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COLOUR VARIATION OF HEAT-TREATED SPRUCE AND BLACK PINE WOOD AS CONSEQUENCE OF LONG-TIME EXPOSURE TO NATURAL LIGHT

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Abstract

*The presented research pursued the colour modifications suffered by heat-treated spruce and black pine wood, when exposed to natural light, as function of time, but also as function of the heat-treatment parameters applied. To this purpose, thin 20x20x0.5mm samples were cut out from wood pieces heat-treated in an electric oven at 180ºC and 200ºC for 1, 2 and 3h. The samples were scanned right after the heat-treatment in order to establish the "initial" colour. Then, the upper half of each sample was covered with a sealer and they were exposed on the inner side of a well-lighted window and scanned again after 1 to 6 months of exposure, in order to evaluate the colour modification of the uncovered part. The results were expressed in the CIE L*a*b system. The obtained results are important with a view to valorise heat-treated spruce and pine wood panels as interior wall claddings and other wooden elements for interior design.*

Key words: *spruce; black pine; heat-treatment; L*a*b colour coordinates; colour change.*

INTRODUCTION

The colour is an important aesthetic characteristic for wood, used as raw material for the manufacturing of various products, such as furniture, decorative objects, wall claddings, floors etc. which surround us in our everyday life, increasing our comfort and life quality. With most wood species, the natural colour is the most appreciated one, but there are also so-called "pale" (very light-coloured) wood species, with no remarkable grain, where a heat-treatment can significantly increase their aesthetic value. Without any addition of chemical substances, but just as a consequence of the high temperature applied, heat-treated wood gets a noble dark colour and a smooth, glossy surface.

With no regard if finished or unfinished, treated or untreated, wood changes its colour in time. The intensity of this natural degradation phenomenon depends in first line on the exposure conditions.

When exposed to outdoor conditions, unprotected wood changes its colour due to a combination of several factors, such as: UV radiation, humidity, heat, air currents, biological agents (Williams 2005). The colour change under influence of UV radiation is due to lignin modifications (Schaller and Rogez 2006). It has been proven that considerable colour changes occur within the first months of outdoor exposure, but then the colour remains steady for a long period of time (Feist 1983).

When exposed to in-door conditions, wood will suffer no colour changes due to UV radiation, because this does not penetrate glass. However, some colour changes still occur in this case, too, due to visible light waves (Williams 2005). These have enough energy to penetrate into wood at a depth of 200µm (Aydin 2005) and degrade the extractible substances which give the colour: organic compounds of various types, which may contain halogens, sulphur and nitrogen.

Reference literature offers numerous results concerning the colour change of wood under influence of visible light (Salcă and Cismaru 2011, McCurdy et al. 2003, Pang and Li 2006). The colour change which wood undergoes through a heat-treatment was also described by several authors (Allegretti et al. 2012; Karlsson et. al. 2012; Akgül and Korkut 2012; Gonzales-Peña and Hale 2009; Esteves et al. 2008; Sehlstedt-Persson 2003). Colour changes of heat-treated wood in time, when exposed to outdoor conditions were explored, among others, by Yildiz et al. (2011), Karlsson and Morén (2010), Ayadi et al. (2003). The main, common, conclusion of these studies was that the heat-treatment delays/decreases the rate of colour change caused by weathering factors, but it does not completely prevent it. The treatment parameters (temperature and time) and species also play an important role with regard to this influence.

OBJECTIVE

The main objective of the present research was to evaluate the colour modifications suffered by heat-treated spruce and black pine wood, when exposed to natural (visible) light, as function of time, but also as function of the heat-treatment parameters applied. The obtained results are important with a view to valorise heat-treated spruce and pine wood panels as interior wall claddings and other wooden elements for interior design.

METHOD, MATERIALS AND EQUIPMENT

Two wide-spread European species were selected for this study, namely spruce (*Picea abies* L.) and black pine (*Pinus nigra* L.).

Boards sized at 620x85x30mm were cut from the same log, then dried down to 12% mc and conditioned for 2 weeks at 20ºC/65%RH in a FEUTRON KPK200 climate chamber. Out of these, 20x20x30mm small samples were cut and oven-dried at 103ºC, considering this as a compulsory condition for an efficient heat-treatment (ThermoWood Handbook).

