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EFFECTS OF DIFFERENT CLIMATE TYPES ON COLOR CHANGE OF WOOD MATERIAL USED OUTDOOR

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ABSTRACT

Field tests are important for evaluating how wood performs in real-world conditions and making informed choices for material selection. These tests help assess wood's durability, strength, decay processes, and resistance against harmful organisms. Furthermore, it helps users make more informed decisions about the color of wood and understand the importance of color changes depending on the place and time of use. Because weather conditions are a significant factor that influences the color of wood. Wood that is exposed to prolonged sunlight, moisture, and rain may experience fading, darkening, or staining in its color. In this study, heartwood, sapwood, and CCB impregnated sapwood samples of Scotch pine, spruce, beech and alder were exposed to the soil contact (hazard class 4) according to EN 252 for 3 years in Trabzon, Muğla, Çanakkale, and Elazığ provinces of Turkey with completely different climatic conditions from each other. Color parameters and color change values were evaluated using $L*$, $a*$, $b*$ and $\Delta E*$ of the samples collected from test sites. The most significant color change was observed at Scotch pine in Çanakkale province. Greater color changes were observed in the heartwood of coniferous species. Impregnated samples showed the least color change.

KEYWORDS: Color change, impregnated wood, climate types, wood type, EN 252.

INTRODUCTION

While wood has numerous advantages, such as being organic, resilient, able to store carbon, using less energy during processing, and having an appealing aesthetic, it also has disadvantages, such as being harmed by a variety of decomposers (Ramage et al. 2017, Zhong and Ma 2022). UV damage is one of the most important disadvantages (Evans et al. 1996, Williams 2005). According to the You et al. (2018) and Sandak et al. (2021), UV deterioration is the primary cause of wood deterioration especially in outdoor wood products. When sunlight interacts photochemically with the lignin in the wood structure, decomposition starts. Rainwater or moisture passing through degraded wood will flow more readily towards the inner layers and produce a gray surface in cellulose. A faster-moving body of water will bring into play sooner elements that might harm wood, like fungal rots (Yu et al. 2018, Sandak et al. 2021). A physical-optical macroscopic characteristic of wood is its distinctive color (Dzurenda et al. 2022). Long-term outdoor exposure to UV damage causes the color of wood to change, which accelerates the aging process (Hon 2001, Baar and Gryc 2011). Age-related color changes and surface roughness limit the marketing potential and consumer confidence in wood products (Petrillo and al. 2019, Sedliacikova et al. 2021). According to Gandelova et al. (2009), UV degradation is a result of the interaction between the sun and the structure of wood. It is correlated with climate data (Sandak et al. 2015, 2017). Given the variety of climates in Turkey, it is anticipated that wood products used outdoors may experience varying degrees of UV deterioration (Temiz et al. 2005). In addition, due to varying lignin and hemicellulose levels, color change values brought on by UV degradation vary depending on the species of wood (Tomak et al. 2014). Şahin (2002) found that the color darkening of coniferous woods is greater than that of deciduous trees and has a positive association with processing time by using artificial aging techniques. On the other hand, less is known about how wood changes color in natural settings. Numerous researches on wood have revealed that color variations may occur based on the wood type (Bourgois et al. 1991), environmental factors, the density and texture of the wood, as well as other factors (Can and Sivrikaya 2019). The studies concerning UV degradation of the wood material, particularly the studies carried out in contact with the soil are of great importance. Factors such as intense humidity, UV rays, mechanical wear, and temperature in the outdoor environment and especially in the 4th hazard class (EN 335, 1992) cause some changes in the color, chemical and physical structure of the wood material. These changes shorten the service life of the tree and increase the repair or replacement costs of decomposed materials and cause significant economic losses (Fidan et al. 2018). With the impregnation process, these degradations can be minimized. It is known that especially impregnation materials containing copper and chromium are very effective in protecting wood in the external environment (Williams 2005, Temiz 2005). However, the number of studies on the durability of impregnated wood in different climatic conditions is very limited.

