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# THE COMPARISON OF THE EFFECT OF UV IRRADIATION AND THE COMBINED EFFECT OF UV IRRADIATION AND WATER LEACHING ON THE COLOR OF GREY POPLAR

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## ABSTRACT

A series of grey poplar (*Populus x canescens*) samples was irradiated by strong ultraviolet (UV) light emitter mercury lamp, while another series of specimens were treated with the combination of UV irradiation and water leaching. The total duration of UV irradiation for both series of specimens was 20 days. The colour parameters (CIE L*, a*, b*) were measured and evaluated after both UV irradiation and water leaching. Due to the 20 days of UV irradiation, the initial redness value of sapwood increased 2.69 times, while leaching reduced this factor to 1.77. In case of heartwood, the initial redness value increased 1.34-fold due to the 20-day UV exposure, while the leaching reduced this factor to 1.14. These multiplier values are 2.07 and 1.44 for the yellowness of sapwood, as well as 1.57 and 1.29 for the yellowness of heartwood. The leaching partly removed the yellow and red chromophore molecules generated by the UV irradiation. The samples were slightly lighter after water leaching.

KEYWORDS: Grey poplar, colour change, photodegradation, leaching by water.

## INTRODUCTION

The machined surface, regardless of the anatomical plane, reveals the colour variations between earlywood and latewood. The natural hues of wood provide warm feeling. Within its cellular structure, wood contains microscopic “mirrors” along the fibres. The sheen created by these micro mirrors results in a texture that is more refined, gentle, natural, and aesthetically pleasing than that of plastic or metal (Masuda 2001). The primary chemical compounds responsible for wood colour are the extractives (Umezawa 2001).

Just like other physical characteristics, the colour of wood is sensitive to light and heat, therefore it changes dramatically due to sunlight and rain during outdoor weathering (Tolvaj and Mitsui 2005, Tolvaj and Papp 1999). Untreated wood surfaces start yellowing and finally turn to grey, due to the washing effect of rainwater during weathering (Tolvaj and Papp 1999). Chemical analyses revealed that the primary cause of deterioration is related to the decomposition of lignin and extractives (George et al. 2005, Pandey and Vuorinen 2008, Popescu et al. 2011, Timar et al. 2016, Cogulet et al. 2016, Liu et al. 2017, 2019, Yu et al. 2021). The generated free radicals react with oxygen to produce carbonyl chromophoric groups (Tolvaj and Faix 1995, Pandey 2005, Xie et al. 2005, Timar et al. 2016). Chromophoric groups play a partial role in the discoloration of wood. Additionally, the extractives in wood are sensitive to light exposure, and the degradation products of these chromophores also contribute to colour changes (Chang et al. 2010, Fan et al. 2010). Arpaci (2021) found that high-density species are more stable against colour change during natural weathering than low-density species.

To monitor the photodegradation behaviour of wood, detailed research was carried out using 15 species (Persze 2011, Csanády et al. 2015). The results indicated that changes in the red hue were highly dependent on the wood species, primarily due to variations in extractive content, whereas changes in the yellow hue were largely independent of species. While the chemical structure of the main cell wall components, i.e. cellulose, hemicellulose, and lignin, shows minimal variation among wood species, there are significant differences in the composition of the extractives (Umezawa 2001).

A study on the colour and chemical changes in lime wood (*Tilia vulgaris* L.) treated with a $CO_2$ laser and subsequently exposed to UV radiation found that the total colour difference increased after UV exposure, and the surface of the laser-treated samples became lighter. In contrast, the surface of the untreated sample darkened after UV irradiation (Kubovský et al. 2016). A study examined the impact of UV irradiation on various native and exotic wood species. The findings confirmed that UV radiation led to rapid colour changes and increased surface roughness in extractive-rich wood species during the initial exposure period. Statistical analysis revealed that, over an extended exposure period, native wood species exhibited greater overall colour change and surface roughness compared to exotic species (Tomak et al. 2024). A study aimed to compare the effects of selected aging factors such as UV radiation and complex artificial weathering methods on colour. The processes resulted in the darkening of wood surfaces and the development of brown shades (Jankowska et al. 2020). Some results show, that in case of sugi wood (*Cryptomeria japonica* D. Don), under the combined effects of light and oxygen, the colour of the heartwood darkens and eventually becomes close to black in the presence of moisture (Chang 2000). Gindl et al. (2012) assume that UV irradiation acts as an ablation process, modifying (cleaning) the wood surface and opening the pits in spruce. The relationship between artificial light and sunlight was investigated on three wood species, namely teak (*Tectona grandis* L.F.), mabberley (*Stereospermum colais*) and Basra locus (*Dicorynia guianensis*). The results show that the artificial light treatment was 30 times faster than the sunlight treatment (Liu et al. 2019).

