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Research Article / Araştırma Makalesi

The effect of different wood varnishes on surface color properties of heat treated wood materials

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Abstract: This study investigates the effects of different wood varnishes on the surface color properties of heat treated wood. Samples prepared from Oriental beech (*Fagus orientalis* L.) and Scots pine (*Pinus sylvestris* L.) are subjected to heat treatment at 190, 200, and 210 ° C for 2 h. Sample surfaces are then covered with cellulosic (SZ), synthetic (ST), polyurethane (PU), and water-based (SB) wood varnishes, and the color properties of samples are determined according to the three-dimensional CIEL*a*b* color space. Results show a decrease in the L* and b* values of samples by 64% and 70%, respectively, depending on the process temperature after heat treatment. The a* value increases by up to 96% for Scots pine samples and up to 56% for beech samples. Color values of heat treated samples change significantly after varnish is applied; L* values of all samples are reduced compared to unvarnished samples and samples are seen to darken. However, the a* value of heat treated Scots pine samples increases significantly after varnishing, while that of heat-treated beech samples at high temperatures (200 and 210 °C) generally decreases. Nevertheless, the b* value decreases significantly in both wood species subjected to application of PU and ST varnishes, and the total color change (ΔE*) of varnished specimens is generally higher for samples heat-treated at 200 °C. Results show that ST varnish has the largest effect on color change and SB varnish has the smallest effect. The use of SB varnishes is thus preferable when it is necessary to preserve the color of samples from either species following heat treatment.

Keywords: Wood material, heat treatment, varnish, color change

Isıl işlemli ahşap malzemelerin yüzey renk özelliklerine farklı ahşap verniklerinin etkisi

Özet: Bu çalışmada, ısıl işlemli ahşapların yüzey renk özelliklerine farklı ahşap verniklerinin etkisi araştırılmıştır. Doğu kayını (*Fagus oriantalis* L.) ve sarıçam (*Pinus sylvestris* L.) odunundan hazırlanmış örneklere 190, 200 ve 210 °C sıcaklıkta 2 saat süresince ısıl işlem uygulanmıştır. Daha sonra örnek yüzeyleri selülozik (SZ), sentetik (ST), poliüretan (PU) ve su bazlı (SB) ahşap vernikleri ile kaplanmıştır. Örneklerin renk özellikleri üç boyutlu CIEL*a*b* renk uzayına göre belirlenmiştir. Araştırma sonuçlarına göre, ısıl işlem sonrası işlem sıcaklığına bağlı olarak örneklerde L* değeri %64, b* değeri %70 oranında azalmıştır. a* değeri ise sarıçam örneklerde %96'ya kadar artarken, kayın örneklerde %56 oranına kadar azalmıştır. Isıl işlemli örneklerin renk değerleri vernik uygulamalarından sonra önemli derecede değişmiştir. Verniksiz örneklere göre tüm örneklerin L* değeri azalmış ve örnekler daha da koyulaşmıştır. Vernikleme sonrası, ısıl işlemli sarıçam örneklerin a* değeri önemli oranda artarken, yüksek sıcaklıkta (200 ve 210 °C) ısıl işlemli kayın örneklerde genellikle azalmıştır. b* değeri ise PU ve ST vernik uygulanmış her iki ağaç türünde önemli oranda azalmıştır. Verniklenmiş örneklerdeki toplam renk değişimi (ΔE*) değeri genel olarak 200 °C'de ısıl işlemli örneklerde daha yüksektir. Ayrıca, renk değişiminde ST vernik en fazla etkiye sahip iken, SB vernik en az etkiye sahiptir. Isıl işlem sonrası kayın ve sarıçam odunlarında elde edilen ahşap renginin maksimum düzeyde korunması arzu ediliyor ise SB vernikler tercih edilebilir.

Anahtar kelimeler: Ahşap malzeme, ısıl işlem, vernik, renk değişimi

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1. INTRODUCTION

Wooden material is an engineering material with superior properties when compared to other materials. Easy-workability, aesthetic appearance, good resistance despite its lightness and being a renewable and sustainable natural material are some of these properties. However; because wood is an organic material, it could be deformed by the environmental factors such as water, light, heat and microorganisms. This situation significantly limits the usage of the wooden material especially under the outer environmental conditions. The properties of wooden material show differences depending on its structure and chemistry. For this reason; its resistance could be enhanced against the deforming impacts by changing the main chemical and structural properties of the wood with the use of different wood modification techniques. One of the most important techniques used in the wood modification is thermal-heat treatment.

Significant and permanent changes occur in the structure of the chemical components (hemicellulose, celluloses and lignin) of the wooden material with the heat treatment (Yılgör, 1999; Kamdem et al., 2002; Tjeerdsma and Militz, 2005; Yang et al., 2007; Kocaefe et al., 2008; Esteves and Pereira, 2009; Tümen et al., 2010; Aydemir et al., 2011). The hygroscopic property of the wood decreases, its dimensional stability increases and its resistance to the insects and microorganisms improve as a result of the heat treatment (Aydemir et al., 2011; Pelit et al., 2014; Kocaefe et al., 2015; Kamdem et al., 2002; Lekounougou and Kocaefe, 2014). These property changes are generally attributed to the thermal deformation of the hemicellulose and the dimension of the changes also shows an increase as the treatment temperature increases (Hill, 2006; Mitani and Barboutis, 2014). In addition; various extractive substances withdraws from the wood, ph decreases, heat insulation improves and the wood gains new physical properties such as attractive dark color (Hill, 2006; Huang et al., 2012).

