

COLOR AND LIGHT- INDUCED DISCOLORATION OF WOOD FROM THE TROPICAL SPECIES JATOBA AND AFRICAN PADAUK

Jan BAAR

Ing. – Mendel University in Brno – Faculty of Forestry and Wood Technology

Address: Zemědělská 3, 61300 Brno, Czech republic

E-mail: jan.baar@mendelu.cz

Stefano D'AMICO

Dr. – University of Natural Resources and Life Sciences, Vienna (BOKU) – Institute of Food Technology

Address: Muthgasse 18, 1190 Wien, Austria

E-mail: stefano.damico@boku.ac.at

Rupert WIMMER

Prof. Dr. – University of Natural Resources and Life Sciences, Vienna (BOKU) – Institute of Natural Materials Technology, IFA Tulln

Address: Konrad-Lorenz-Straße 20, 3430 Tulln an der Donau, Austria

E-mail: rupert.wimmer@boku.ac.at

Abstract:

*This study investigates the relationships between total extractive content and wood color as well as discoloration caused by artificial sunlight, of the tropical species Jatoba (*Hymenaea courbaril* L.) and African Padauk (*Pterocarpus soyauxii* Taub). The surface color was measured before and after light exposure by a spectrophotometer (CIEL*a*b*). Wood powder samples were extracted with acetone/methanol/distilled water mixture to determine the total extractives content. Color parameters of wood were related to the amount of extractives. The influences on the individual parameters L*, a* or b* were found to be species dependent. The strongest influence was observed for lightness L*. The other color parameters measured after ultraviolet- light exposure were also related to the extractives contents, or to generated photodegradation products.*

Key words: *extractives; photodegradation; color; Jatoba; African Padauk.*

INTRODUCTION

Surface color together with color stability after light exposure is among the most important aesthetic aspects of wood used for exterior as well as interior purposes. The color of wood is determined by existing chemical components that interact with light, i.e., the presence or absence of extractives in the wood structure (Hon and Minemura 2001). Extractives have a very heterogeneous chemical background including lipids, phenolic compounds, terpenoids, fatty acids, resin acids, steryl esters, to sterols and waxes (Shebani *et al.* 2008). Among the different extractive component the phenolic components play a crucial role with respect to light sensitivity (Chang *et al.* 2010).

The sunlight, i.e. the ultraviolet (UV) portion of the electromagnetic spectrum causes most of the observed color changes. Exposure to light causes darkening of the wood surface, leading to a photo-discoloration and to a photo-degradation (Pandey 2005). The reaction is related to oxygen and free radical reactions that are formed during photo-degradation of lignin and extractives (Feist and Hon 1984, Hon 1991). Phenolic extractives undergo rapid photochemical changes and during photo-degradation chromophoric groups are created (Pandey 2005, Chang *et al.* 2010). The amount of extractives affects the intensity of wood color, whereas their chemical nature of the prevalent extractives determines the type and speed of the photodegradation processes (Romagnoli *et al.* 2013). UV-induced discolorations of extractive-rich wood are most likely caused by phenolic compounds: carbonyl groups containing chemical structures seem to be in associated with observed wood color changes (Dirckx *et al.* 1987, Hon 1991).

In this work, we explore relationships among heartwood color, discoloration after artificial sunlight irradiation, and the total extractive content of two tropical species. We hypothesize that wood samples with higher extractives content are more prone to discoloration after UV irradiation. We also hypothesize that the type of discoloration is species dependent, which might be linked to the involved extractives.

MATERIAL AND METHODS

Fourteen heartwood samples of the two tropical species Jatoba (*Hymenaea courbaril* L.) and African Padauk (*Pterocarpus soyauxii* Taub) were chosen for this investigation. These species are commercially viable and they are known for their intense heartwood coloration, which is often subject of high variability. Prior to light exposure the surfaces were sanded, before storing them in a standard-acclimatized darkroom. Samples were irradiated for 144 hours in a xenon test chamber Q SUN Xe-1, Q-Lab Corporation, U.S.A., which uses a 1800W xenon arc lamp, with a irradiance intensity of 0.55W/m² at 340nm, and a black panel temperature of 55°C. Specimen positions within the chamber were repeatedly changed to equalize for the radiation intensity.