The heat-treatment was carried out in a BINDER electric oven with natural convection and PID controller, Ist quality and performance class, by applying two different temperatures (180ºC and 200ºC) for 1, 2 and 3 hours.

After being heat-treated, the samples were cooled down in an essiccator and then thin colour specimens 20x20x0.5mm were cut out from the middle part of each sample. They were scanned immediatly after being cut, by using a Mustek 1248UB scanner with a resolution of 600x1200dpi (pixel/millimeter), at a resolution of 300dpi..

Hereinafter, the upper half of each specimen's surface was covered with a sealing band and the specimens were exposed on the inner side of a well-lighted window. At regular periods of time (1, 2, 3 …6 months), the specimens were scanned again in order to evaluate the colour modification of the uncovered part.

The colour sample obtained at the first scanning (right after the heat-treatment) was considered as the „reference colour". All the other colour samples obtained from the same specimen after 1 to 6 months of exposure to natural light were related to this one, in order to evaluate the colour change in time.

The three-dimensional *L**, *a**, *b** colour space (Fig. 1), recommended by CIE (Commission Internationale de l'Eclairage) was used for a quantitative colour assessment, each colour sample being characterised by three colour coordinates, obtained by means of the Corel PHOTO-PAINT 11 program:

● the lightness L^*, which may range between 0-black and 100-white; this means that a high L^* value characterises a light colour and that the decrease of L^* means darkening;

● the red-green share a^*;

● the blue-yellow share b^*.

By comparing the $L^*a^*b^*$ values obtained from the same sample at different moments of time, conclusions regarding the influence of the time of exposure to light upon the colour intensity could be drawn.

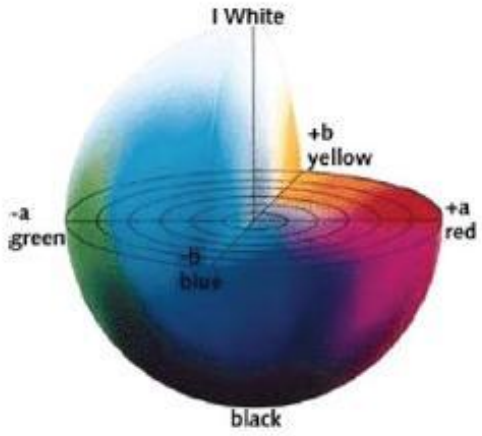


Fig. 1. CIELab Colour Space (Source: www.linocolor.com)

The lightness change (ΔL^*), which is the most expressive and the total colour change (ΔE^*) were calculated with the expressions:

$$\Delta L^* = L^*_{exposed} - L^*_{initial} \quad (1)$$

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

where $\Delta a^* = a^*_{exposed} - a^*_{initial}$ and $\Delta b^* = b^*_{exposed} - b^*_{initial}$.

By comparing the ΔL^* and ΔE^* values, conclusions regarding the influence of the heat-treating parameters upon the colour stability could be drawn.

RESULTS AND DISCUSSIONS

The colour evolution of the two heat-treated wood species, expressed by means of the three colour coordinates $L^*a^*b^*$, as function of time and the heat-treatment applied, is presented in Tables 1, 2 and illustrated in Tables 3-6. The values of the lightness change (ΔL^*) and total colour change (ΔE^*) are also given in Tables 3-6.

As shown in Table 1, the $L^*a^*b^*$ coordinates obtained right after the heat-treatment ("initial" values) are in good accordance to the values obtained by Allegretti et al. (2012) for spruce, heat-treated at

160-220ºC for 0,75-18h in vacuum (p=150, 210, 350mbar) and to the ones obtained by Esteves et al. (2008) for pine (*Pinus pinaster*), heat-treated at 170-200ºC for 2-24h in superheated steam. As expected, the luminosity is higher in case of the lower temperature and the lower time of treatment and it decreases steeply (darkening effect of the heat-treatment) as temperature and time increase. Similar *L** values were obtained for both species: ranging between 65 (after the heat-treatment at 180ºC/1h) and around 30 (after the heat-treatment at 200ºC/3h).

