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Change of Wood Moisture Content During Artificial Light Irradiation and its Influence on Colour Measurement

Promjena sadržaja vode u drvu tijekom izlaganja umjetnoj svjetlosti i njezin utjecaj na mjerenje boje

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ABSTRACT • *This paper discusses the differences between colour parameters of dried and conditioned wood surfaces irradiated by light. Samples of two wood species – Hevea (Hevea brasiliensis Müll. Arg.) and Jatoba (Hymenaea courbaril L.) – were exposed to artificial sunlight. During this process, sample moisture content decreased by 6 %. The colour parameters were measured immediately after irradiation and after conditioning on former moisture content level. Statistically significant differences were found between colour parameter values. Nevertheless these differences were too low for practical importance.*

Key words: *colour, conditioning, moisture content, light irradiation*

SAŽETAK • *U radu se analiziraju razlike parametara boje površine suhoga i kondicioniranog drva nakon izlaganja umjetnoj svjetlosti. Uzorci dviju vrsta drva – Hevea brasiliensis Mull Arg. i Hymenaea courbaril L. – bili su izloženi umjetnoj Sunčevoj svjetlosti. Tijekom tog procesa sadržaj vode u uzorcima smanjen je za 6 %. Parametri boje izmjereni su odmah nakon izlaganja svjetlosti i nakon kondicioniranja uzoraka na početni sadržaj vode. Utvrđene su statistički značajne razlike između vrijednosti parametara boja. Ipak te su razlike premalene da bi imale praktičnu važnost.*

Ključne riječi: *boja, kondicioniranje, sadržaj vode, izlaganje svjetlosti*

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1 INTRODUCTION
1. UVOD

Wood in outdoor use is exposed to weathering. The appearance and surface properties of wood are mainly changed by sunlight, especially its UV part, which induces photochemical reactions in wood (Hon, 2001; Müller *et al*., 2003). It is difficult to repeat the natural weathering conditions, therefore the wood photodegradation is often induced in artificial conditions by xenon lamp as the most frequently used light source (Tolvaj and Varga, 2012).

Due to the light, the colour of most wood species changes to yellow up to brown because of lignin and extractive photo-oxidation (Feist and Hon, 1984). Wood rich in extractives can fade before browning shows distinctly (Feist, 1983). The reddish brown heartwood of Jatoba is characterized by distinct darkening if it is exposed to sunlight (Jankowska *et al*., 2011; Baar and Gryc, 2012). The minor effect of UV light on chromatic parameters with slight reddening was showed for Jatoba (Pastore *et al*. 2004; Costa *et al*. 2010). Decrease in value of lightness and increase in the chromaticity parameters *a* and *b* was observed in light coloured Hevea by Srinivas and Pandey (2012).

The photodegradation of wood surface is closely connected to surface heating and subsequent thermal degradation. The temperature of wood surface exposed to sunlight depends on its darkness; sun-irradiated wood can reach 60 °C, or even 90 °C if it is dark enough (Tolvaj *et al*., 2011). During wood photodegradation experiments under artificial conditions, higher temperatures ranging between 40 and 60 °C are often used in the testing chamber for a period of up to 500 hours (Chang *et al*., 2010; Tolvaj and Mitsui, 2005; Blanchard and Blanchet, 2011; Pastore *et al*., 2004). This temperature is high enough for wood drying, especially where it is applied in the long term. According to Brunner and Hildebrand (1987), the normal drying temperature used in industry for wood drying ranged from 40 to 90 ºC. Simpson (1999) stated that a typical hardwood drying schedule in United States of America might begin at 49 °C and 80 % relative humidity when the lumber is green.

The moisture content of wood is changed during the irradiation if the relative air humidity is not controlled. Hon and Minemura (2001) stated that colour is darker in unseasoned wood than in seasoned one, because of free water which replaces the air inside the cell. The index of refraction of water is higher than that of air, which results in an increase of scattering events before the light leaves the surface. Part of the diffuse light is captured within the wet layer of the surface, so less light is reflected from a wet surface (Meichsner *et al*., 2011). On the other side, there is limited information as to whether the change of moisture content below fibre saturation point influences colour parameters as well. Neméth *et al*. (2013) showed for black locust and poplar wood that colour co-ordinates were not influenced by moisture content below fibre saturation point if the temperature was kept low.