The mobile spectrophotometer spectro-guide 45/0 (45/0 measuring geometry, 10° standard observer, D65 standard illuminant, aperture 11mm, CIEL*a*b* color system; BYK-USA Inc.) was used to measure surface color before and after irradiation. To describe the color space the CIEL*a*b* rectangular color system was applied. CIEL*a*b* is defined by the achromatic lightness axis (L*), the chromatic green-red axis (a*) and the chromatic blue-yellow axis (b*). While lightness L* ranges between 0 (black) to 100 (white), the actual color of the wood is characterized by a* and b* (+a* red, -a* green, +b* yellow, -b* blue). Parameters were measured at five different spots on each sample and averaged. The overall color change was determined by the color deviation ΔE*, which was calculated according to (1):

$$\Delta E = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \quad (1)$$

,where: ΔL*, Δa*, Δb* represent the differences between the color of original and exposed wood surfaces. Low ΔE* was equivalent to a low color change. For determining the extractives content the samples were pre-split before milled to wood powder in a Retsch grinder ZM 1000 (0.25mm mesh sieve). The extraction of the absolutely dried wood powder was carried out in an Accelerated Solvent Extractor, ASE, Dionex®. About 0.3g of powder was extracted in an acetone/methanol/distilled water mixture (35:35:30, v/v/v). The solvent was evaporated from the extract in a pre-weighed Erlenmeyer flask, followed by a drying step in a desiccator. The flask was then re-weighed. The total amount of extractives was determined relative to the dry weight of the wood powder. For each sample two repetitions were done.

RESULTS AND DISCUSSION

Extractive contents found in the acetone-methanol-distilled water extract are summarized in Table 1 for both species. Total extractive content ranged between 6 % and 27 %, with average values of 12 % for Jatoba, and 16 % for African Padauk. Higher extractive contents were found for African Padauk, with the highest value at 27%. The lowest extractive content was 6.4 %, obtained for Jatoba.

Table 1

Mean, minimum and maximum values and coefficients of variation (CV) of total extractive contents in the heartwood of Jatoba (*Hymenaea courbaril* L.) and African Padauk (*Pterocarpus soyauxii* Taub.)

	Mean value (%)	Minimum (%)	Maximum (%)	CV (%)
African Padauk	15.6	10.6	26.9	27.9
Jatoba	12.3	6.4	17.0	25.8

The here examined species have dark-colored differentiated heartwood. The color of fresh African Padauk heartwood is vivid red and varies from orange-brown to reddish-brown hue. Jatoba usually shows shades of brown, with occasionally purple tones. It was found that the total extractives in Jatoba were linked to lightness L^* . In our work, we found a significant positive relationship between L^* and the extractive content (Table 2, $r=0.79$, Fig. 1) of the unexposed wood surface. A similar correlation was found for the chromatic parameter b ($r=0.85$). One of main color components in Jatoba wood is yellow since with higher extractive contents the wood became yellower and lighter. After irradiation the relationships between total extractives and color parameters did change. Especially a^* showed a positive correlation for both species. Ishiguri *et al.* (2003) exposed the extracts of Sugi to UV and found that the n-hexane-soluble fraction contained substances that shifted the color to yellow, while the acetone-soluble fraction caused a color change into the red.

Table 2

Pearson correlation coefficients (r) between color parameters (before and after irradiation) and total extractives of African Padauk and Jatoba (*significant at 95% confidence level)

	L		a		b		ΔE
	before	after	before	after	before	after	
African Padauk	-0.89*	-0.80*	-0.43 NS	-0.54*	-0.37 NS	-0.81*	-0.22 NS
Jatoba	+0.79*	-0.29 NS	+0.06 NS	+0.84*	+0.85*	-0.05 NS	0.86*

For African Padauk an opposite trend for L^* was observed, as Table 2 (Fig. 2) shows a negative correlation coefficient ($r=-0.89$). Higher extractive contents have led to a darker wood color. No significant correlation was found between total extractives content and chromatic parameters a^* and b^* . After irradiation L^* was still negatively correlated. Likewise, all obtained color parameters were also strongly correlated. As a result, the amount of extractives was found to be linked to the color change after irradiation.