Today, most industrialized heat treatment method is applied between the temperatures 150 °C and 260°C and in various periods (Sandberg et. al., 2013). The increase in the measuremental stability of the wood with heat treatment and also the increase in its resistance to biological deformations are the most important advantages. However; the decrease in the mechanical resistance properties of the wood with heat treatment and the increase in its vulnerability are the important disadvantages due to the experienced mass losses and thermal degradation (Bekhta and Niemz, 2003; Yıldız et. al., 2006; Boonstra, 2008; Korkut et. al., 2008; Kocaefe et. al., 2008). These undesired side effects occurring as a result of the heat treatment limit the general commercial usage of the wood with heat treatment (Boonstra, 2008). The color of the wooden material darkens with the impact of the high temperature. The material gains a brownish color tone and a characteristic smell. The change of color in the material is dependent on the heat treatment method and especially the treatment temperature and period (Mayes and Oksanen 2002). The wooden materials in which there has been a change of color due to the heat treatment may be appreciated by most users. This situation is especially more obvious in the light color wood types such as pine, beech, poplar and ash wood (Ayadi et. al., 2003). The color stability resistance of the heat treated wood against the outer environmental conditions is better than that of normal wood. However; color change occurs as in normal wood if no external protection is applied to the surface of the wood with heat treatment (Syrjanen and Kangas, 2000; Ayadi et. al., 2003, Aydemir and Gündüz, 2009).

The reason for the color differences between the tree species stems from difference in the chemical composition and especially the genetic factors such as the extractive substance content amount of every species. In addition; the environmental factors such as exposure to light, heat, humidity, alkaline or acids and the technical factors such as steaming, drying and finishing treatments change the color of the wood surface and affect its aesthetic properties (Bekhta et. al., 2014). Furniture and decoration elements made of wooden material and layer maker finishing tools in the protection of the various structure elements are widely used today. Varnishes and paints are the most widely used finishing tools and they form the outer layer of the treated wood. The main purpose of the finishing treatments is to protect the surface of the wood and to give a nice appearance to it (Kurtoğlu, 2000; Sönmez, 2005; Rowell, 2012). The main binding resins determine the basic properties of the varnishes and paints to be used for the finishing treatment. Alkyd, polyurethane, acrylate, polyester and nitrocellulose are the widely used binding resins today. In addition; special resins are attain by using the different combinations of these resins in different amounts (Sönmez and Budakçı, 2004; Rowell, 2012). Within the light of the information in the literature; the purpose of this study is to determine the changes occurring in the surface color of the wooden varnishes (cellulosic, polyurethane, synthetic and water-based) in different properties applied to the wooden material surfaces with heat treatment in high temperature values (190°C, 200 °C and 210°C).

2. MATERIALS AND METHOD

2.1. Material

Within the scope of the study; the samples of scotch pine (*Pinus sylvestris* L.) and Eastern beech (*Fagus orientalis* L.) widely used in the furniture and woodwork industry have been used. Scotch pine with which the samples have been prepared have been supplied from the area of Ordu Mesudiye Directorate of Forestry Operation Melet Operational Chiefdom and also Eastern beech with which the samples have been prepared have been supplied from the area of Ordu Akkus Directorate of Forestry Operation Akkus Operational Chiefdom. The plank timbers with fresh state humidity have been cut in rough measurements from the sapwood part in the automatic-controlled band saw machine. After that; the samples have been dried in the automatically controlled classical drying oven up to approximately 12% humidity and they have been cut in the measurements 450 × 95 × 15 mm (longitudinal direction × tangential direction × radial direction) (Figure / Şekil 1).

Figure 1. Preparation of samples in draft dimensions
Şekil 1. Örneklerin taslak ölçülerde hazırlanması

2.2. Method

2.2.1. Heat treatment

The application of heat treatment to the prepared samples has been carried out in three stages (drying in high temperature, heat treatment, cooling and conditioning) according to ThermoWood® method (Figure / Şekil 2). In the second stage, heat treatment has been applied in the aimed three different temperatures (190, 200 and 210°C) for two hours to the samples dried up to approximately 0% humidity by rapidly increasing the oven temperature with the use of heat and steam in the first stage. In the third stage, the temperature has been decreased, water spray has been used and the humidity amount of the samples has been increased to approximately 4-6% (ThermoWood Handbook, 2003). The total heat treatment period has taken 38 hours for each temperature value.

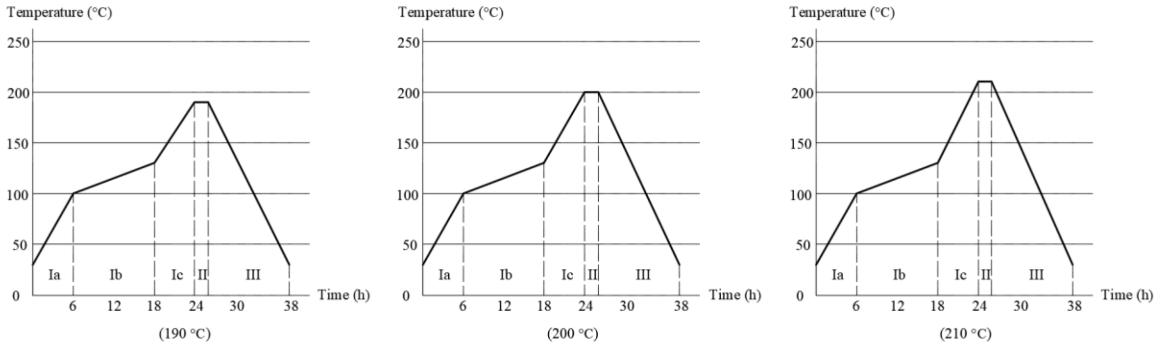

Figure 2. Heat treatment processes
Şekil 2. Isıl işlem prosesleri

The samples have been rested under atmospheric conditions for 2-3 weeks after the heat treatment. Following that; the samples have been cut in the dimensions 80 × 80 × 10 mm (longitudinal direction × tangent direction × radial direction) and in a way that it will have six repetitions (n=6) for each variable (Figure /Şekil 3). A total of 192 samples have been prepared. The samples have been kept in the air-conditioning cabinet whose relative humidity is 65±3% at 20±2°C according to TS 2471 (1976) until they reach constant weight (The equilibrium moisture amount averages of the samples have been detected as 9.1% at 190°C, 8.0% at 200°C and 7.3% at 210°C). After that; the surfaces of the samples have been respectively sanded with 150 and 180 sandpaper, their dust has been taken with compressed air and they have been made ready for varnishing.