The leaching effect of rain is the second most damaging factor in the outdoor weathering of wood. However, the impact of water leaching on colour change has been scarcely studied. Some studies address the combined effects of light exposure and water leaching during artificial weathering (Pandey and Khali 1998, Kamdem and Greiler 2002, Hansmann et al. 2006, Fufa et al. 2013). These studies monitored the combined effect of the two factors, without isolating their individual impact. Kannar et al. (2018) studied the weathering properties of spruce wood generated by separate UV irradiation and water leaching. The 50 days UV radiation multiplied the initial redness value by 4.48, and the leaching reduced this factor to 3.28. These values for yellowness were 2.13 and 1.71.

A study evaluated the effect of accelerated weathering on eucalyptus clones used for decking, thermally modified at 185°C and 200°C, both with and without stain application. Colour measurements and accelerated weathering tests were conducted on samples with and without stain application at three stages: before weathering, after 168 h (seven days) of exposure, and after 336 h (fourteen days) of exposure. The unstained woods exhibited greater total colour variation compared to the coated ones. Consequently, thermal treatments enhanced the colour stability and resistance of the thermally modified eucalyptus wood compared to the untreated control samples (Andrade et al 2024).

The objective of this study was to characterize and compare the surface degradation of untreated wood (spruce, oak, black locust, pine, Douglas fir, larch, maple, poplar and alder) caused by weathering. Oak wood showed the least amount of discoloration, whereas spruce wood showed the most. Among the softwoods, the depth of colour changes was similar (Oberhofnerová et al. 2017). The aim of this study was to investigate the separate individual colour alteration effects of UV light irradiation and water leaching during artificial weathering of grey poplar wood.

## MATERIAL AND METHODS

Grey poplar (*Populus x canescens*) specimens having low extractive content were chosen for the colour change test. The specimens were prepared with dimensions of 150 x 30 x 10 mm (L x R x T). Two series of 5 specimens were created, and 10 points were measured on each specimen. The UV irradiation and the leaching effect of the rain were simulated by the following experiments. Samples were irradiated by a mercury lamp and then plunged into distilled water (wet treatment). A double mercury vapor lamp, as a strong UV light emitter, provided the light irradiation. The total electric power of the applied double mercury lamps was 800 W. The UV irradiation was 80% of the total light emission of the lamps. Specimens were located at a distance of 64 cm from the lamp. The temperature in the chamber was set to 34°C during the irradiation. The irradiation time was 48 h, followed by 24 h water leaching. These two treatments together constituted one cycle, and this cycle was repeated 10 times. The other series of specimens got light irradiation only (dry treatment). All colour data presented in this study are the average of 50 measured data.

The colour of the wood specimens was measured after each (UV and leaching) treatments. The radial surface was used for colour measurement, generating the average colour data of earlywood and latewood. The colour measurement was carried out after both light irradiation and water leaching during all the 10 cycles. Wet samples were dried at 60°C up to the initial weight after each leaching. This process guaranteed that the colour measurement was done at the same moisture content each time. Measurements were carried out with a Konica-Minolta 2600d colorimeter. The CIE L* (Lightness), a* (Redness), b* (Yellowness) colour space data were calculated based on the D65 illuminant and 10° standard observer with an aperture diameter of 8 mm.

