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The effect of some chemicals on the color properties of Beech (*Fagus Orientalis* L.) wood

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Abstract

Aim of study: Wood material has a unique color in the natural condition. The wood colorization process is necessary to provide a tonality in the wood materials used in interior design and decoration and to obtain different colors. One of the most important steps of the coloring or bleaching process is selecting appropriate chemical for wood type. The aim of this study was to determine the effect of hydrogen peroxide, ammonia, sodium silicate and acetic acid applied periodically three times on the color changes of radial and tangent sections of beech (*Fagus Orientalis* L.) samples.

Area of study: This study was conducted at Karabük University and Düzce University, in Turkey.

Material and Methods: The color values of the samples were measured according to the CIEL*a*b* color system.

Main results: As a result, the effect of cutting direction, chemical type, and application repeat on changes in the color values of beech samples was found significant.

Research highlights: The maximum color change in the beech samples was determined in the radial section as cutting direction, in the application of the sodium silicate as the chemical type and it was also obtained in the third repeat as the number of applications.

Keywords: Beech wood, Chemicals, Color changing

Bazı kimyasalların Kayın (*Fagus Orientalis L.*) odununun renk özellikleri üzerine etkisi

Özet

Çalışmanın amacı: Doğal haldeki ağaç malzemenin kendine özgü bir rengi vardır. İç mimari ve dekorasyonda kullanılan ağaç malzemelerde renk uyumunu sağlamak veya farklı görüntüler elde etmek için çoğu zaman renklendirme ve renk açma işlemlerine ihtiyaç vardır. Renklendirme veya renk açma işleminin en önemli basamaklarından birisi ağaç türüne uygun kimyasalın seçilmesidir. Bu araştırmanın amacı, kayın (*Fagus Orientalis* L.) odunundan radyal ve teğet kesitte hazırlanmış örneklere belirli aralıklarla üçer kez uygulanan hidrojen peroksit, amonyak, sodyum silikat ve asetik asit kimyasallarının örneklerde meydana getirdiği renk değişimini belirlemek içindir.

Çalışma alanı: Bu çalışma Karabük Üniversitesi ve Düzce Üniversitesinde gerçekleştirilmiştir.

Materyal ve Yöntem: Örneklerin renk değerleri CIEL*a*b* renk sistemine göre ölçülmüştür.

Sonuçlar: Araştırma sonuçlarına göre; kayın örneklerin renk değerlerindeki değişimde kesiş yönü, kimyasal çeşidi ve uygulanma tekrarı önemli bulunmuştur.

Araştırma vurguları: Örneklerdeki en fazla renk değişiminin; kesiş yönü olarak radyal kesitte, kimyasal çeşidi olarak sodyum silikat uygulamasında ve uygulama sayısında ise üçüncü tekrarda olduğu belirlenmiştir.

Anahtar kelimeler: Kayın odunu, Kimyasallar, Renk değişimi

Introduction

Color is one of the most important properties of wood regarding aesthetic and decorative aspects. The color of the material may differ from one species to another. Similarly, not only may it differ in same species, but it may also differ in parts of the same wood prepared from a lumber. The color of wood material can be affect some properties of wood such as texture, density, the amount of moisture, the quantity of color pigments in the cell membrane and so forth (Sönmez, 2005; Budakçı et al., 2012).

Color is as important as the size and form in the wooden furniture. The color of the wooden furniture is expected to be compatible with the interior design components such as wall, ceiling, floor, carpets, curtains, etc. While the color of the wood in its natural state often does not meet such a need. Before finishing process, desired color harmony can be achieved with surface operations such as bleaching and coloring on the surfaces (Çakıcıer, 1996; Özçifçi et al., 1999; Örs and Atar, 2001). Also bleaching process is performed in the industrial applications such as eliminate the color differences during furniture production or prevent to color changes that may occur after production of furniture (Sönmez, 2005).

Bleaching is the process of lightening of wood surface color with a appropriate solution. When natural wood material exposed to external impacts, especially, a darkening in color occurs. Bleaching chemicals are reactives that affect the secondary components of wood. These chemicals make colors lighter by affecting the secondary components of wood instead of destroying the color. (Wagner and Kiclighter, 1986; Budakçı and Atar, 2001). This process significantly effects some wood surface properties such as hardness, color, gloss, roughness, adhesion, scratch (Özdemir and Hızıroğlu, 2007; Budakçı and Karamanoğlu, 2014; Özdemir et al., 2015).