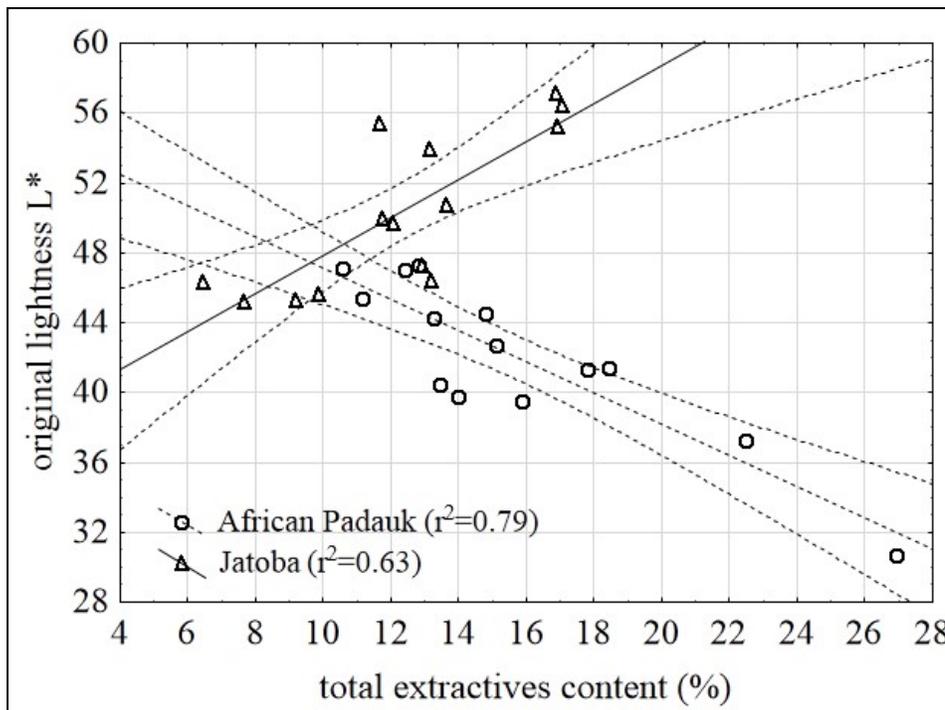


Fig. 1.
Relationship between total extractives and original lightness (L*) in African Padauk and Jatoba.

Wood absorbs light beyond 500nm because of the presence of phenolic substances such as flavonoids, stilbenes, lignans, tannins, and quinone (Hon and Minemura 2000). A wide range of these extractives can also be found in tropical species. Discoloration of wood during exposure to sunlight or weathering is correlated to the type and the content of these compounds (Nzokou and Kamdem 2006). Research has shown that significant correlations exist between phenolic extractives and color parameter in temperate species such as larch, walnut or American black cherry (Burtin *et al.* 1998, Gierlinger *et al.* 2004, Mayer *et al.* 2006) and also tropical species (Moya *et al.* 2012).

For both species an overall color change ΔE^* was visible after irradiation (24.4 for African Padauk and 11.6 for Jatoba). ΔE^* needs to have a minimum 3 to be visually recognizable (Hon and Minemura 2001). Extractives are responsible for the initial intensive photo-discoloration and with higher contents a color change will be more distinct. In Jatoba a strong positive correlation between overall color change ΔE and the total extractives content was found (Fig. 2). This trend was not seen in African Padauk. The changes in lightness L^* and b^* are the main contributors to ΔE in Jatoba, with both parameters being strongly correlated to the extractive content. On the contrary, in African Padauk the changes after irradiation in both chromatic parameters were distinct but seemingly less affected by the extractives. It becomes clear that extractives influence the individual color parameters in different ways, with ΔE being widely unrelated to the extractives contents.

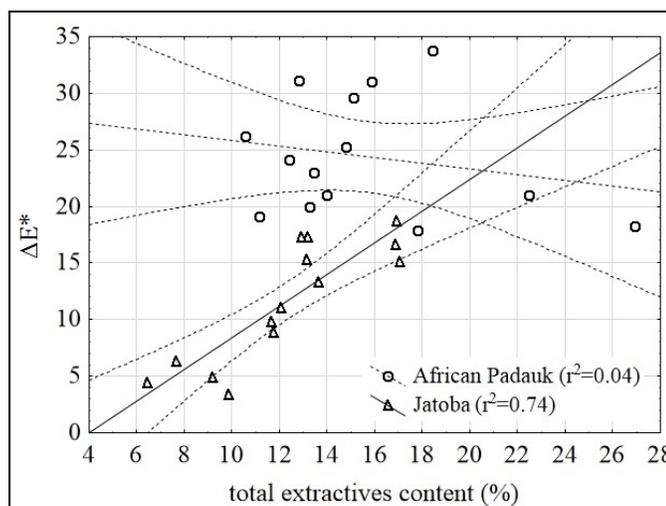


Fig. 2.
Relationship between overall color change ΔE and the total extractives content in African Padauk and Jatoba.