## RESULTS AND DISCUSSION

The main goal of this study was to compare the colour modification of photodegraded wooden surfaces with and without water leaching. These alterations are visible in Figs. 1-5 showing the changes of the 3 colour coordinates. The changes are presented based on UV irradiation time as independent variable. Fig. 1 represents the change of lightness. In the first 6 days the UV irradiation produced intensive and continuous lightness decrease, as reported in earlier papers (Cogulet et al. 2016, Tolvaj and Faix 1995, Oltean et al.2010, Sharrat et al. 2009). The decrease was slow for dry sapwood and negligible for dry heartwood afterward. Leached samples showed slight lightness increase after 6-day UV irradiation. The water leaching partly washed out the degradation products of the light irradiation. This phenomenon generated lightness increase after the third cycle of treatment.

A recent study (Kannar et al. 2018) shows, that the lightness of dry spruce wood decreased to 22,96 %- of the initial value, after 20 days of treatment and in case of leached spruce wood lightness decreased to 20,76%. In comparison the lightness of dry poplar sapwood decreased by 11.60%, the dry heartwood decreased by 9.16%. The leached poplar sapwood decreased by 9.33%, the leached heartwood decreased by 7.65%. Poplar wood lost less lightness value during treatment than spruce wood.

The lightness values are calculated from the Y tristimulus value. The other coordinates a* and b* are calculated using two tristimulus values. The Y tristimulus value is determined by the total visible part of the reflection spectrum. That is why the lightness change is not useful in determining the individual chemical changes. Redness and yellowness change reflect more precisely the chemical alterations than the lightness change (Tolvaj 2024).

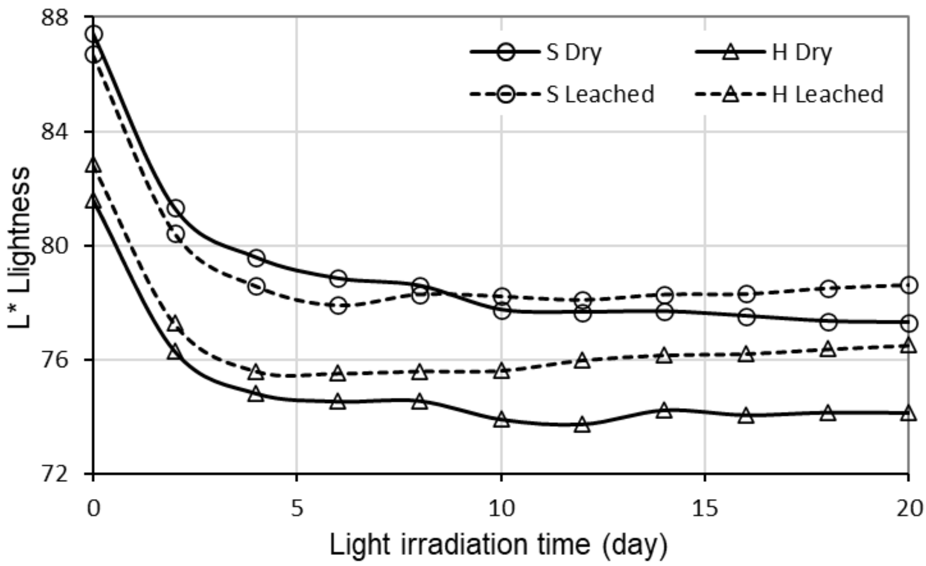


*Fig. 1: Lightness change of grey poplar sapwood (S) and heartwood (H) caused by UV*

*irradiation (Dry) and by UV irradiation and water leaching (Leached).*

The greatest difference between the effects of dry and wet treatments was found for the yellow colour coordinate (Fig. 2). The irradiation time in Fig. 2 include the duration of UV irradiation only, for the correct comparison of the two types of treatments (leaching time is not included). The individual effect of leaching will be presented in Figs. 3 and 5. The yellowness value increased rapidly during the first cycle. The curve of leached samples ran slightly above the curve of dry UV treatment during the first two cycles. After this point the two curves separated, and the curve of leached samples was under the curve of dry UV treated samples. The distance between the two lines increased with irradiation time. This fact shows that yellow chromophores were leached out continuously by water. The exact determination of the types of leached molecules requires further chemical investigation. The yellowness of dry samples increased up to the $14^{th}$ day of UV irradiation and remained almost constant during the further treatment. The yellowness value of leached samples increased during the first 3 days of treatment only and slightly decreased after that. While the 20-day UV irradiation increased the initial yellowness value of sapwood by a factor of 2.07, UV irradiation followed by leaching resulted in only a 1.44-fold increase in yellow colour. In case of heartwood, the 20 days UV irradiation multiplied the initial yellowness value 1.57 times, and the leaching reduced this factor to 1.29. Previous research (Kannar et al. 2018) showed that yellowness of dry spruce was 2.06 times higher after 20-day treatment, while the increase in yellowness of leached samples was 1.81-fold. Comparing these two results, the change in yellowness was lower for grey poplar than for spruce.