There are many studies in the literature on the color properties of wood materials exposed to bleaching solutions or impregnation, especially in the tree species which are frequently used in the woodworking sector. The color of wood material exposed to outdoor conditions get darker and the color properties of each wood species is affected in different amounts due to chemicals changes on the microstructure (Feirer, 1984). It was stated that the glossiness value of wood material exposed to outdoor conditions decreased and the bleaching process with chemicals decreased this effect of outdoor conditions (Budakçı and Atar, 2001). According to a study performed with 11 different chemical bleach solutions on the 5 different wood, each solution effects wood and its properties differently and each solutions is not suitable with each wood species (Herstedt and Herstedt, 2017).

The coloring process is made to change the wavelength of reflected light from the surface of the wood by forming new compounds on the wood texture using chemical methods or impregnating color pigments into wood (Sönmez, 2005). In the natural state and without any protective layer, wood material is destroyed in a shot time when exposed to external effect. Bleaching chemicals cannot protect wood material against external effects because they does not form a protective layer. For this reason, bleached wood surfaces must be covered with a protective layer (Sönmez, 1989).

The goal of this study, was to determine the effect of hydrogen peroxide, ammonia, sodium silicate and acetic acid applied periodically three times on the color properties (L^*, a^*, b^* and ΔE^*) of radial and tangent sections of beech (*Fagus Orientalis* L.) wood samples.

Material and Method

Wood material

Eastern beech (*Fagus Orientalis L.*), which is often preferred in furniture production, was used in the study. Attention was paid to ensure that no rot, knot, crack, color, or density differences were present in the beech samples (TS 2470 1976). Beech samples was cut with the dimensions of 190×140×15 mm from both radial and tangential section. Surfaces of the samples were sanded with 220 grit sandpaper and then samples were stored in climate room

(RH 65 ± 3% and 20 ± 2 °C) for 3 weeks (TS 2471 1976).

Chemicals

In the study, 50% hydrogen peroxide (H_2O_2), 80% acetic acid (CH_3COOH), ammonia (NH_3), 40°–42° sodium sillicate (Na_2SiO_3) solutions was preferred as chemicals because these were widely used in bleaching process of wood.

Hydrogen peroxide, acetic acid and ammonia solutions were applied to sample surfaces for thrice with 48 hours intervals. Because sodium silicate takes longer to dry out, it was applied with 72 hours intervals for thrice. Chemicals were applied to wood surface with a colorless (white) cloth and chemical residues removed from the surface with distilled water after waiting 10 minutes.

Determination of color

Before and after the implementation of chemicals, color values of all samples were determined with Superchroma spectrophotometer (Braive Instruments) according to ASTM D2244 (2015). The differences in colors and their locations are determined according to the L*, a*, and b* color coordinates in the CIEL*a*b* color scheme (Fig. 1). In this scheme, L* (lightness) is located on the black-white axis (L* = 0 for black, L* = 100 for white), a* on the red-green axis (positive values for red and negative values for green), and b* for the yellow-blue axis (positive values for yellow and negative values for blue) (Oliver et al., 1992; McGuire, 1992; Mononen et al., 2002). The color red (+a) and the color yellow (+b) was independently investigated in order to determine which color tone was affected in each color during change and in addition, the total change in color (ΔE*) was calculated using the following Eq.1:

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

where ΔL* ($L^*_{treated}$ - $L^*_{control}$) is the color change of black-white, Δa* ($a^*_{treated}$ - $a^*_{control}$) is the color change of red-green, Δb* ($b^*_{treated}$ - $b^*_{control}$) is the color change of yellow-blue. The low ΔE* values obtained from the calculations would indicate very low or no change in color (Söğütlü and Sönmez, 2006).