The researchers conducted in contact with the soil are quite important. In the outdoor environment, particularly in the 4th hazard class (EN 335, 1992), factors such as high humidity, UV radiation, mechanical abrasion, and temperature affect the color, chemical composition, and physical structure of the wood material. These factors reduce the wood's lifetime, raise the price of repairing or replacing deteriorated parts, and result in considerable financial losses (Fidan et al. 2018). These degradations can be reduced by the impregnation procedure. It is well known that impregnation materials, in particular those containing copper and chromium, are particularly good at shielding wood from the elements (Williams 2005, Temiz 2005). However, very few studies show how long impregnated wood lasts in various environmental circumstances.

The purpose of this study was to compare the color changes of CCB impregnated sapwood, nonimpregnated sapwood, and heartwood of Scotch pine, spruce, beech, and alder woods exposed to soil contact for 3 years, under various climatic conditions.

MATERIAL AND METHODS

Material

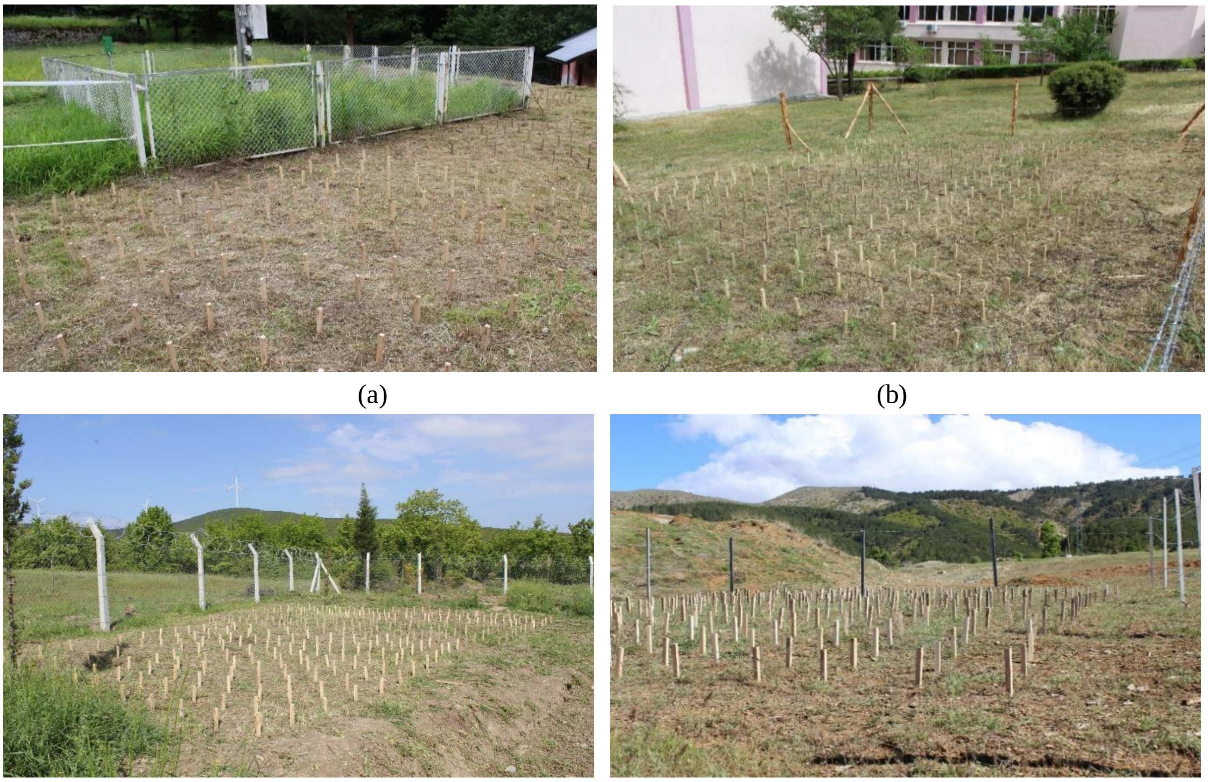
The samples were obtained from 30 logs with an average diameter of 40 cm. All trees were cut in the winter season of 2015 year. In the study, CCB (copper-chromium-boron) was used as the impregnation material. According to DIN 68 800-3 (1997), CCB is used in the impregnation of wood that is in the 1st, 2nd, 3rd and 4th hazard classes. CCB was obtained from the Emsan Korusan Chemical Company (Istanbul, Turkey). The measurements were carried out in the Application Laboratory of the Forest Industry Engineering Department, Faculty of Forestry, Karadeniz Technical University.