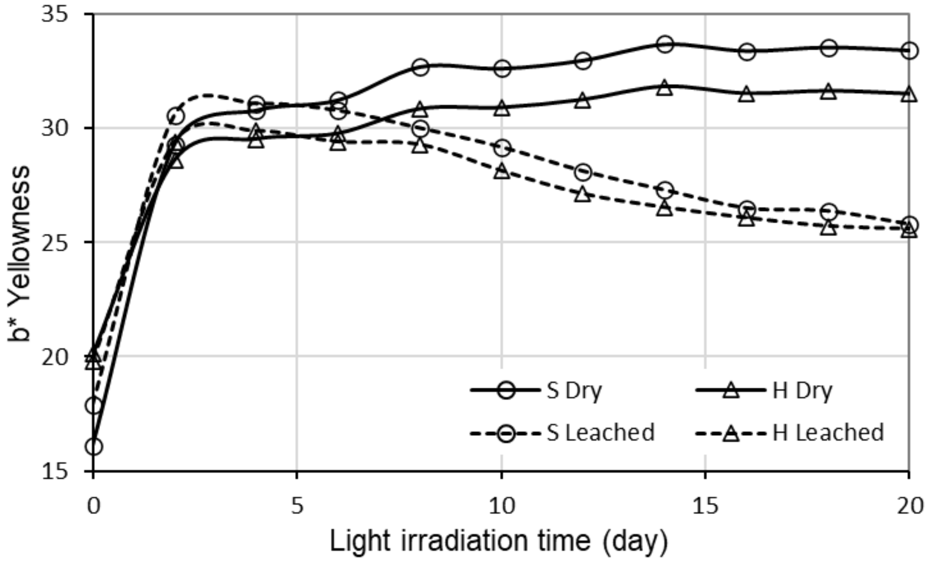


*Fig. 2: Yellowness change of grey poplar sapwood (S) and heartwood (H) caused by UV irradiation (Dry) and by UV irradiation and water leaching (Leached).*

Three phenomena contributed to the change in yellowness. The UV light degraded the chromophore compounds of wood reducing the yellowness value. The chromophore products of lignin degradation intensified this value, but the leaching mitigated it. During the first three cycles the effect of lignin degradation was dominant. Between the fourth and the sixth cycles, the effect of leaching compensated for that of the yellow chromophore production and the intensity of yellowness remained constant. After the seventh cycle the leaching was slightly more dominant than the photodegradation and the yellowness value decreased. The reason, for the yellowness values of leached samples being slightly above the values of dry UV treatment in the first three cycles might be that the leaching opened new surface for the photodegradation. The applied treatments generated small yellowness homogenization between sapwood and heartwood.

Fig. 3 represents the yellowness change of heartwood during the cyclic UV irradiation and water leaching. The UV irradiation produced a substantial yellowness value increase during the first day of treatment, as reported in earlier papers (Cogulet et al. 2016, Tolvaj and Faix 1995, Sharrat et al. 2009, Wang and Ren 2008, Persze and Tolvaj 2012). This rapid change was followed by moderate increase for dry samples (empty columns). Yellowness of leached samples increased only during the first 4 days of UV irradiation (columns marked by parallel lines). After that, the yellowness value decreased slightly. The water leaching reduced the yellowness intensity in all cases (grey columns). The individual leaching effects were negligible after the fourth cycle. Sapwood showed similar yellowness alterations by water leaching as heartwood did.