Table 1

Evolution of *L*a*b** colour coordinates of heat-treated spruce and black pine wood after 1, 2 and 3 months of exposure to natural light

Species	Heat-treatment	*L*a*b**			
		Initial	After 1 month	After 2 months	After 3 months
Spruce	180°C/1h	65*11*18	60*13*19	54*17*22	53*16*21
	180°C/2h	57*12*19	55*12*19	51*14*20	49*15*19
	180°C/3h	57*13*20	56*12*19	51*15*21	50*15*20
	200°C/1h	40*15*19	42*14*20	42*16*21	
	200°C/2h	32*14*16	35*13*18	35*14*18	
	200°C/3h	28*13*14	33*11*16	33*11*15	
Black Pine	180°C/1h	63*11*18	57*12*18	54*15*21	51*15*20
	180°C/2h	58*11*18	55*12*18	51*14*20	49*15*20
	180°C/3h	55*13*20	43*13*18	42*15*20	39*16*19
	200°C/1h	40*13*17	41*13*18	43*13*19	
	200°C/2h	31*13*15	32*12*16	34*12*17	
	200°C/3h	33*13*15	35*12*16	38*11*16	

Table 2

Evolution of *L*a*b** colour coordinates of heat-treated spruce and black pine wood after 4, 5 and 6 months of exposure to natural light

Species	Heat-treatment	*L*a*b**		
		After 4 months	After 5 months	After 6 months
Spruce	180°C/1h	52*16*21		
	180°C/2h	50*14*19		
	180°C/3h	49*16*21		
	200°C/1h	40*18*22	38*18*21	38*18*20
	200°C/2h	34*16*19	33*15*18	33*15*18
	200°C/3h	32*11*15	31*11*15	27*12*15
Black Pine	180°C/1h	51*16*21		
	180°C/2h	49*16*20		
	180°C/3h	39*16*19		
	200°C/1h	41*16*21	39*16*19	38*16*19
	200°C/2h	32*14*17	31*13*17	34*16*19
	200°C/3h	36*12*17	36*12*16	35*12*15

Table 3

Luminosity change and total colour change of **spruce** wood samples heat-treated at **180ºC**, after 1 to 4 months of exposure to natural light compared to initial colour (right after the heat-treatment)

HT time	After 1 month	After 2 months	After 3 months	After 4 months
1h	 ΔL^*= -5 ΔE^*=5,48	 ΔL^*= -11 ΔE^*=13,15	 ΔL^*= -12 ΔE^*=13,34	 ΔL^*= -13 ΔE^*=14,25
2h	 ΔL^*= -2 ΔE^*=2	 ΔL^*= -6 ΔE^*=6,4	 ΔL^*= -8 ΔE^*=8,54	 ΔL^*= -7 ΔE^*=7,28
3h	 ΔL^*= -1 ΔE^*=1,73	 ΔL^*= -6 ΔE^*=6,40	 ΔL^*= -7 ΔE^*=7,28	 ΔL^*= -8 ΔE^*=8,60

Let us examine now the evolution of a spruce sample heat-treated at 180ºC for 3h (Fig. 2). Its initial colour coordinates were 57*13*20. After being exposed for four months to visible light, its colour coordinates became 49*16*21. It can be noticed that the luminosity decreased continuously, the biggest drop (steepest decrease) being within the second month of exposure (from L^*=56 after 1 month to L^*=51 after the second month). The luminosity change of this sample after 4 months of exposure was ΔL^*=8,60.

With the black pine sample heat-treated at 180ºC for 3h (Fig. 3), the greatest luminosity change occurred right within the first month (from L^*=55 initially, to L^*=43 after the first month). During the further months of exposure, the luminosity continued decreasing, but not as steeply, reaching L^*=39 and thus a luminosity change ΔL^*=16,31 after 4 months of exposure, two times higher than in the case of spruce, heat-treated with the same schedule.

Figures 2 and 3 clearly show that, the samples heat-treated at 180ºC suffered a significant colour change during their exposure to visible light, mainly due to the luminosity decrease: they became darker in time. Unlike this, the wood samples treated at 200ºC displayed right after the heat-treatment

a much darker colour than the ones treated at 180ºC, with a luminosity *L** ranging between 40 (after 1h of heat-treatment) and 30 (after 3 hours). When exposed to natural light, one could notice a slight colour lightening within the first three months (marked by the slight increase of the *L** coordinate), followed by the reverse tendency during the next three months and ending, after 6 months of exposure, with a colour very close to the initial one.