Impregnation method

The impregnation process was carried out according to the full cell method. Since spruce wood is a difficult to impregnate species, at 5% concentration, Scotch pine, beech and alder woods were impregnated at 3% concentrations. A pre-vacuum of 680 mmHg was applied to all samples for 30 min and a pressure of 8 bar for 30 min. After impregnation, the retention in the samples was determined. Approximately 1000 test samples were impregnated in this study. The 4th hazard class retention amount in vacuum pressure type impregnation operations using CCB is 18 kg/m^3 (EN-599). In the study, maximum attention was paid to the selection of samples that provide values close to this retention amount.

Research method

The dimensions for Scotch pine, spruce, beech and alder heartwood, CCB impregnated sapwood and nonimpregnated sapwood samples were 20 x 20 x 300 mm. The samples were driven into the soil according to the EN 252 (1989) standard. In the study, 4 different pilot provinces representing 4 different climate types were selected. As shown Fig. 1, the pilot province of Black sea region was 'Trabzon'; the pilot province of Mediterranean region was ‘Muğla’; the pilot province of terrestrial climate region was ‘Elazığ’ and the pilot province of mixed climate region was ‘Çanakkale’, respectively.



(a) (b) (c) (d)

Fig. 1: Trial areas by provinces/regions: a) Trabzon province, b) Muğla province, c) Çanakkale province, d) Elazığ province.

The experimental regions were chosen by taking into consideration their proximity to meteorology measuring sites. In May 2016, the samples were positioned in the experimental regions which in a protected, undisturbed, smooth, weed-free, homogenous, well-drained area. The samples were buried the soil to a depth of half their lengths (15 cm) with a distance of 30 cm apart from each other and with their tangential faces facing south (Fig. 1). A total of 1500 samples (600 sapwood, 600 impregnated sapwood, and 300 heartwood) were analyzed for this study. The number of samples used in the study is shown in Tab. 1 as test and control samples including the type and part of wood they were taken.

Tab. 1: Total number of samples in the study.

Wood type	Climate type/Region	Sapwood	Impregnated sapwood	Heartwood	Total
Scotch pine	Blacksea (Trabzon)	30	30	15	75
	Mediterranean(Muğla)	30	30	15	75
	Mixed (Çanakkale)	30	30	15	75
	Terrestrial (Elazığ)	30	30	15	75
Spruce	Blacksea (Trabzon)	30	30	15	75
	Mediterranean (Muğla)	30	30	15	75
	Mixed (Çanakkale)	30	30	15	75
	Terrestrial (Elazığ)	30	30	15	75
Beech	Blacksea (Trabzon)	30	30	15	75
	Mediterranean (Muğla)	30	30	15	75
	Mixed (Çanakkale)	30	30	15	75
	Terrestrial (Elazığ)	30	30	15	75

Alder	Blacksea (Trabzon)	30	30	15	75
	Mediterranean (Muğla)	30	30	15	75
	Mixed (Çanakkale)	30	30	15	75
	Terrestrial (Elazığ)	30	30	15	75
Control samples (samples in laboratory)		120 (30x4)	120 (30x4)	60 (15x4)	300
Total samples		600	600	300	1500

Note: Heartwood was studied with 5 repetitions, sapwood and impregnated sapwood with 10 repetitions.

Climate index

Scheffer (1971) climate index was calculated according to Eq. 1 in order to reveal the effect of climate difference on wood samples in the study:

$$Sheffer\ Climate\ Index = \sum_{January}^{December} \frac{(t-2)(d-3)}{16{,}7} \qquad (1)$$

where: t - monthly average temperature (°C), g - monthly rainy days (>0,25mm).