We assumed that the moisture content of samples is decreased during irradiation process because of higher temperature and that its change can influence the measurement of colour parameters of irradiated surface.

2 MATERIAL AND METHODS
2. MATERIJAL I METODE

The wood species used were Hevea (*Hevea brasiliensis* Müll. Arg.) and Jatoba (*Hymenaea courbaril* L.) heartwood from commercial sources. Twenty-five samples of each species, measuring 15 × 4 × 50 mm (L × R × T) with sanded tangential surface, were exposed to artificial sunlight of a xenon lamp (1800W xenon arc lamp – full-spectrum, irradiance 0.55 W/m^2 – 340 nm) for up to 192 hours at 60 °C without controlling relative air humidity. The sample dimension in longitudinal direction was adapted to the measuring aperture of spectrophotometer and was as short as possible because of easier moisture content equalization and more homogeneous moisture content distribution after irradiation.

Samples were removed from the chamber at regular intervals and put into the drying chamber with the temperature preset at 60 °C during sample weighing and colour measurement. The colour changes were first analyzed immediately after exposure at two marked spots on each sample. Discolouration of wood surface due to UV irradiation was measured by mobile spectrophotometer Spectro-guide 45/0 (45/0 measuring geometry, 10º standard observer, D65 standard illuminant, aperture 11 mm, CIEL**a***b** colour system) in the following intervals: 1, 2, 4, 6, 12, 24, 48, 96, 192 hours. Colour parameters *L*, *a*, *b* were measured at two marked spots on each specimen and the average value was calculated. These values were used to calculate the overall colour change *E* according to the following equation:

$$\Delta E^* = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2}$$

where ΔL^*, Δa^*, Δb^* represent the differences between the colour parameter values of original and irradiated surfaces.

After colour measurement, the samples were stored in a dark room for conditioning till the moisture content was stable and colour was measured again at the same spots. Samples weight was measured before exposure, after taking them out from the xenon test chamber and then again following conditioning. The samples were dried in the drying chamber at 103 °C at the end of the experiment to get the oven-dry sample weight. Moisture content was calculated using the following equation:

$$MC = (m_w - m_0) / m_0$$

where m_0 is the mass of the oven-dry specimen and m_w is the mass of the specimen at the given moisture content.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

The average moisture content of samples before irradiation was 7.4 % in conditioned state for both spe-

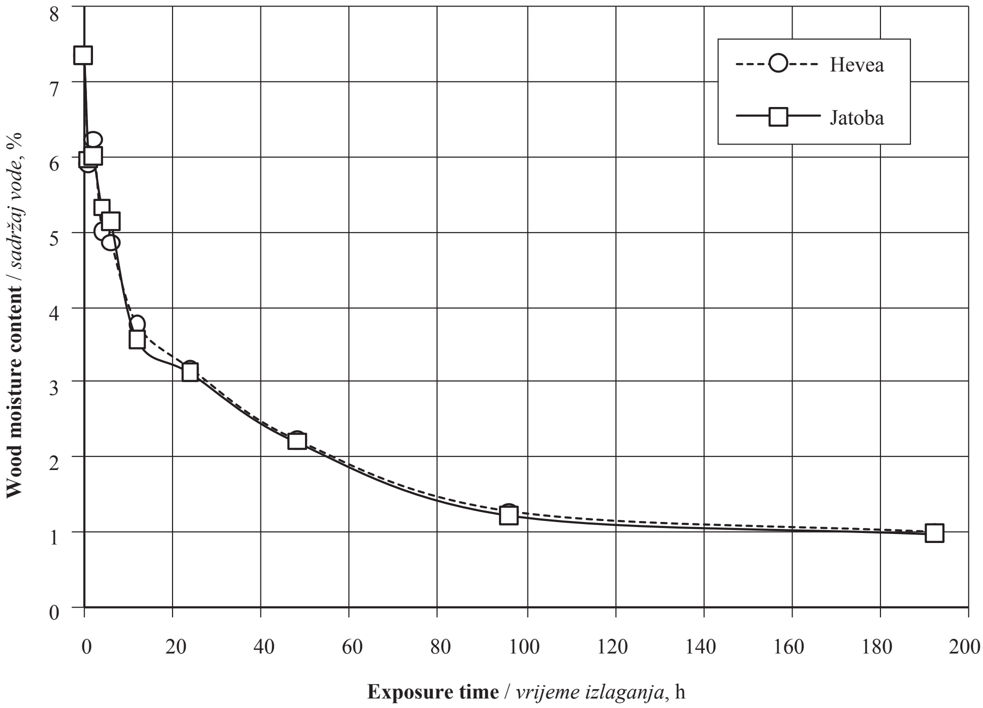

Figure 1 Moisture content change due to light-irradiation
Slika 1. Promjena sadržaja vode zbog izlaganja svjetlosti