Figure 3. Cutting of samples after heat treatment
Şekil 3. Isıl işlem sonrası örneklerin kesilmesi

2.2.2. Varnish

Cellulosic (SZ) with shining property, synthetic (ST), two-component polyurethane (PU) and two-component water-based (SB) wood varnishes have been used in the study. Some technical properties belonging to the used varnishes are given in Table / Tablo 1. The principles specified in ASTM-D 3023 (2011) have been respected in the varnishing of the test sample. In addition; the suggestions of the companies manufacturing the varnishes have been taken into consideration.

Table 1. Some properties of varnishes
Tablo 1. Verniklere ait bazı özellikler

Type of varnish	pH	Density (g/cm³)	Application viscosity (sn/DIN Cup 4 mm/20 ˚C)	Amount of varnish applied (g/m²)	Solid content (%)	Method of application	Gun tip opening (mm)
SZ (filling)	3.5	0.94	18	120	25.9	Spray gun	1.8
SZ (topcoat)	4.6	0.93	18	120	24.8	Spray gun	1.8
PU (filling)	6.7	1,01	18	100	40.4	Spray gun	1.8
PU (topcoat)	5.4	0.99	18	100	45.2	Spray gun	1.8
ST	6.2	0.94	18	100	54.1	Brush	-
SB (filling)	8.1	1.11	18	70	34.2	Spray gun	0.8
SB (topcoat)	8.2	1.15	18	75	34.1	Spray gun	0.8

SZ, PU and SB varnishes have been applied as fill coat and top coat. SZ and PU fill varnishes have been applied with the interval of 15 minutes; SB fill varnish has been applied with the interval of one hour as two coats and the sample surfaces have been sanded with 320 sandpaper after waiting for 24 hours. SZ, PU and SB top coats have been applied as two coats with the intervals specified in the fill coat on the sample surfaces whose dust has been taken. ST varnish has been applied as three coats with the interval of 24 hours. Light sandpapering has been applied between the coats with 300 sandpaper. All the varnished samples have been kept for 5 weeks in the room temperature in parallel to the ground plane without any exposure to any direct sunlight (Figure / Şekil 4).

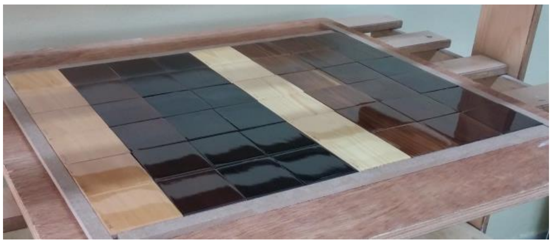

Figure 4. Drying of varnished scots pine and Eastern beech samples

Şekil 4. Verniklenmiş sarıçam ve doğu kayını örneklerin kurutulması

2.2.3. Color measurement

The surface color values of scots pine and Eastern beech samples before and after treatment were determined with a *BYK-Gardner Spectrophotometer* colorimeter according to ASTM D2244 (2015) standard. In the three-dimensional CIEL*a*b* color space, each color can be expressed as a point in Euclidean space, which is associated with subjective color perception and defined in three coordinates (Figure / Şekil 5) (Mononen et al., 2002; Gonzalez-Pena and Hale, 2009). In this space, L* (lightness) is positioned on the black-white axis (L* = 0 for black, L* = 100 for white), a* on the red-green axis (red for positive values and green for negative values), and b* for the yellow-blue axis (yellow for positive values and blue for negative values) (Söğütlü and Sönmez, 2006).

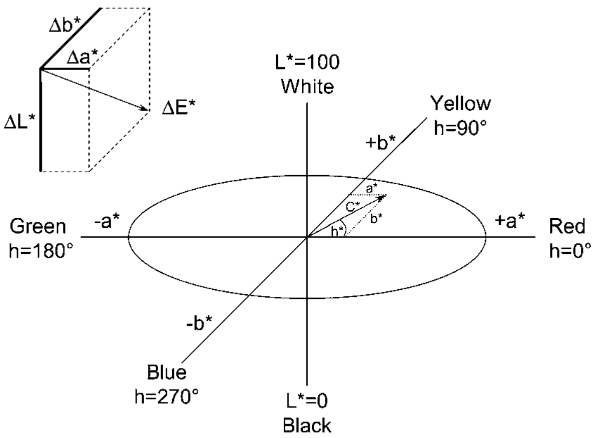

Figure 5. Three-dimensional CIEL*a*b* color space (Gonzalez-Pena and Hale, 2009)
Şekil 5. Üç boyutlu CIEL * a * b * renk uzayı (Gonzalez-Pena and Hale, 2009)

In the study; L*, a* and b* color parameters of the treated and untreated samples have been examined independent of one another. In addition; respective ΔL*, Δa* and Δb* expressing the differences between the values of L*, a* and b* parameters before and after the varnishing applications have been determined according to the Equation 1, 2 and 3. The total color change/difference (ΔE*) occurring on the varnished sample surfaces when compared to the non-varnished samples have been determined with the use of Equation 4.

$$\Delta L^* = L^*_v - L^*_k \quad (1)$$

$$\Delta a^* = a^*_v - a^*_k \quad (2)$$

$$\Delta b^* = b^*_v - b^*_k \quad (3)$$

$$\Delta E^* = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \quad (4)$$

Here; "*v*" expresses the value after varnishing and "*k*" expresses the value before varnishing. Measurements have been taken from three different zones of each sample (n=6) before and after the treatment in the determination of the color parameters (L*, a* and b*) and their averages have been saved as single value.

2.2.4. Statistical analysis

Analysis of variance (ANOVA) tests were performed to determine the effect of heat treatment and varnish application on surface color properties of scots pine and Eastern beech samples (0.05 significance level).In addition, in both types of wood subjected to heat treatment and varnishing,, the average values of color parameters were compared with multiple Duncan tests.

3. RESULTS AND DISCUSSION

According to the result of the variance analysis; heat treatment temperature and varnish type variables and the mutual interaction between these variables have been found significant on the change in L*, a*, b* color values of scotch pine and Eastern beech samples (Table / Tablo 2). L*, a*, b* average color values of control (untreated), heat-treated and varnished wooden samples and homogeneity groups according to the result of Duncan test multiple comparison are given in Table / Tablo 3.