Color analysis

L*, a* and b* values in tangential directions were measured with a Konica Minolta CR-400 brand color measuring device before the test samples were applicated to the ground. After the soil contact test, samples were measured again at the end of the exposure period with the same device in a tangential direction and always from the same place. Color measurement analysis before and after the test was performed in accordance with ISO 7724-2 (1984) standards. Each sample was measured in 3 replicates and the average of these values was taken. CIE*Lab* (Commission Interational de i'Eclairage) system consists of three variables (ISO 7724-2). L*: stands for light stability, a* and b* are chromatographic coordinates (+a* for red, -a* for green, +b* for yellow, -b* for blue). Color changes in the test samples that remained in soil contact. The L^*, a^* and b^* values were determined according to the Eqs. 2-4:

$$\Delta L^* = Lf^* - Li^* \qquad (2)$$
$$\Delta a^* = af^* - ai^* \qquad (3)$$
$$\Delta b^* = bf^* - bi^* \qquad (4)$$
$$\Delta E^* = \sqrt{(\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2})} \qquad (5)$$

ΔL*, Δa* and Δb* denote color changes occurring at the start (i) and at different time intervals (f). ΔE* represents the total color change. A low ΔE* value indicates lowly or moderately color change or color stability, whereas a high ΔE* value indicates color has highly changed. Tab. 2 represents total color change range.

Tab. 2: ΔE total color change range (Barcík et al. 2015).*

ΔE^* range	Change
$0.2 < \Delta E^*$	Invisible differences
$0.2 < \Delta E^* < 2$	Minor differences
$2 < \Delta E^* < 3$	Color change can be seen with a high quality filter
$3 < \Delta E^* < 6$	Color change can be seen with a medium quality filter
$6 < \Delta E^* < 12$	Big color changes
$\Delta E^* > 12$	Completely different color

Statistical analysis

The data were recorded as means and ± standard deviations and analyzed by using SPSS version 23.0. Data were obtained analyzed by ANOVA and tests of significance were carried out using Duncan's multiple range tests.

RESULTS AND DISCUSSION

It is well known that climatic factors cause changes in the color of wood utilized in outdoor environments (Moya and Calvo-Alvarado 2012). The study included information on average temperature, average number of sunny days, and average number of wet days obtained from the nearest meteorology stations to the trial regions, where the wood samples were allowed to naturally age for three years in contact with the soil (Tab. 3). The Blacksea climate was identified as having the most precipitation (Trabzon). The Mediterranean climate (Muğla) was found to have the highest temperature. The longest sunshine duration was determined in the terrestrial climate (Elazığ). In the mixed climate (Çanakkale), the number of rainy days, the number of sunny days and the temperature values were found close to the average of other climate types.

Tab. 3: Climate data.

Region	Year (months)*	Average temperature	Average number of rainy days	Average number of sunny days
Trabzon	2016 (5) – 2017 (4)	9.13	14.75	141.32
	2017 (5) – 2018 (4)	10.51	14.92	143.19
	2018 (5) – 2019 (4)	9.69	19.00	136.47
Muğla	2016 (5) – 2017 (4)	15.25	6.75	159.58
	2017 (5) – 2018 (4)	16.15	8.83	120.54
	2018 (5) – 2019 (4)	15.58	10.92	139.71
Çanakkale	2016 (5) – 2017 (4)	14.81	7.67	258.27
	2017 (5) – 2018 (4)	15.71	8.67	200.41
	2018 (5) – 2019 (4)	15.51	11.75	187.00
Elazığ	2016 (5) – 2017 (4)	14.03	6.42	220.61
	2017 (5) – 2018 (4)	15.58	6.83	240.83
	2018 (5) – 2019 (4)	14.59	13.00	209.21

Note: (5) represents May of that year, (4) April of that year (between May and next April).