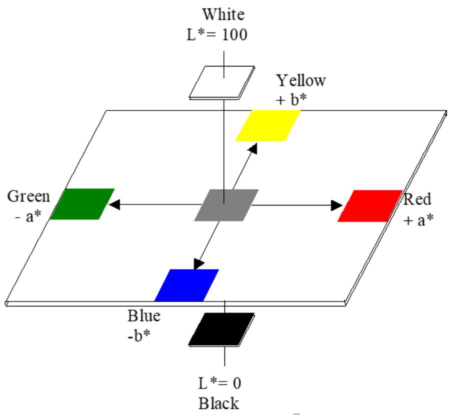

Figure 1. CIEL*a*b* color scheme

Statistical analysis

The MSTAT-C package program was used for statistical evaluations. Multiple analysis of variance (ANOVA) tests were performed to determine the effect of different chemicals applied at certain intervals on the color parameters (L*, a*, b* and ΔE*) of the beech wood samples (0.05 significance level). Significant differences between the groups were compared using the Duncan test.

Results and Discussion

The color changes on radial and tangent section of samples caused by different chemicals applied thrice at specific intervals were shown in Table 1.

Table 1. The average L *, a *, b * and ΔE * values of Eastern beech samples before and after chemical application (*n* = 10)

Chemical type	Application repeat	Cutting direction							
		Tangential section				Radial sections			
		L*	a*	b*	ΔE*	L*	a*	b*	ΔE*
Acetic acid	Control	70.09 (3.93)	4.02 (0.69)	22.09 (1.19)	-	74.24 (1.02)	3.33 (0.61)	20.40 (0.89)	-
	1 times	72.05 (3.18)	3.34 (0.54)	22.63 (0.92)	2.62 (1.77)	74.58 (1.12)	3.30 (0.70)	22.13 (1.31)	2.13 (1.29)

Table 1. *(continued)*

	2 times	71.12 (2.89)	3.26 (0.60)	22.15 (1.14)	2.28 (1.20)	73.16 (1.54)	3.90 (1.01)	22.91 (1.26)	2.97 (2.01)
	3 times	69.77 (2.64)	7.25 (0.59)	23.52 (1.37)	4.24 (1.16)	73.20 (1.84)	6.53 (0.70)	22.14 (0.91)	4.16 (0.85)
Ammonia	Control	69.27 (2.72)	3.97 (0.88)	19.30 (1.47)	-	73.97 (1.83)	4.75 (1.27)	21.44 (1.13)	-
	1 times	59.18 (3.67)	4.54 (1.03)	17.59 (1.39)	10.32 (3.56)	60.13 (2.93)	6.80 (1.20)	18.71 (1.07)	14.48 (3.11)
	2 times	58.14 (3.13)	7.58 (1.19)	21.69 (1.43)	12.09 (3.60)	55.44 (1.21)	11.60 (1.27)	22.51 (0.72)	19.85 (2.24)
	3 times	59.44 (3.09)	7.11 (1.08)	21.83 (1.40)	10.80 (3.58)	56.13 (2.50)	10.50 (0.65)	22.76 (0.49)	18.86 (3.31)
Hydrogen peroxide	Control	66.92 (4.25)	4.72 (1.32)	18.71 (2.44)	-	74.59 (1.77)	4.26 (0.85)	20.05 (1.34)	-
	1 times	78.40 (2.81)	1.94 (1.67)	21.49 (1.07)	12.40 (3.12)	82.45 (2.03)	-0.13 (1.86)	17.44 (2.42)	9.53 (2.29)
	2 times	84.74 (3.32)	-2.52 (2.31)	16.74 (2.49)	19.74 (2.82)	87.05 (1.36)	-3.70 (0.89)	13.83 (1.20)	16.08 (1.90)
	3 times	87.27 (1.90)	-0.05 (1.30)	17.57 (1.33)	21.21 (2.62)	89.10 (0.90)	-0.68 (0.47)	14.95 (1.24)	16.26 (1.99)
Sodium silicate	Control	70.70 (2.27)	4.12 (1.22)	18.80 (1.55)	-	74.38 (1.01)	3.91 (0.99)	19.50 (0.74)	-
	1 times	57.17 (2.72)	8.57 (1.46)	28.80 (1.84)	17.53 (2.88)	54.33 (1.89)	9.24 (0.63)	28.25 (1.72)	22.67 (1.26)
	2 times	58.18 (2.83)	10.44 (1.28)	29.79 (1.45)	17.86 (1.30)	60.86 (3.17)	8.49 (1.73)	23.72 (4.10)	15.40 (3.97)
	3 times	57.02 (3.02)	10.41 (1.34)	31.25 (1.46)	19.58 (2.65)	59.84 (2.42)	8.66 (1.73)	26.64 (3.74)	17.16 (4.03)