Table 2. Analysis of variance results for L*, a*, b* color values of heat treated scots pine and Eastern beech samples applied with different varnishes

Tablo 2. Farklı vernikler uygulanmış ısıl işlemli sarıçam ve Doğu kayını örneklerin L*, a*, b* renk değerleri için varyans analizi sonuçları

Wood type	Factor	L*		a*		b*	
		F-ratio	*p*-value	*F*-ratio	*p*-value	*F*-ratio	*p*-value
Scots pine	Heat treatment (A)	17937.932	0.0000*	2378.2671	0.0000	1722.7698	0.0000
	Varnish type (B)	1125.1743	0.0000	300.1184	0.0000	101.5275	0.0000
	Interaction (AB)	45.6008	0.0000	58.4684	0.0000	80.6383	0.0000
Eastern beech	Heat treatment (A)	31685.052	0.0000	1885.1876	0.0000	6960.3486	0.0000
	Varnish type (B)	3444.1261	0.0000	111.5899	0.0000	161.1898	0.0000
	Interaction (AB)	104.7985	0.0000	82.9819	0.0000	266.9031	0.0000

*: Significant at 95% confidence level ($p \leq 0.05$)

The application of heat treatment has significantly changed L*, a*, b* color values of scotch pine and Eastern beech samples. The lightness (L*) value in both tree species has been measured higher (81.38 for scotch pine and 67.50 for Eastern beech) in control (with no heat treatment) samples (Table / Tablo 3). After heat treatment; L* value of samples has significantly decreased depending on the increase in the treatment temperature and the samples have darkened (Figure / Şekil 6). When compared to control samples, L* value has decreased up to respectively 46%, 54% and 62% at 190, 200 and 210 °C in heat-treated scotch pine samples; and it has decreased up to respectively 48%, 58% and 64% in Eastern beech samples. In previous studies; it has been expressed that the color of the wood has darkened more with the increase the heat treatment temperature and duration (Militz, 2002; Bekhta and Niemz 2003; Mitsui et.al., 2003; Özçifçi et.al., 2009; Gündüz et.al., 2010; Aksoy et.al., 2011; Akgül and Korkut, 2012; Toker et.al., 2016). The color of the wood tends to darken due to the important changes in the chemical components of the wood such as degradation of amorphous carbonhydrates during the heat treatments at high temperature (Kamperidou et al., 2012; Toker et al., 2016). It has been specified (Bekhta and Niemz 2003) that the changes in the L* value of the heat treated wood mainly depend on the degradation of hemicelluloses and wood color has become darker than the beginning (Huang et al., 2012; Bekhta et al., 2014), the degree of the thermal degradation in the wooden material is directly related with the darkening degree in the color of the wood (Poncsak et al., 2006) and there are strong correlations between the total change in the wood color and resistance properties after the heat treatment (Bekhta and Niemz 2003). In addition; it has been reported that the color changes occurring as a result of the heat treatment are probably related to the modification of polysaccharide structures, the vaporization of colorant extracts and rapid oxidation of lignin and some chemical elements at high temperature (Şahin and Korkut, 2016).

a* value of the scotch pine samples has significantly increased after the heat treatment and the samples tend to turn red (Figure / Şekil 6). However; the increase in the temperature of the treatment has caused a decrease in a* value. The increase in a* value has occurred higher in the scotch pine samples to which heat treatment has been applied at 190°C and the ratio of increase in these samples is at the level of 96% when compared to the controls. In the Eastern beech; a*value after the heat treatment has decreased depending on the increase in the temperature of the treatment and the green color tendency of the samples has increased. The decrease in the a* value of the samples with heat treatment at 190, 200 and 210 °C is respectively 16%, 34% and 56% when compared to the samples with no heat treatment (Table / Tablo 3). b* value of the samples has decreased in both tree species depending on the application of heat treatment and the increase in the temperature of the heat treatment. The samples tend to turn blue. After the heat treatment; the decrease in the b* value occurring when compared to the control (with no heat treatment) samples have occurred respectively as 4%, 17% and 40% in the scotch pine samples with heat treatment at 190, 200 and 210 °C and it has occurred respectively as 28%, 51% and 70% in Eastern beech samples (Table / Tablo 3). In the study performed by Toker et al. (2016), heat treatment has been applied to the samples of scotch pine and Eastern beech at the temperature of 205, 220 and 235°C for the periods of 1, 3 and 5 hours. After the heat treatment, it has been expressed that L*, a* and b* values of the samples have decreased depending on the increase in the temperature and period of the treatment. In the study conducted by Bekhta and Niemz (2003); it has been specified that b* value of spruce wood samples has increased together with the increase in the temperature of the heat treatment up to 150°C (it is in maximum level at this temperature) and it has started to decrease after this point; and a* value has increased to maximum level at 200°C. It has been reported that a* value of heat-treated hornbeam wood has increased after treatment at 170°C and it has decreased at 190 and 210°C; and b* value has decreased in all treatment temperatures (Gündüz and Aydemir, 2009). It has been stated that b* value in heat-treated Eastern beech samples has increased at the beginning (at 140°C) and it has decreased in the next temperatures (170 and 200 ° C); a* value has decreased also depending on the increase in the temperature after the heat treatment (Baysal et al., 2014).

Table 3. The mean values of L*, a*, b* before and after the processing of scots pine and Eastern beech samples
Tablo 3. Sarıçam ve Doğu kayını örneklerin işlem öncesi ve sonrası L*, a*, b* ortalama değerleri