In this study, the highest climate index was calculated in Trabzon. The lowest climate index was found in Muğla (Tab. 3). A profound color change in the samples can be explained by the length of the exposure time to natural aging, temperature, solar radiation, and number of sunny and rainy days (Rüther and Jelle 2013). Although it differs by species, the resistance of the wood to color change declines in the process of time. According to Sundqvist (2002), wood's color altered as exposure time and temperature increased. According to Feist (1990), exposure to sunlight (UV and IR rays), precipitation, and temperature result in a number of intricate chemical processes that erode the surface of the wood. The service life of wood is impacted by climatic variation depending on the climate's conditions. In determining the performance of wood left in contact with the soil in the external environment, the effect of the climate is also important, as well as the anatomical structure, strength, and natural durability of the wood (Winandy and McDonald 1993, Highley 1999, Gündüz 2007). Creation of climate index maps according to wood usage area. It is a very important finding in the selection of the impregnation method and the impregnation material to be applied for the protection of the wood, and it is important in terms of effective and economic protection (Gündüz and Vurdu 1995).

The changes in color coordinates and color values of wood samples given in terms of ΔL^*, Δa^*, Δb^*, ΔE^*, and Duncan homogenity groups of One-way Anova test are presented in Tabs. 4, 5, 6 and 7.

Tab. 4: Color change values of test samples.

Region	Wood		L^*_{first}	a^*_{first}	b^*_{first}	L^*_{last}	a^*_{last}	b^*_{last}	ΔL^*	Δa^*	Δb^*	ΔE^*
Blacksea	Scotch pine	Sapwood	80.91	5.14	26.43	52.79	2.78	10.24	28.12	2.36	16.19	32.63^{h}
		Impregnated sapwood	55.82	2.76	23.39	48.57	3.42	16.15	7.25	-0.66	7.25	10.70^{abc}*
		Heartwood	80.58	5.90	26.54	48.99	2.11	7.74	31.59	3.79	10.09	37.19^{h}
	Spruce	Sapwood	78.13	5.44	20.78	54.80	3.81	11.86	23.33	1.63	8.92	25.33^{g}
		Impregnated sapwood	53.95	3.35	21.36	50.77	2.27	16.34	3.18	1.09	5.01	6.90^{a}*
		Heartwood	83.22	4.03	20.65	52.27	2.47	9.25	30.94	1.56	11.40	33.04^{h}
	Beech	Sapwood	67.22	7.35	23.02	47.87	3.92	11.97	19.35	3.43	11.05	22.98^{fg}
		Impregnated sapwood	54.87	5.40	23.15	58.09	1.67	12.58	-3.22	3.74	10.58	12.49^{bcd}
		Heartwood	67.18	7.84	19.36	57.32	3.43	11.98	9.85	4.41	7.38	14.14^{cde}
	Alder	Sapwood	68.35	7.55	23.44	54.95	3.48	12.11	13.39	4.07	11.33	19.29^{ef}
		Impregnated sapwood	55.05	5.29	19.49	55.26	1.85	12.89	-0.21	3.44	6.60	8.07^{ab}*
		Heartwood	67.52	9.97	22.32	57.70	3,56	12.44	9.82	6.41	9.89	16.99^{de}

Note: $6 < \Delta E^* < 12$ High color change, $\Delta E^* > 12$ Completely different colors. Different letters on the same line indicate statistical difference ($p < 0.05$).

As can be seen in Tab. 4, the surface of alder heartwood for 3 years appeared more reddish (Δa^*,+) color while the surface of Scotch pines-impregnated showed greenish (Δa^*,-) color. All wood types showed yellowish surfaces with positive Δb^* values. The high Δb^* value was found in sapwood samples of Scotch pine. Looking at the ΔL^* values of Table 4, it can be seen that all values varied from –3.22 to 31.59 depend on the wood type, and the part of wood in the Blacksea region. The lighter surfaces obtained with high positive ΔL^* values while the darker surfaces obtained with lower ΔL^* *values.* In the Blacksea climate, the darker colors were found for impregnated wood of Scotch pine, Spruce, Beech, Alder compared to sapwood and heartwood of all wood types. The lightest color was obtained with the surface of Scotch heartwood (ΔL^*: 31.59). Tab. 4 shows that, in the Blacksea region (Trabzon), all wood sample surfaces showed significantly color changes depend on experimental parameters such as wood type and part of wood. ΔE^* values ranged from 6.90 to 37.19. The highest ΔE^* values were found for Scotch pine heartwood, Scotch pine sapwood and Spruce heartwood. Additionally, as can be seen from homogeneity groups in Tab. 4, it is clear that there is no significant difference for ΔE^* values between Scotch pine heartwood, Scotch pine sapwood and spruce heartwood. The lowest ΔE^* value was found to be 6.90 for impregnated spruce wood. The lower color changes (ΔE^*) were observed in impregnated wood samples. Furthermore, according to the classification stated in Tab. 2 it can be concluded that the impregnated wood samples with the values between 9.13 and 12.46 had the high color change, while the other wood samples with the values higher than 12 showed completely different color.