Values in parenthesis are standard deviations

Applied chemicals and number of repetition of these chemicals changed of L*, a*, b* color values of beech samples. L*, a*, b* and ΔE* values were separately analyzed for determining of the color change amount and factors which are effective on the color changes of samples.

Color lightness value (L*)

Analysis of variance (ANOVA) results of color lightness (L*) values of samples applied with acetic acid, ammonia, hydrogen peroxide and sodium silicate at different repetition numbers were shown in Table 2.

Table 2. ANOVA results of the L* values of beech samples

Factors	Degrees of freedom	Sum of squares	Mean square	F-value	Level of significance ($p \leq 0.05$)
Cutting direction (A)	1	360.464	360.464	55.0875	0.0000
Chemical type (B)	3	21953.876	7317.959	1118.3581	0.0000
Interaction (AB)	3	188.136	62.712	9.5839	0.0000
Application repeat (C)	3	855.219	285.073	43.5659	0.0000

Table 2. *(continued)*

Interaction (AC)	3	228.684	76.228	11.6494	0.0000
Interaction (BC)	9	8992.765	999.196	152.7009	0.0000
Interaction (ABC)	9	228.713	25.413	3.8836	0.0001
Error	288	1884.523	6.543		
Total	319	34692.379			

According to ANOVA results; there was a significant interaction between cutting direction, chemical type and application repetition number factors and these factors was also significant on the changes of the L* values of beech samples ($p \leq 0.05$). Duncan test results of the comparison in the level of cutting direction, chemical type and application repetition number were given in the Table 3.

Table 3. Duncan test results of the L* values in the level of comparison of cutting direction, chemical type and application repetition number

Cutting direction	Mean	*HG*	
Tangential section	68.09	b	*LSD* ± 0.5629
Radial sections	70.21	a	
Chemical type	Mean	*HG*	
Ammonia	61.46	c	*LSD* ± 0.7960
Sodium silicate	61.56	c	
Acetic acid	72.28	b	
Hydrogen peroxide	81.31	a	
Application repeat	Mean	*HG*	
1 times	67.29	c	*LSD* ± 0.7960
2 times	68.59	b	
3 times	68.97	b	
Control	71.77	a	

HG: Homogeneous group

According to table 3; the L* value was found higher (70.21) on the radial section when compared with the tangential section. It could be said that the type of the rays of beech samples were effective on the results. Due to the anatomical structure of the beech wood, rays is found in the form of dots on the tangential section and in the form of strands on the radial section (Örs and Keskin, 2008). In terms of chemical type, the highest L* value found on the samples applied hydrogen peroxide (81.31), the lowest value found on the both samples applied ammonia (61.46) and sodium silicate (61.56) which are statistically insignificant. Ammonia and sodium silicate chemicals, which are alkaline, caused a reduction in the L* value of beech samples (Table 1). It was reported that alkaline chemicals causes darkening of color conditions of wood materials and also acidic chemicals causes lightening and bleaching of the color of the wood material (Şanıvar, 2001; Sönmez, 2005). In terms of repetition number, the highest L* value found on the untreated (control) samples (71.77), the lowest value was found on the samples one times treated with different chemicals. However, L* value was increased both tangential (30%) and radial (19%) section of samples with the increase in the repetition number of the hydrogen peroxide (Table 1).

Red-green color value (a*)

ANOVA results of the red-green color (a*) values of samples treated with acetic acid, ammonia, hydrogen peroxide and sodium silicate at different repetition numbers were given in the Table 4.