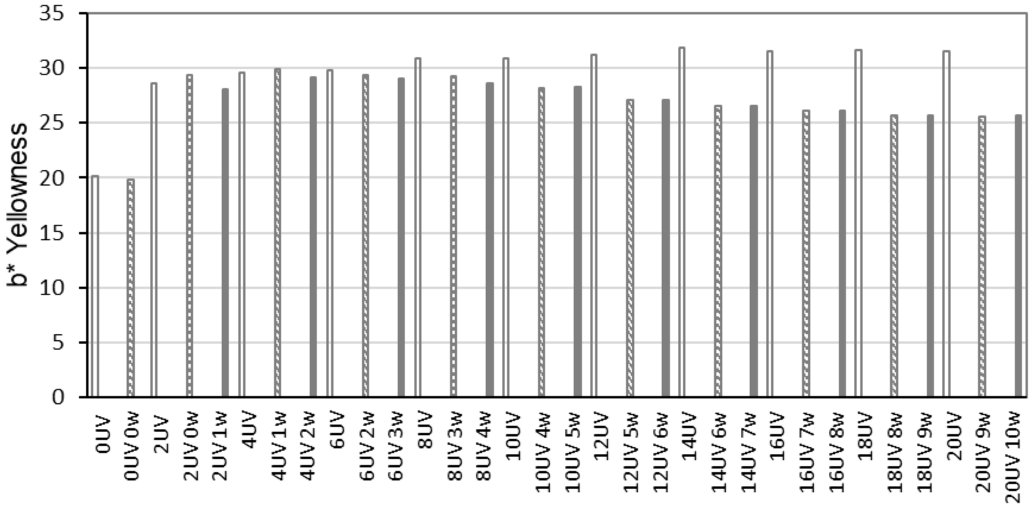


*Fig. 3: Yellowness change of heartwood caused by UV irradiation and water leaching.*

Fig. 4 shows the redness change during the 10 cycles of UV irradiation and water leaching. Pure UV irradiation (dry treatment) generated intensive redness value increase during the first 8 days of irradiation. After this period, the redness value had a plateau in case of heartwood for the remaining test period. In case of the dry sapwood, the redness value increased slightly after the fourth cycle. The curve of leached samples ran slightly above the curve of dry UV treatment in the first 5 days of UV irradiation. This statement is hardly visible in Fig. 4 because of the different starting points, but the parallel offset of the lines confirms it. The reason could be that the leaching opened new surfaces for the photodegradation. The redness value of leached sapwood samples increased during the first six days of treatments, then it slightly decreased. Duration of redness value increase was only 2 days for heartwood. The distance between the two lines (dry and leached) increased slightly with irradiation time. This fact shows that red colorants were leached out continuously by water. The applied treatments generated redness homogenization between sapwood and heartwood.

In case of sapwood the 20-day UV irradiation multiplied the initial redness value 2.69 times, and the leaching reduced this factor to 1.77. In case of heartwood the 20-day UV irradiation multiplied the initial redness value 1.34 times, and the leaching reduced this factor to 1.14. The exact determination of the types of leached molecules requires further chemical investigation. According to a recent study (Kannar et al. 2018), the initial redness value of spruce was 3.59 times higher after 20-day UV irradiation, while the leaching reduced this factor to 3.16. Comparing these results, the change in redness value was lower for grey poplar wood than for spruce. Considering the strength values (Poplar bending strength 67.5 MPa, Spruce bending strength 49-78-136 MPa) (Molnár et al. 2024), grey poplar can be a good substitute for spruce in the wood industry with proper wood protection.