Heat treatment	Varnish type	Wood type					
		Scots pine			Eastern beech		
		L*	**a***	**b***	**L***	**a***	**b***
Untreated	Unvarnished	81.38 A^HG (0.68)	5.49 K (0.26)	22.66 FG (0.23)	67.50 A (0.56)	11.62 EF (0.27)	21.61 D (0.34)
	SZ	74.33 C (1.13)	6.46 IJ (0.48)	28.30 CD (0.37)	56.78 D (1.01)	16.76 B (0.49)	33.06 B (0.46)
	PU	74.41 C (0.99)	6.14 J (0.51)	29.80 B (0.28)	57.70 C (0.39)	15.47 C (0.38)	32.72 B (0.32)
	ST	73.31 C (0.28)	6.81 I (0.20)	35.16 A (0.33)	54.26 E (1.07)	18.62 A (0.57)	38.96 A (0.47)
	SB	78.55 B (0.44)	5.31 K (0.15)	27.39 D (0.34)	62.88 B (0.74)	13.91 D (0.21)	27.62 C (0.17)
190 °C	Unvarnished	43.61 D (1.19)	10.78 G (0.06)	21.72 G (0.57)	35.34 F (0.68)	9.78 G (0.18)	15.57 F (0.54)
	SZ	26.91 G (1.74)	16.48 C (0.24)	28.84 BC (0.92)	14.51 I (0.92)	14.79 C (0.22)	17.45 E (0.98)
	PU	27.16 G (2.32)	16.79 C (0.19)	27.18 D (1.56)	14.73 I (0.99)	12.28 E (0.79)	12.40 H (1.51)
	ST	20.59 I (2.08)	18.96 A (0.43)	27.86 CD (2.35)	6.44 L (1.40)	11.64 E (2.15)	7.71 J (2.22)
	SB	31.58 F (1.38)	14.91 E (0.24)	28.86 BC (0.68)	23.77 H (0.76)	13.99 D (0.25)	21.34 D (0.41)
200 °C	Unvarnished	37.31 E (0.17)	10.55 G (0.13)	18.70 H (0.24)	28.68 G (0.75)	7.63 H (0.30)	10.62 I (0.67)
	SZ	19.29 J (0.35)	15.50 D (0.60)	22.90 F (0.71)	7.97 JK (0.60)	8.17 H (0.83)	6.55 K (0.77)
	PU	17.55 K (0.84)	14.48 E (0.67)	17.39 I (1.33)	7.46 K (0.51)	4.37 K (0.68)	2.44 N (0.63)
	ST	11.70 MN (1.30)	17.66 B (0.50)	16.78 IJ (2.00)	2.30 N (0.40)	2.46 L (0.73)	1.53 N (0.41)
	SB	23.50 H (0.99)	15.03 DE (0.37)	25.23 E (0.71)	14.18 I (0.49)	10.85 F (0.43)	13.60 G (0.91)
210 °C	Unvarnished	30.73 F (0.43)	8.95 H (0.13)	13.50 K (0.26)	24.10 H (0.53)	5.15 J (0.30)	6.51 K (0.45)
	SZ	12.70 M (0.89)	12.64 F (0.57)	14.15 K (1.02)	8.33 J (0.42)	4.05 K (0.57)	3.73 M (0.38)
	PU	11.06 N (0.82)	10.72 G (0.47)	9.27 L (0.89)	5.50 M (0.42)	1.35 M (0.32)	0.39 O (0.22)
	ST	4.82 O (0.65)	10.28 G (1.35)	6.12 M (1.02)	1.47 O (0.09)	0.94 M (0.22)	0.51 O (0.13)
	SB	15.64 L (1.04)	12.36 F (0.41)	15.78 J (0.77)	8.04 JK (0.46)	6.18 I (0.60)	5.00 L (0.85)

Values in parenthesis are standard deviations
HG: Homogeneity group according to the Duncan test comparisons
The same letters in each column indicate that there is no statistically significant difference

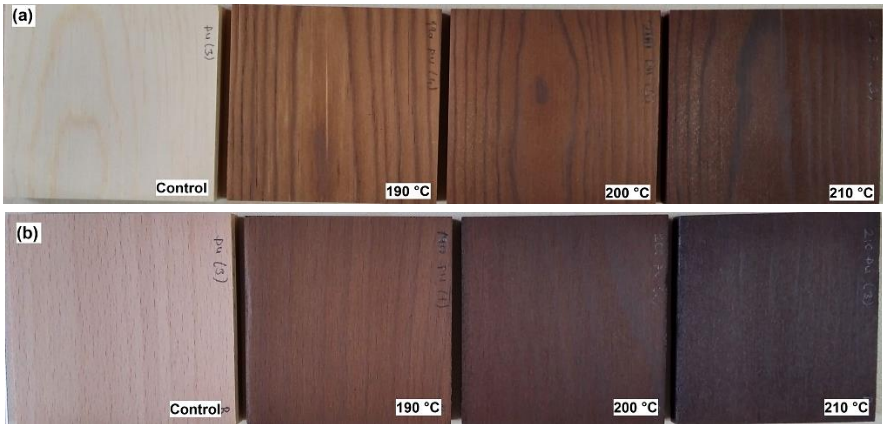

Figure 6. Appearance of scots pine (a) and Eastern beech (b) samples before and after heat treatment
Şekil 6. Sarıçam (a) ve Doğu kayını (b) örneklerinin ısıl işlem öncesi ve sonrası görünüşü

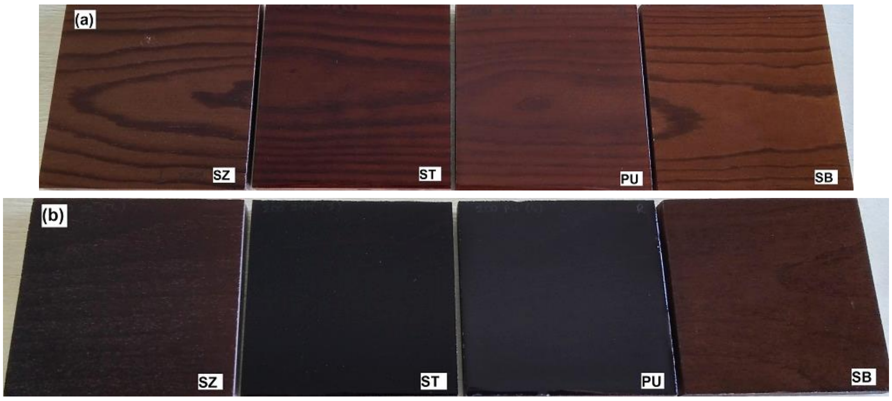

Figure 7. Appearance of scots pine (a) and Eastern beech (b) samples heat treated at 200 ° C after different varnish applications
Şekil 7. 200 °C'de ısıl işlem görmüş sarıçam (a) ve doğu kayını (b) örneklerinin farklı vernik uygulamalarından sonraki görünüşü