cies. During the process of light-irradiation, when the temperature was kept at 60 ºC, the moisture content of samples decreased depending on the duration of the irradiation cycle. The change of moisture content is shown in Figure 1. After the longest uninterrupted interval of irradiation (96 hours), the moisture content of samples was lower than 1 %. The changes in relative humidity and temperature of the surrounding air established conditions suitable for wood drying. Changes in wood moisture content are usually gradual, and short-term fluctuations tend to influence only the wood surface. The sample dimension, especially in longitudinal direction, was as short as possible to intensify drying in the whole volume and to get homogenous distribution. Usually, the tested samples are more large-sized and the moisture changes are mostly limited to the surface, however the colour is measured just there.

The colour parameters *L**, *a** and *b** of samples were measured in intervals immediately of the chamber when the surface was still dried. After each interval, samples were conditioned to the moisture content around 7.5 %. Table 1 shows the colour parameters and colour change Δ*E* for samples before and after conditioning after the last period of irradiation (96 hours). The discoloration development of both species corresponded to colour changes stated in literature (Pastore *et al*., 2004; Costa *et al*., 2010; Srinivas and Panday, 2012). All three parameters had slightly higher values after conditioning. The difference of these colour parameters was about 1, so it is not detectable by human eye. The chromatic parameters *a** and *b** were more intensive with higher moisture content. On the other hand, the surface colour of dried wood was darker than wood with higher moisture content. It differs from the situation when free water is present in wood, as the surface looks darker with higher wood moisture content. The refractive index of the fibres is completely altered when water molecules get trapped in the cell wall, which changes the amount of light internally reflected back to the observer's eye, hence the shade of the colour is perceived differently. Németh *et al*. (2013) analyzed colour change during drying under different temperature conditions in Black locust and Poplar. In both cases more distinct discolouration was caused by higher temperature (60 and 80 ºC). The colour parameters were almost stable when the wood was only ex-

Table 1 Colour parameter values measured before and after sample conditioning (192 hours)
Tablica 1. Vrijednosti parametara boje mjerene prije i nakon kondicioniranja uzoraka (192 sata)

Wood species *Vrsta drva*	**Treatment** *Obrada*	***L****	***a****	***b****	**Δ*E****
Hevea	Non-irradiated / *bez izlaganja*	72.74	4.58	21.11	-
	Irradiated / *izlagano svjetlosti*	74.76	3.15	28.75	8.53
	Conditioned / *kondicionirano*	75.23	3.91	30.09	9.77
Jatoba	Non-irradiated / *bez izlaganja*	49.26	11.26	23.06	-
	Irradiated / *izlagano svjetlosti*	47.35	11.31	20.53	5.86
	Conditioned / *kondicionirano*	48.09	12.68	21.8	5.58