Table 4. ANOVA results of the a* values of the beech samples

Factors	Degrees of freedom	Sum of squares	Mean square	F-value	Level of significance ($p \leq 0.05$)
Cutting direction (A)	1	1.360	1.360	0.9773	--^{ns}
Chemical type (B)	3	2730.471	910.157	654.1450	0.0000
Interaction (AB)	3	172.664	57.555	41.3654	0.0000
Application repeat (C)	3	186.215	62.072	44.6119	0.0000
Interaction (AC)	3	2.900	0.967	0.6947	--^{ns}
Interaction (BC)	9	1379.078	153.231	110.1296	0.0000
Interaction (ABC)	9	65.262	7.251	5.2116	0.0000
Error	288	400.714	1.391		
Total	319	4938.663			

According to ANOVA results, cutting direction factor and interaction of cutting direction-application repetition number factors was insignificant on the changing of a* values of beech samples. But, other factors and their reciprocal interactions was significant ($p \leq 0.05$).

Duncan test results of the comparison in the level of cutting direction, chemical type and application repetition number were given in the Table 5.

Table 5. Duncan test results of the a* values in the level of comparison of cutting direction, chemical type and application repetition number

Cutting direction	Mean	*HG*	
Tangential section	4.92	a	*LSD* ± 0.2595
Radial sections	5.05	a	
Chemical type	**Mean**	***HG***	
Hydrogen peroxide	0.48	d	*LSD* ± 0.3670
Acetic acid	4.37	c	
Ammonia	7.11	b	

Table 5 *(continued)*

Sodium silicate	7.98	a	
Application repeat	Mean	*HG*	*LSD* ± 0.3670
Control	4.14	c	
1 times	4.70	b	
2 times	4.88	b	
3 times	6.22	a	

HG: Homogeneous group

According to ANOVA (Table 5) results, it was found that an insignificant interaction between a* values of radial and tangential section of beech wood. In terms of chemical type, the highest a* value (7,98) found on the samples treated with sodium silicate and the lowest value (0,48) was found on the samples treated with hydrogen peroxide. Hydrogen peroxide caused a significant reduction in the a* value of beech samples. On the other hand, sodium silicate and ammonia chemicals increased a* values of samples (Table 1). In terms of repetition number, the highest a* value (6.22) found on the samples treated 3 times with chemicals and the lowest value (4.14) was found on the untreated (control) samples. The a* values of samples generally increased with the increase of application repetition number. However, this does not include the hydrogen peroxide (Table 1).

Yellow-blue color value (b*)

ANOVA results of the yellow-blue color (b*) values of samples treated with acetic acid, ammonia, hydrogen peroxide and sodium silicate at different repetition numbers were given in the Table 6.

Table 6. ANOVA results of the b* values of the beech samples

Factors	Degrees of freedom	Sum of squares	Mean square	F-value	Level of significance ($p \leq 0.05$)
Cutting direction (A)	1	85.512	85.512	29.8727	0.0000
Chemical type (B)	3	2816.246	938.749	327.9425	0.0000
Interaction (AB)	3	179.438	59.813	20.8950	0.0000
Application repeat (C)	3	295.394	98.465	34.3977	0.0000
Interaction (AC)	3	83.858	27.953	9.7650	0.0000
Interaction (BC)	9	1480.233	164.470	57.4561	0.0000
Interaction (ABC)	9	177.811	19.757	6.9018	0.0000
Error	288	824.412	2.863		
Total	319	5942.905			

According to ANOVA results; there was a significant interaction between cutting direction, chemical type and application repetition number factors and these factors was also significant on the changes of the b* values of beech samples ($p \leq 0.05$). Duncan test results of the comparison in the level of cutting direction, chemical type and application repetition number were given in the Table 7.

Table 7. Duncan test results of the b* values in the level of comparison of cutting direction, chemical type and application repetition number

Cutting direction	Mean	*HG*	
Radial sections	21.09	b	*LSD* ± 0.3723
Tangential section	22.12	a	
Chemical type	**Mean**	***HG***	
Hydrogen peroxide	17.60	d	*LSD* ± 0.5266
Ammonia	20.73	c	
Acetic acid	22.25	b	
Sodium silicate	25.84	a	
Application repeat	**Mean**	***HG***	
Control	20.04	c	*LSD* ± 0.5266
2 times	21.67	b	
1 times	22.13	ab	
3 times	22.58	a	