The lightness difference (ΔL*) calculated according to the samples without varnish after the varnish applications is in minus direction and it is generally higher in the Eastern beech samples and these samples have more tendency to darken (Figure / Şekil 7). Lightness (L*) value of all the control and heat-treated samples has decreased after the varnish applications and the samples have darkened (Table / Tablo 3, Figure / Şekil 8). L* value of the heat-treated samples have been affected by the varnish applications when compared to the control (with no heat treatment) samples. Depending on this; ΔL* value has been determined as higher in the heat-treated samples. ΔL* value has increased depending on the increase in the temperature of the heat treatment in scotch pine samples and higher values have been attained at 200 and 210 °C. In Eastern beech samples, higher values have generally been attained at 190 and 200 °C (Figure / Şekil 8). It has been specified in the literature that the chemical components (especially hemicellulose) of the wooden cell wall have been demolished and degraded and the structure of these components have changed (Kamdem et al., 2002; Tjeerdsma and Militz, 2005; Yang et al., 2007; Kocaefe et al., 2008; Tümen et al., 2010; Aydemir et al., 2011). It could be said that the heat-treated samples whose structure has changed when compared to normal wood show a different interaction with the varnish chemical applied to their surface and their tendency to darken has increased. On the other hand; the impact of the varnish type is significant on ΔL* values and ΔL* values have been determined as higher in the samples on which ST varnish has been applied. In other words; ST varnish has caused to more darkening in the samples. It has also been observed that SB varnish has the least impact; SZ and PU varnishes show similar impact (Figure / Şekil 7 and 8). It has been stated that during the heat treatment of the wood, more intense acetic and formic acid formation has been experienced in the high treatment temperature and long treatment period and this has caused to the decrease in the lightness (L*) value of the wood (Sundqvist et al., 2006). It is considered that the acidic structure (Table / Tablo 1) of the varnishes (except for SB varnish) used in the study may be efficient in the increase in the darkening tendency of the varnished and heat-treated samples.

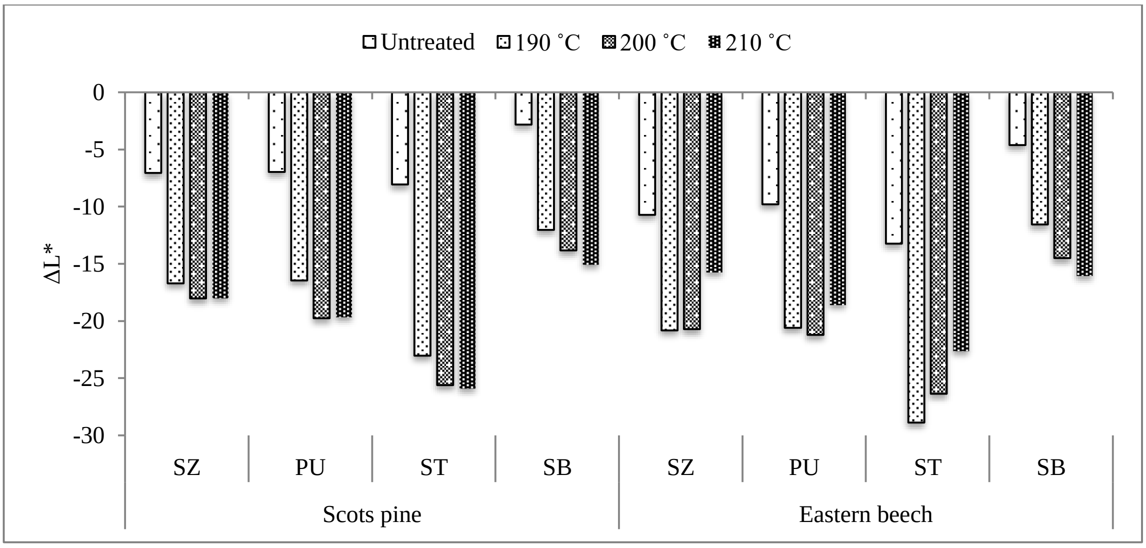

Figure 8. The change-difference (ΔL*) in the lightness value of control and heat treated samples after varnishing
Şekil 8. Vernikleme sonrası kontrol ve ısıl işlemli örneklerin ışıklılık değerindeki değişim-fark (ΔL*)

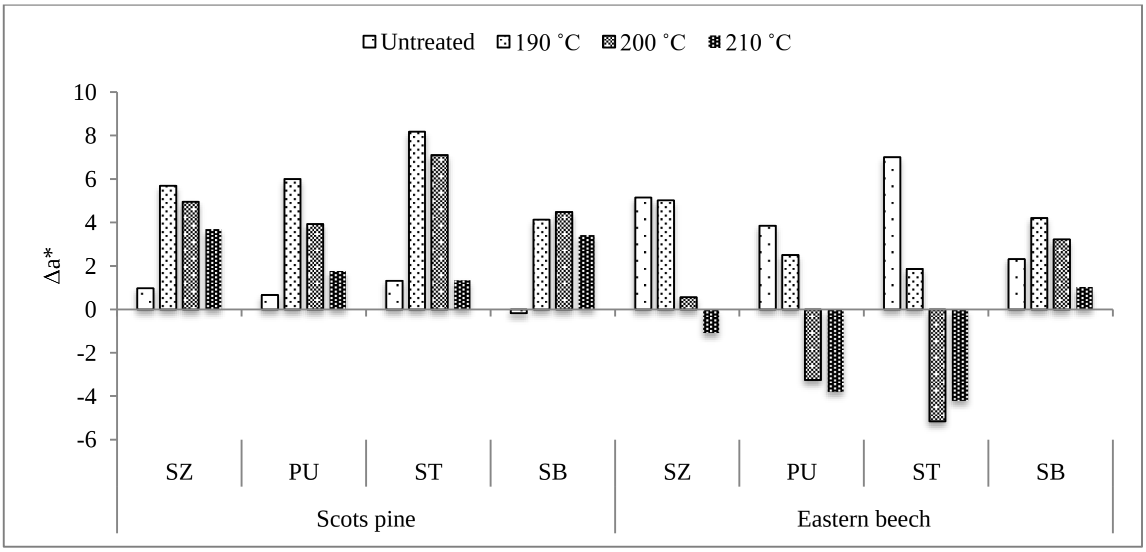

Figure 9. Red-green color change (Δa*) in control and heat treated samples after varnishing
Şekil 9. Vernikleme sonrası kontrol ve ısıl işlemli örneklerde kırmızı-yeşil renk değişimi (Δa*)