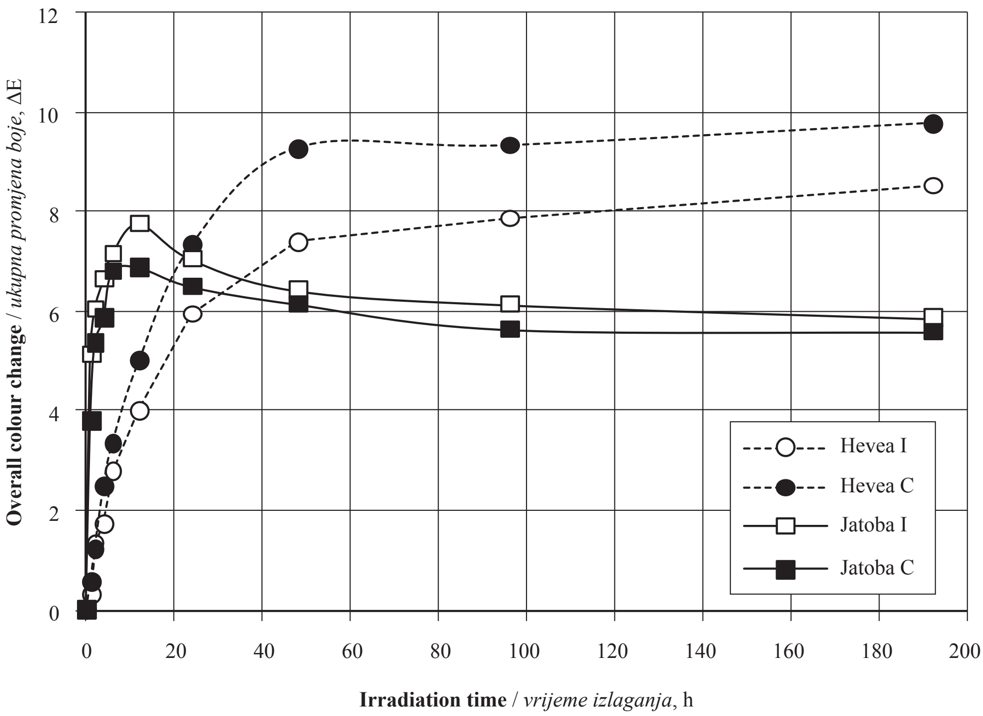

Figure 2 Differences in overall colour change Δ*E* after irradiation and conditioning (I – irradiation, C – conditioning)
Slika 2. Razlike ukupnih promjena boje nakon izlaganja svjetlosti i kondicioniranja (I – drvo izlagano svjetlosti, C – kondicionirano drvo)

posed to the temperature of 20 ºC and the wood moisture content was below 20 %.

The highest differences between dry and conditioned surface were found for overall colour change Δ*E*. Figure 2 shows its value progress during irradiation. The changed wood moisture content influenced more the colour of light-coloured Hevea than dark brown Jatoba. The colour of wood is probably influenced by moisture content below fibre saturation point as well. The expected difference in moisture content (up to 6.5 %) during irradiation is too low to see distinct colour change and, therefore, in this case the sample conditioning is not necessary.

The paired *t*-test was used for finding statistical differences between values measured before and after sample conditioning. The *p* values for individual colour parameters and intervals, taking Hevea as an example, are stated in Table 2. The values after conditioning differed significantly from values measured before conditioning for all intervals, even for the shortest irradiation interval (1 hour), when the moisture content decreased only by 1 %. The surface is dried more intensively and it reaches similar moisture content independently of the duration of exposure, whereas longer period is necessary for the decrease in moisture content of the inner part. However, from a practical point of view, these differences are negligible, because they are too low to be seen by the human eye. Also, the colour variation in the same wood piece can lead to higher differences if it is not measured exactly at the same spot.

4 CONCLUSION
4. ZAKLJUČAK

The moisture content of samples decreases during the process of artificial light irradiation if the temperature is higher (40-60 ºC) and moisture content in the chamber is not controlled. Therefore, the samples should be conditioned before colour measuring to provide identical conditions. Statistically significant differences were found between values of colour parameters measured before and after conditioning. From a practical point of view, these differences are negligible. They are too low to be seen by the human eye and usually not measured at exactly the same spot, which prob-

Table 2 The *p* value of paired *t*-test for colour parameters measured before and after conditioning (at 95 % confidence level) for Hevea ($^{n.s.}$ statistically non-significant)
Tablica 2. Vrijednosti vjerojatnosti *p* za *t*-test između parova izmjerenih parametara boje prije i nakon kondicioniranja za drvo *hevea* ($^{n.s.}$ statistički nije značajno)

Colour parameter *Parametar boje*	**Time of irradiation, h** / *Vrijeme izlaganja svjetlosti, h*								
	1	2	4	6	12	24	48	96	192
Δ*E*	0.004	0.09$^{n.s.}$	0.000	0.000	0.000	0.000	0.000	0.000	0.000
*L**	0.000	0.07$^{n.s.}$	0.000	0.000	0.000	0.000	0.000	0.000	0.000
*a**	0.000	0.000	0.035	0.011	0.002	0.91$^{n.s.}$	0.000	0.37$^{n.s.}$	0.000
*b**	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

ably leads to higher differences in wood colour because of its heterogeneity.

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