HG: Homogeneous group

According to table 7; the b* value was found higher (22.12) on the tangent section when compared with the radial section. In terms of chemical type, the highest b* value (25.84) found in the samples treated with sodium silicate and the lowest value (17.60) was found in the samples treated with hydrogen peroxide. It is found that the b* value of samples treated with sodium silicate was significantly higher when compared with control samples. In addition, a slight increase was observed in the b* values of samples (especially 3 times) treated with acetic acid and ammonia. Treatment of hydrogen peroxide led to decrease in the b* values of the samples (Table 1). In terms of repetition number, the highest b* value (22.58) found in the samples treated 3 times with chemicals and the lowest value (20.04) was found in the untreated (control) samples. The b* values of samples treated with sodium silicate was increased depending on the application repetition number, especially on the tangential section. It was observed that the decrease ratio of b* value was more in the samples treated twice with hydrogen peroxide (Table 1)

Total color change (ΔE*)

Analysis of variance (ANOVA) results of total color change (ΔE*) values of samples applied with acetic acid, ammonia, hydrogen peroxide and sodium silicate at different repetition numbers were shown in Table 8.

Table 8. ANOVA results of the ΔE* values of the beech samples

Factors	Degrees of freedom	Sum of squares	Mean square	F-value	Level of significance ($p \leq 0.05$)
Cutting direction (A)	1	33.041	33.041	4.8250	0.0291
Chemical type (B)	3	8259.041	2753.014	402.0214	0.0000
Interaction (AB)	3	851.810	283.937	41.4631	0.0000
Application repeat (C)	2	280.568	140.284	20.4856	0.0000
Interaction (AC)	2	18.328	9.164	1.3383	0.2645^{ns}
Interaction (BC)	6	741.154	123.526	18.0384	0.0000
Interaction (ABC)	6	234.408	39.068	5.7051	0.0000
Error	216	1479.153	6.848		
Total	239	11897.503			

ns: not significant

According to ANOVA results, it was found that an insignificant interaction between cutting direction-application repetition number factors on the changing of ΔE* value of beech samples ($p \leq 0.05$). Also, it was observed that there was a significant interaction between other factors.

Duncan test results of the comparison in the level of cutting direction, chemical type and application repetition number were given in the Table 9.

Table 9. Duncan test results of the ΔE* values in the level of comparison of cutting direction, chemical type and application repetition number

Cutting direction	Mean	*HG*	
Tangential section	12.56	b	*LSD* ± 0.6659
Radial sections	13.30	a	
Chemical type	Mean	*HG*	
Acetic acid	3.07	d	*LSD* ± 0.9417
Ammonia	14.40	c	
Hydrogen peroxide	15.87	b	
Sodium silicate	18.37	a	
Application repeat	Mean	*HG*	
1 times	11.46	b	*LSD* ± 0.8155
2 times	13.28	a	
3 times	14.03	a	

HG: Homogeneous group

According to the result of comparison (Table 9); total color change value (ΔE*) was found higher on the radial section (13.30) than radial section. However, the total color change in both surfaces was close to each other. In terms of chemical type, the highest ΔE* value (18.37) was found in the samples treated with sodium silicate and the lowest value (3.07) was found in the samples treated with acetic acid. The significant increase in the a* value and noteworthy reduction in the L* value affected the ΔE* value of samples treated with sodium silicate (Table 1). In terms of application repetition number, the highest ΔE* value was found in the samples treated for two times (14.03) and three times (13.28) and the lowest value (11.46) was found in the samples treated for one times. The value of ΔE* of beech samples increased depending on the number of the repetition of the chemicals application.

Conclusion

The L* value of beech samples was increased in the samples treated with hydrogen peroxide and decreased in the samples treated with ammonia or sodium silicate. Acetic acid application was not caused an important change in the L* value. The a* and b* values of samples decreased with the hydrogen peroxide application. On the other hand, sodium silicate application caused an important increase in the a* and b* values of samples. While acetic acid had the lowest effect on the total color change value (ΔE*), sodium silicate had highest effect. In addition, the increment in the repetition number increased the ΔE* value of samples. It is believed that research results may be useful in achieving color matching and in reducing the effects of subsequent color changes such as protective layer application, heat, light, exposure to various chemical especially in interior applications of beech wood.

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