a* value of the scotch pine samples have shown an increase after the varnishing applications. a* value has significantly increased after varnishing especially in the heat-treated scotch pine samples (Table / Tablo 3). The difference (Δa*) calculated in a* value is in plus direction when compared to the scotch pine samples with no varnish; in other words, the samples tend to turn red. However; the increase in the temperature of the heat treatment has decreased the reddening tendency of the varnished scotch pine samples. The highest values have been attained in the heat-treated samples at 190°C (Table / Tablo 3, Figure / Şekil 9). a* value has significantly increased after all the varnishing applications in the control (with no heat treatment) Eastern beech samples. a* value has decreased after the varnishing applications depending on the temperature of the treatment in the heat-treated Eastern beech samples. a* value of especially PU and ST varnished beech samples heat-treated at 200 and 210°C has significantly decreased; the difference (Δa*) calculated in a* value when compared to the samples with no varnish is in minus direction and the green color tendency of the samples has increased (Figure / Şekil 9). However; a* value of the SB varnished beech samples heat-treated at 190 and 200°C is higher when compared to the beech samples with no heat treatment. a* value of the SB varnished beech samples has also decreased together with the increase in the temperature of the heat treatment. In addition; the change in a* value occurring due to the difference in the temperature of the heat treatment in both tree species has been realized as lowest in SB varnished samples and as highest in ST varnished samples (Table / Tablo 3, Figure / Şekil 9).

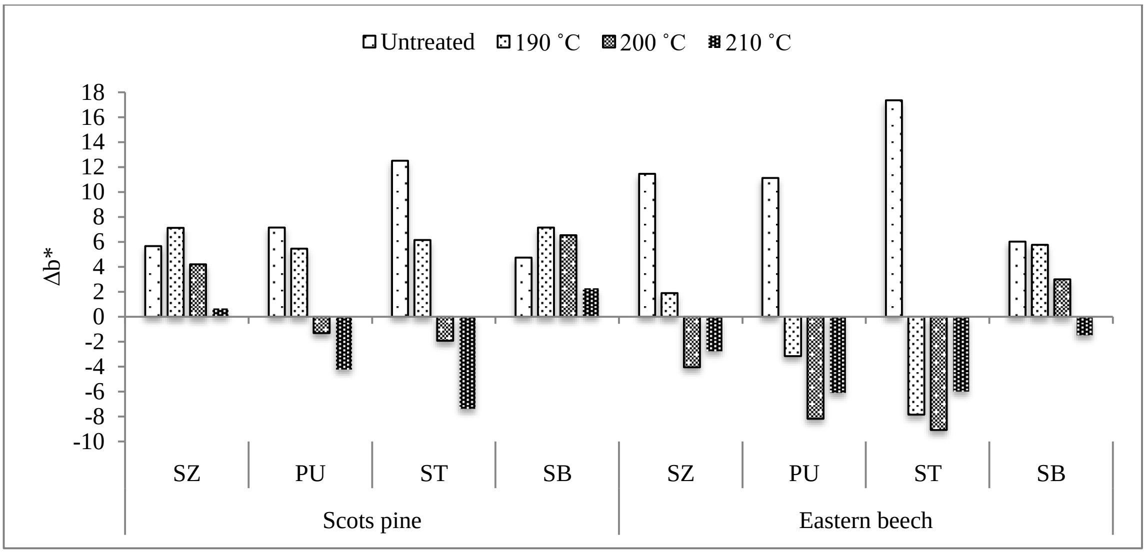

Figure 10. Yellow-blue color change (Δb*) in control and heat treated samples after varnishing
Şekil 10. Vernikleme sonrası kontrol ve ısıl işlemli örneklerde sarı-mavi renk değişimi (Δb*)

b* value of the scotch pine and Eastern beech samples with no heat treatment has increased after all varnish applications and the samples have a tendency of yellowing. The highest values have been attained in ST varnished samples and the lowest values have been attained in SB varnished samples. It has been reported that the amines taking place in the structure of the solvent based varnished turn yellow in time as a result of oxidation, but these chemicals causing to yellowing have not been used in the production of water based varnishes (Johnson, 1997) and in addition; the water based varnishes are the chemical reaction drying ones which do not change the color of the wood material, mostly produced as colorless and scentless and which do not turn yellow (Yıldız, 1999). b* value of the heat treated samples has generally been found lower after varnishing when compared to the control (with no heat treatment) samples. b* value of all the varnished samples have significantly decreased depending on the increase in the temperature of the heat treatment. This situation is clearer especially in PU and ST varnished and heat treated samples (Figure / Şekil 7). When compared to the samples with no varnish, the difference (Δb*) calculated in b* value of these samples is in minus direction and the samples tend to turn blue. On the other hand; when compared to the samples with no heat treatment, the change occurring in b* value after the varnish applications in the samples treated with heat in different temperatures is in the lowest level in SB varnished samples and in the highest level in ST varnished samples (Table / Tablo 3, Figure / Şekil 10).