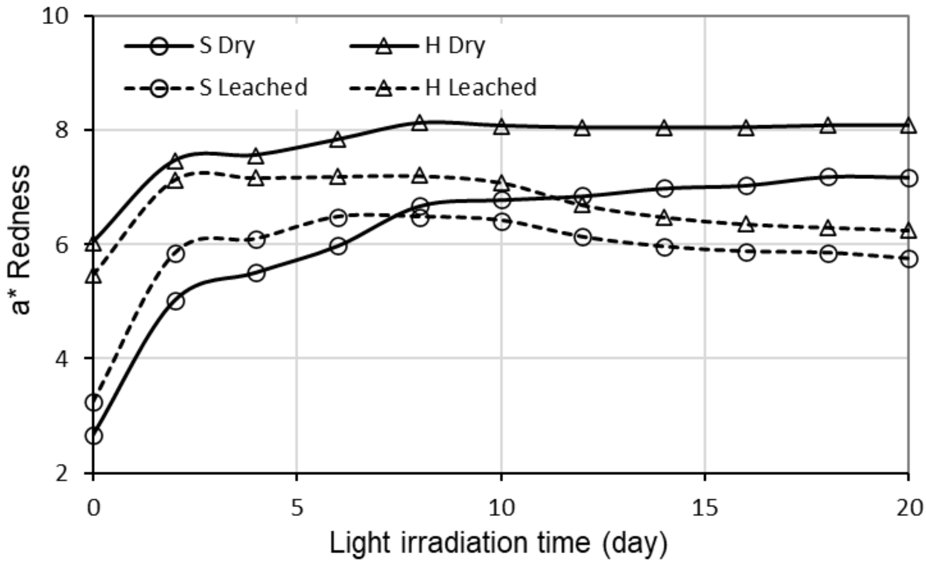


*Fig. 4: Redness change of grey poplar sapwood (S) and heartwood (H) caused by UV irradiation (Dry) and by UV irradiation and water leaching (Leached).*

The increase of redness value was generated partly by the degradation products of extractives (Timar et al. 2016). The same thing occurs during the steaming of wood (Tolvaj et al. 2010, 2012). Grey poplar wood has low extractive content; therefore, the degradation products of lignin play an important role in redness change. During light irradiation phenolic groups react with photons and form phenolic radicals that transform into **o** and **p** quinonoid structures (Cogulet et al. 2016, Pandey 2005, Leary 1968). These newly generated quinones increased the value of redness. Most red dyestuffs produced by plants are quinones (Melo 2009, Mills & White 2011).

Fig. 5 shows the redness change of sapwood during the cyclic UV irradiation and water leaching. The dry samples presented continuous redness value increase during the whole UV irradiation period. The tendency to increase was rapid during the first 2 days of irradiation and moderate thereafter. The UV irradiation generated redness value increase during the first 6 days treatment for leached samples, then the redness values slightly decreased. The water leaching partly washed out the water-soluble chromophore degradation products. The greatest leaching effect occurred during the first leaching. After the fourth cycle, the individual leaching effect was negligible. Heartwood suffered similar redness change due to the water leaching as sapwood did (not presented).

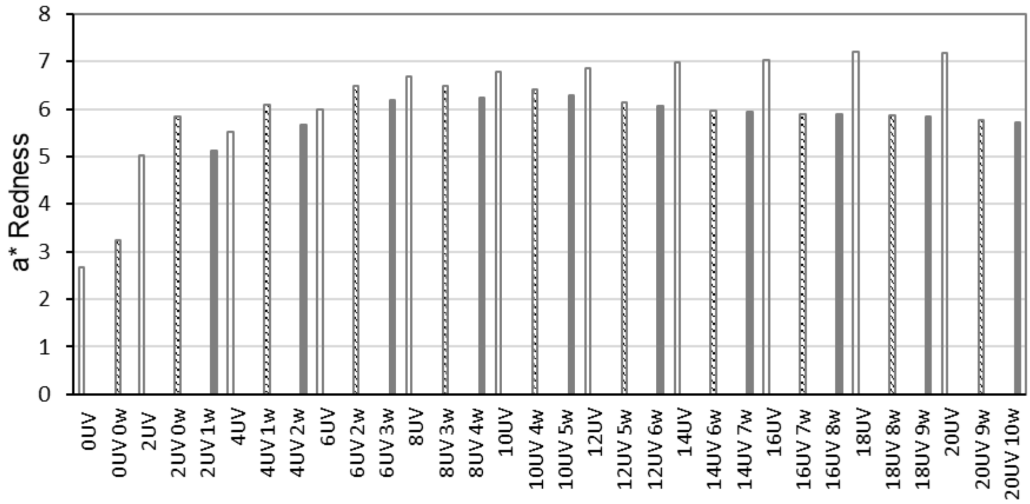


*Fig. 5: Redness change of sapwood caused by UV irradiation and water leaching (w).*