Table 4

Luminosity change and total colour change of **black pine** wood samples heat-treated at **180ºC**, after 1 to 4 months of exposure to natural light compared to initial colour (right after the heat-treatment)

HT time	After 1 month	After 2 months	After 3 months	After 4 months
1h	 *ΔL*= -6* *ΔE*=6,08*	 *ΔL*= -9* *ΔE*=10,3*	 *ΔL*= -12* *ΔE*=12,81*	 *ΔL*= -12* *ΔE*=13,34*
2h	 *ΔL*= -3* *ΔE*=3,16*	 *ΔL*= -7* *ΔE*=7,87*	 *ΔL*= -9* *ΔE*=10,05*	 *ΔL*= -9* *ΔE*=10,49*
3h	 *ΔL*= -12* *ΔE*=12,17*	 *ΔL*= -13* *ΔE*=13,15*	 *ΔL*= -16* *ΔE*=16,31*	 *ΔL*= -16* *ΔE*=16,31*

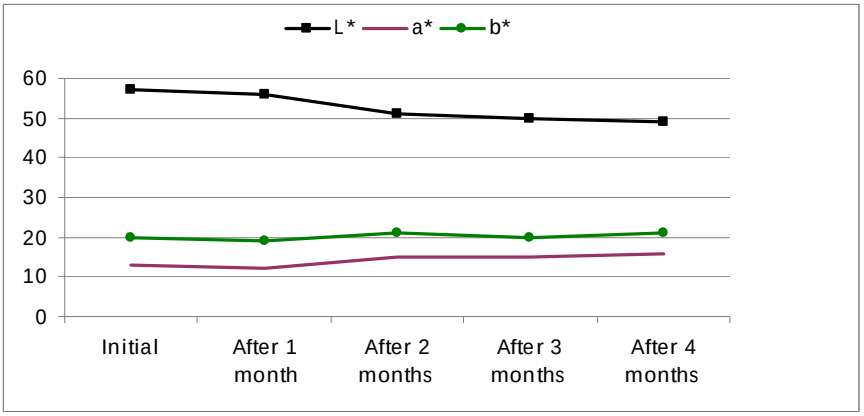


Fig. 2. Evolution of L*a*b* colour coordinates of spruce wood, heat-treated at 180ºC for 3h, then exposed to visible light.

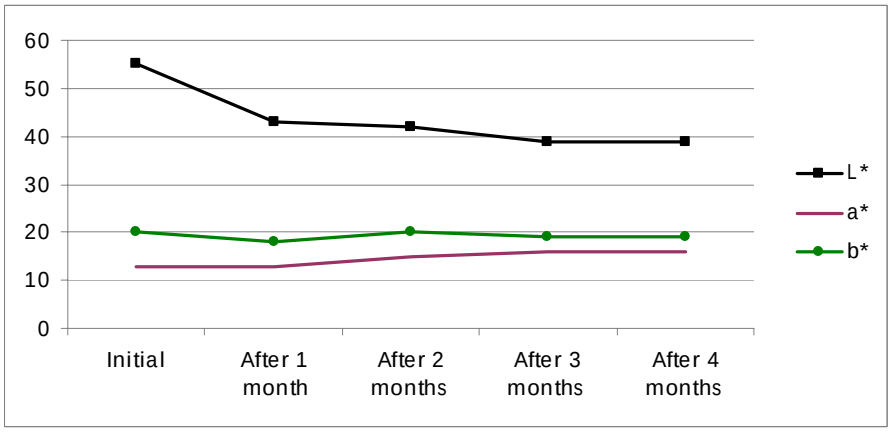
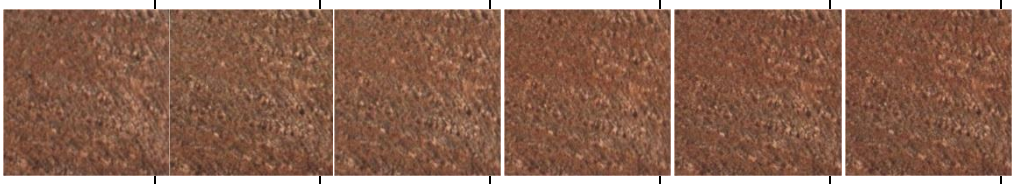
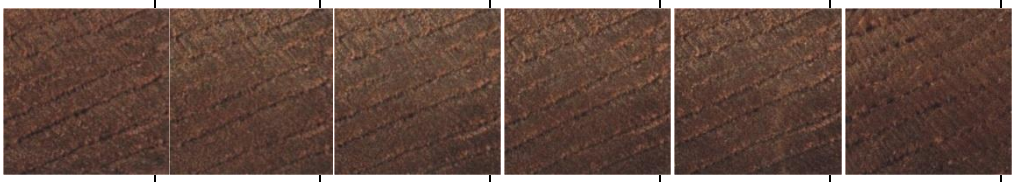