Color change has occurred in all the control and heat treated samples after the application of wooden varnishes with different properties. The value of total color change (ΔE*) occurring in the varnished samples has generally been determined as a little more in the beech samples when compared to the scotch pine samples. Heat treated samples have been affected from the varnish applications more when compared to the control (with no heat treatment) samples in both tree species and ΔE* value has been found higher in these samples. The attained results are also in accordance with the results of the previous studies (Yalınkılıç, 2013, Mıdıroğlu, 2015). Moreover; the difference between the samples with and without heat treatment is higher in scotch pine samples after the varnishing applications when compared to the beech samples. Although the impact of the temperature of the heat treatment is not very clear for the heat treated scotch pine samples on ΔE* values, it is in higher values at 200 and 210°C. The impact of the temperature of the heat treatment is more obvious on the ΔE* values of the heat treated beech samples and the values are generally higher at 190 and 200°C. However; ΔE* value has also shown an increase together with the increase in the temperature of the heat treatment in SB varnished beech samples. ΔE* values of both control samples and the scotch pine and beech samples treated with heat in different temperatures are the highest on ST varnished surfaces and the lowest on SB varnished surfaces. In other words; ST varnish has affected the color parameters of the samples as the most and SB varnish has affected it as the least. ΔE* values of SZ and PU varnished have given results very close to each other (Figure / Şekil 11). In a previous similar study; synthetic, parquet varnish and water based varnish have been applied on the surfaces of the samples of beech, oak, poplar, scotch pine and fir wood to which heat treatment has been applied in two different temperatures (165 and 175°C) and in two different periods (2 and 4 hours) and ΔE* value measured on the surfaces of the samples is the lowest in water based varnish and the highest in the synthetic varnish (Yalınkılıç, 2013). In another study; water based, acrylic, UV-dried varnish and teak oil have been applied to the surfaces of the Eastern spruce sample heat-treated at 190 and 212°C. It has been specified that ΔE* value of the samples is the highest in the varnishing application with teak oil and acrylic varnish and the lowest in water based varnish application (Mıdıroğlu, 2015), also, the highest color change has occurred in the samples to which synthetic varnish has been applied when cellulosic, synthetic, polyurethane and acid-catalyst varnish have been applied to the woods of oak, Eastern beech, chestnut and scotch pine (Sönmez, 1997).

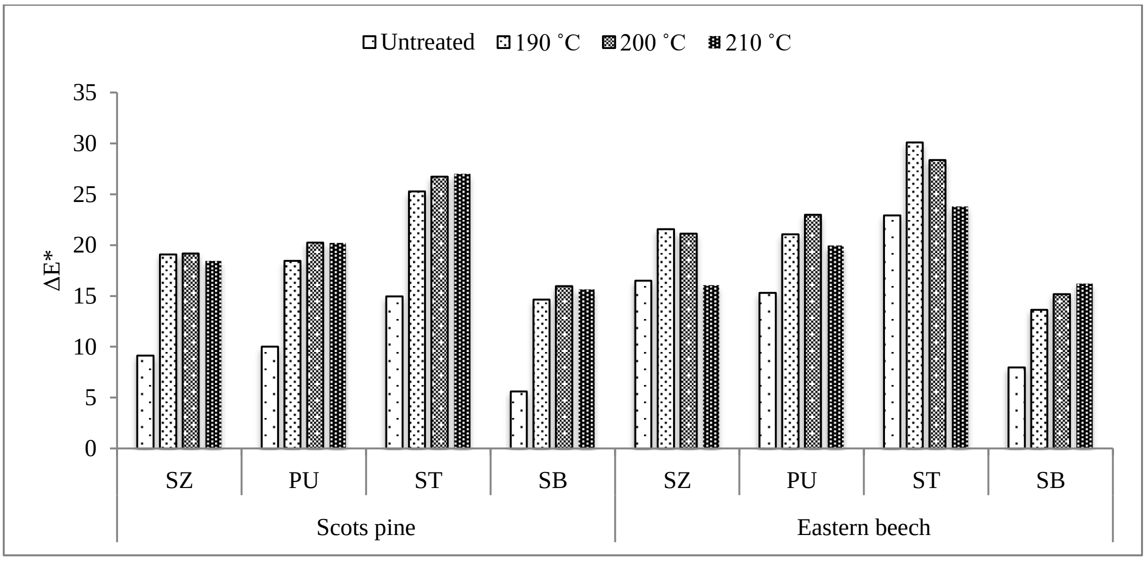

Figure 11. Total color change (ΔE*) in control and heat treated samples after varnishing
Şekil 11. Vernikleme sonrası kontrol ve ısıl işlemli örneklerde toplam renk değişimi (ΔE*)

4. CONCLUSIONS AND RECOMMENDATIONS

In this study; the impact of the wood varnishes with various properties applied to the surfaces of scotch pine and Eastern beech samples to which heat treatment has been applied in different temperatures on the color properties has been examined. The color properties of the samples have significantly changed after heat treatment. L* value has decreased up to 62% in scotch pine samples and up to 64% in beech samples; b* value has decreased up to 40% in Scotch Pine samples and up to 70% in beech samples depending on the application of heat treatment and the increase in the temperature of the treatment. a* value of scotch pine samples have increased up to 96% with the application of heat treatment. However; the increase in the temperature of the treatment tends to decrease a* value. a* value of beech samples has decreased up to 56% after the heat treatment depending on the increase in temperature.

The color values of L*, a* and b* of both control and heat treated tree species have significantly changed after the varnishing applications. L* value of all the samples has decreased when compared to the samples with no varnish. This situation is more obvious especially in the samples with heat treatment and the samples have darkened more. a* value of heat treated scotch pine samples and control beech samples have significantly increased after varnishing. However, the increase in the temperature of heat treatment has decreased a* value of these samples. The a* value of especially PU and ST varnished beech samples heat treated at 200 and 210°C has significantly decreased and the green color tendency of the samples has increased. After the varnishing applications, b* value of the control (with no heat treatment) samples has increased and these samples tend to turn yellow. b* value of especially PU and ST varnish applied samples has significantly decreased depending on the increase in the temperature of the heat treatment and the samples tend to turn blue. Heat treated samples have generally been affected by the varnishing applications more when compared to the control samples. Although total color change value (ΔE*) is not very clear in both varnished tree species, it is higher in the samples heat treated at 200°C. In addition; while ST varnish has the ST varnish has the most impact on the ΔE* values of the samples; SB varnish has the least impact.

Consequently; the use of water based varnishes could be suggested if the wooden material surface is coated with an external protector after the heat treatment and the attained surface color is not desired to change or desired to change in the least amount. It should not be forgotten that the varnish applications cause to important color changes in especially the heat treated beech wood. Furthermore; the dark color in lighter tones attained from the wood material in low temperature of heat treatment could be increased with varnish applications (especially ST varnish) and the material could be made more attractive.

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