parameters," *Wood Research* 55(2), 81-88.

Varga, D., and Van der Zee, M. E. (2008). "Influence of steaming on selected wood properties of four hardwood species," *Holz als Roh und Werkstoff* 66(1), 11-18. DOI: 10.1007/s00107-007-0205-5

Varga, D., Tolvaj, L., Tsuchikawa, S., Bejo, L., and Preklet, E. (2017). "Temperature dependence of wood photodegradation monitored by infrared spectroscopy," *Journal of Photochemistry and Photobiology A: Chemistry* 348, 219-225. DOI: 10.1016/j.jphotochem.2017.08.040

Zivkovic, V., Arnold, M., Radmanovic, K., Richter, K., and Turkulin, H. (2013). "Spectral sensitivity in the photodegradation of fir wood (*Abies alba* Mill.) surfaces: Colour changes in natural weathering," *Wood Science and Technology* 48(2), 239-252. DOI: 10.1007/s00226-013-0601-4

Article submitted: June 20, 2019; Peer review completed: August 13, 2019; Revised version received: August 14, 2019; Accepted: August 15, 2019; Published: August 29, 2019.
DOI: 10.15376/biores.14.4.8250-8256