Fig. 3. Evolution of L*a*b* colour coordinates of black pine wood, heat-treated at 180ºC for 3h, then exposed to visible light.

Table 5

Luminosity change and total colour change of **spruce** wood samples, heat-treated at **200ºC**, after 1 to 6 months of exposure to natural light compared to initial colour (right after the heat-treatment)

HT time	Initial	After 1 month	After 2 months	After 4 months	After 5 months	After 6 months
1h		*ΔL*=2* *ΔE*=2,45*	*ΔL*=2* *ΔE*=3,00*	*ΔL*=0* *ΔE*=4,24*	*ΔL*=-2* *ΔE*=4,12*	*ΔL*=-2* *ΔE*=3,74*
2h		*ΔL*=3* *ΔE*=3,74*	*ΔL*=3* *ΔE*=3,61*	*ΔL*=2* *ΔE*=4,12*	*ΔL*=1* *ΔE*=2,45*	*ΔL*=1* *ΔE*=2,45*
3h		*ΔL*=5* *ΔE*=5,74*	*ΔL*=5* *ΔE*=5,48*	*ΔL*=4* *ΔE*=4,58*	*ΔL*=3* *ΔE*=3,74*	*ΔL*=-1* *ΔE*=1,73*

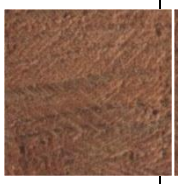
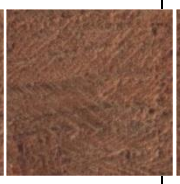
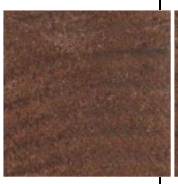
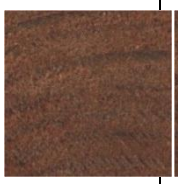
Let us analyse now the evolution of the colour coordinates of the spruce sample heat-treated at 200ºC for 3h (Fig. 4): initially, these were 28*13*14. After being exposed for one month to visible light, the luminosity of the sample increased to *L**=33 (slight colour lightening). It remained constant at this value for two more months and then it started decreasing. After 6 months of exposure to visible light, the colour coordinates of this sample were 27*12*15, very close to the initial colour coordinates (see also colour sample in Table 5). This indicates a much better colour stability of the spruce samples heat-treated at 200ºC than that of those heat-treated at 180ºC.

With the black pine sample heat-treated at 200ºC for 3h (Fig. 5), a similar evolution of the luminosity was observed: during the first three months, the colour got lighter (*L** increased by the same Δ*L**= 5 as in the case of spruce), and then it began darkening again. After 6 months of exposure, the colour coordinates of this sample were 35*12*15, compared to the initial 33*13*15. It is to be expected that after two more months (after a total of 8 months of exposure), the colour would reach again the initial shade. Thus, it can be concluded that the black pine wood has a slower colour modification than spruce, but the tendency to revert in time to the initial colour (obtained right after the heat-treatment) is also confirmed in this case.

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Table 6

Luminosity change and total colour change of **black pine** wood samples, heat-treated at **200ºC**, after 1 to 6 months of exposure to natural light compared to initial colour (right after the heat-treatment).