Fig. 6 presents the locations of colour dots on the a*-b* plane during the 20-day UV irradiation and water leaching. Filled symbols represent the starting points belonging to the untreated samples. These dots are followed by the dots of UV irradiated samples after 2-, 4-, 6-, 8-, 10-, 12-, 14-, 16-, 18- and 20-day exposure. This figure represents the change of hue and chroma values as well. Chroma value is determined by the distance between the colour dot and the origin of the coordinate system. The chroma values of dry samples increased considerably during the treatment. Similar chroma value increase happened for leached samples during the first 4 days of UV irradiation only, while the leaching reduced the chroma values afterwards. Decrease of chroma value showed the leaching effect. The hue value of sapwood samples did not change during the first cycle and slightly decreased afterward. Heartwood samples presented slow but continuous hue value increase.

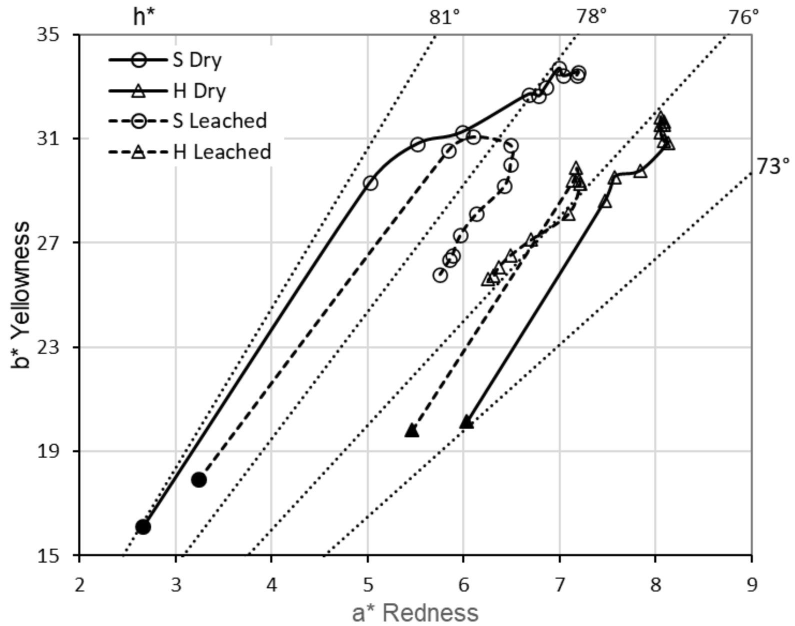


*Fig. 6: Redness, yellowness and hue angle values of grey poplar sapwood (S) and heartwood (H) caused by UV irradiation (Dry) and by UV irradiation and water leaching (Leached).*

## CONCLUSIONS

One series of grey poplar heartwood and sapwood specimens was irradiated by strong UV light emitter mercury lamp (dry series) and another series of specimens were treated with a combination of UV irradiation and water leaching (leached series). The leaching partly removed the yellow and red chromophore molecules generated by the UV irradiation. The specimens become slightly lightened after water leaches. The applied treatments generated colour homogenization between sapwood and heartwood. In the case of sapwood, 20-day UV irradiation multiplied the initial redness value by 2.69, and leaching reduced this factor to 1.77. In the case of heartwood, 20 days of UV irradiation multiplied the initial redness value by 1.34, and leaching reduced this factor to 1.14. These values for yellowness were 2.07 and 1.44 for sapwood, and 1.57 and 1.29 for heartwood. In comparison to the spruce wood, the grey poplar undergoes less change. The lightness and redness of grey poplar changed less during treatment than that of spruce. Except of the dry sapwood, the changes in yellowness were also less for grey poplar than for spruce. Grey poplar is therefore less sensitive to the radiation used than spruce, and its original colour changes less. Considering the similar bending strength values, poplar bending strength 40-67.5-90 MPa, spruce bending strength 49-78-136 MPa (Molnár et al. 2024), in wood industry the grey poplar can be a good substitute for spruce with proper wood protection.

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