Extractives are known to undergo photo-reactions and contribute to the photo-discoloration of wood (Pandey 2005). Chang *et al.* (2010) applied the lightfastness test to extracted and non-extracted samples of *Acacia confusa*. While in the extracted specimens the lignin was found as the source for derivatives responsible for the color change, the extractives were the major source in the non-extracted samples. In a next step of this research a detailed investigation of individual extractive compounds will be done.

CONCLUSIONS

Wood color is related to the amount as well as the chemical nature of the intrinsic extractives. The amount of extractives influences the individual color parameters L^* , a^* or b^* of wood surfaces. The strongest correlation was found between lightness L^* and total extractives content, in both species. During irradiation the color distinctively changed, which was most likely caused by the generated photodegradation products of the extractives. Jatoba showed a higher overall color change ΔE , along with increasing extractives content. A higher extractive content also means higher production of photodegradation products. This relationship was not seen in African Padauk, which is most likely linked to the specific nature of its extractives, having an adverse effect on the obtained color change.

REFERENCES

- Burtin P, Jay-Allemand C, Charpentier JP, Janin G (1998) Natural wood colouring process in *Juglans* sp. (*J. nigra*, *J. regia* and hybrid *J. nigra* 23 × *J. regia*) depends on native phenolic compounds accumulated in the transition zone between sapwood and heartwood. *Trees* 12:258-264
- Chang TC, Chang HT, Wu CL, Lin HY, Chang ST (2010) Stabilizing effect of extractives on the photo-oxidation of *Acacia confusa* wood. *Polymer Degradation and Stability* 95:1518-1522
- Dirckx O, Triboulot MC, Merlin A, Deglise X (1992) Modifications de la couleur du bois d'*Abies grandis* expose a la lumiere solaire. *Annals of Forest Science* 49:425-477
- Feist WC, Hon DNS (1984) Chemistry of weathering and protection. In: Rowell R (ed) *The chemistry of solid wood*. *Advances in chemistry*, vol 207. American Chemical Society, Washington
- Gierlinger N, Jacques D, Grabner M, Wimmer R, Schwanninger M, Rozenberg P, Pâques LE (2004) Colour of larch heartwood and relationships to extractives and brown-rot decay resistance, *Trees* 18:102-108
- Hon DNS (1991) Color and discoloration. In: Hon DNS, Shiraishi N (eds) *Wood and cellulosic chemistry*. Marcel Dekker, New York

Hon DNS, Minemura N (2001) Photochemistry of wood. In: Hon DNS, Shiraishi N (eds) Wood and cellulosic chemistry. Marcel Dekker, New York

Ishiguri F, Maruyama S, Takahashi K, Abe Z, Yokota S, Andoh M, Yoshizawa N (2003) Extractives relating to heartwood color changes in sugi (*Crytomeria japonica*) by a combination of smoke-heating and UV radiation exposure. Journal of Wood Science 49:135-139

Mayer I, Koch G, Puls J (2006) Topochemical investigations of wood extractives and their influence on colour changes in American black cherry (*Prunus serotina* Borkh.) Holzforschung 60:589–594

Moya R, Fallas RS, Bonilla PJ, Tenorit C (2012) Relationship Between Wood Color Parameters Measured by the CIELab System and Extractive and Phenol Content in *Acacia mangium* and *Vochysia guatemalensis* from Fast-Growth Plantations, Molecules 17:3639-3652

Nzokou P, Kamdem DP (2006) The influence of wood extractives on the photodiscoloration of wood surfaces exposed to artificial weathering. Color Research and Application 31:425-434

Pandey KK (2005) A note on the influence of extractives on the photo-discoloration and photo-degradation of wood, Polymer Degradation and Stability 87:375-379

Romagnoli M, Segoloni E, Luna M, Margaritelli A, Gatti M, Santamaria U, Vinciguerra V (2013) Wood colour in Lapacho (*Tabebuia serratifolia*): chemical composition and industrial implications. Wood Science and Technology, Published on-line: 27 February 2013, DOI 10.1007/s00226-013-0534-y

Shebani AN, van Reenen AJ, Meincken M (2008) The effect of wood extractives on the thermal stability of different wood species, Thermochimica Acta 471:43-50