HT time	Initial	After 1 month	After 2 months	After 4 months	After 5 months	After 6 months
1h		 *ΔL*=1* *ΔE*=1,41*	 *ΔL*=3* *ΔE*=3,61*	 *ΔL*=1* *ΔE*=5,10*	 *ΔL*=-1* *ΔE*=3,74*	 *ΔL*=-2* *ΔE*=4,12*
2h		 *ΔL*=1* *ΔE*=1,41*	 *ΔL*=3* *ΔE*=3,74*	 *ΔL*=1* *ΔE*=2,45*	 *ΔL*=0* *ΔE*=2,00*	 *ΔL*=3* *ΔE*=5,83*
3h		 *ΔL*=2* *ΔE*=2,45*	 *ΔL*=5* *ΔE*=5,48*	 *ΔL*=3* *ΔE*=3,74*	 *ΔL*=3* *ΔE*=3,32*	 *ΔL*=2* *ΔE*=2,24*

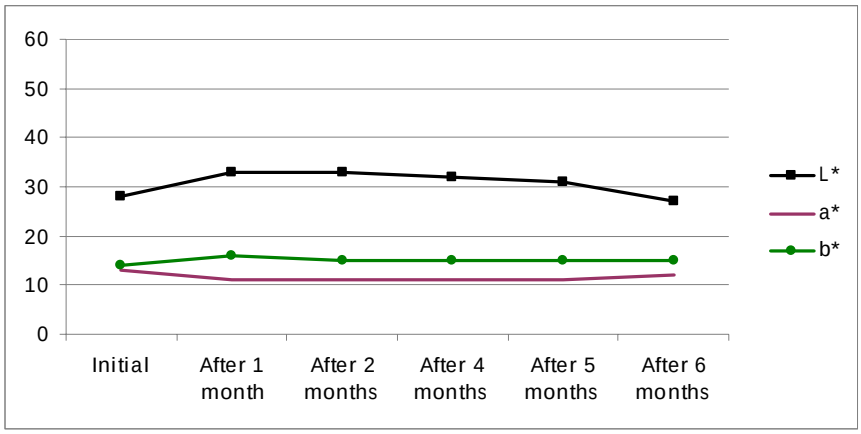


Fig. 4. Evolution of L*a*b* colour coordinates of spruce wood, heat-treated at 200ºC for 3h, then exposed to visible light.

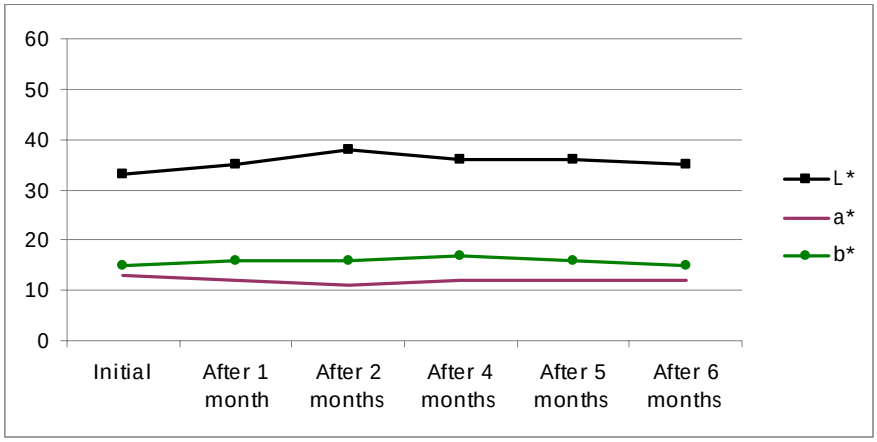


Fig. 5. Evolution of L*a*b* colour coordinates of black pine wood, heat-treated at 200ºC for 3h, then exposed to visible light.

CONCLUSIONS

The results obtained within this research show that heat-treated black pine wood generally undergoes a more significant colour change when exposed to visible light, than spruce wood heat-treated under the same conditions.

Colour measurements on both species revealed that the samples heat-treated at 180ºC have a less stabile colour in time than the samples treated at 200ºC: the total colour change after 4 months for the samples heat-treated at 180ºC/3h was ΔE^*= 8,60 (for spruce) and ΔE^*= 16,31 (for black pine), while the total colour change after 4 months for the samples heat-treated at 200ºC/3h was ΔE^*=4,58 (for spruce) and ΔE^*= 3,74 (for black pine). The same tendency is valid with regard to the influence of the duration of the heat-treatment: the longer the treatment, the better the stability in time of the colour was.

Thus, out of the heat-treatment conditions explored, the best colour stability in time was obtained with the heat-treatment at 200ºC/3h, for both species.

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