Tab. 5: Color change values of test samples.

Region	Wood		L^*_{first}	a^*_{first}	b^*_{first}	L^*_{last}	a^*_{last}	b^*_{last}	ΔL^*	Δa^*	Δb^*	ΔE^*
Mediterranean	Scotch pine	Sapwood	80.15	5.45	25.86	55.14	2.31	7.96	25.01	3.14	17.90	31.03^{d}
		Impregnated sapwood	56.37	2.79	23.14	50.07	3.73	14.90	6.30	-0.94	8.25	11.42^{a}*
		Heartwood	81.06	5.51	26.62	57.42	1.90	7.01	23.64	3.61	19.61	31.01^{d}
	Spruce	Sapwood	81.70	4.21	21.27	55.62	2.42	7.94	26.09	1.80	13.33	29.55^{cd}
		Impregnated sapwood	52.11	8.84	20.57	53.56	2.45	17.13	-1.45	6.39	3.44	9.13^{a}*
		Heartwood	82.05	4.53	22.18	56.97	2.26	7.62	25.08	2.27	14.56	29.27^{cd}
	Beech	Sapwood	70.51	6.64	23.06	51.01	2.70	8.74	19.51	3.93	14.32	24.78^{bc}
		Impregnated sapwood	55.73	5.02	22.16	60.46	1.74	12.21	-4.73	3.27	9.95	12.28^{a}
		Heartwood	68.16	8.26	20.25	52.28	2.09	7.53	15.88	6.17	12.73	21.89^{b}
	Alder	Sapwood	69.49	7.76	23.75	53.15	2.51	8.58	16.34	5.26	15.17	23.29^{b}
		Impregnated sapwood	54.90	4.33	19.14	57.87	1.92	12.02	-2.97	2.40	7.12	9.12^{a}*
		Heartwood	69.04	9.24	22.37	54.85	2.32	8.10	14.20	6.92	14.27	21.39^{b}

Note: 6< ΔE <12 High color change, ΔE >12 Completely different colors. Different letters on the same line indicate statistical difference ($p < 0.05$).

Tab. 5 represents the color coordinates and color change of wood samples in Mediterranean region (Muğla). As can be seen from these data, generally, positive Δa^* values were observed except for impregnated Scotch pine wood sample having -0.94 Δa^* value. Impregnated Scotch pine samples showed greenish color while the alder heartwood samples showed more red color having highest Δa^*+ value (6.92). All wood samples in Mediterranean region resulted positive Δb^* results and their surfaces appeared yellowish. In addition, when evaluating ΔL^* results from Tab. 5, it is clear that, especially, there were notable differences in the ΔL^* values between impregnated wood and nonimpregnated wood parts. Impregnated spruce, beech, and alder wood samples surfaces turned to darker color at the end of test period. The more lighter color surface was obtained from spruce sapwood with the highest ΔL^*value (26.09) compared to all wood samples surfaces in this study. As can be seen in Tab. 5, ΔE^* values ranged from 9.12 to 31.03. Especially, impregnated samples for all wood types showed lower Δ*E** values for the province of Muğla in the Mediterranean. The highest color change values were obtained in Scotch pine heartwood and its sapwood to be 31.01 and 31.03 while the lowest values were obtained in impregnated alder and impregnated spruce wood to be 9.12 and 9.13, respectively. Duncan homogeneity groups for these samples also revealed that, there were no differences as statistically in their values. Similarly, it was also seen from the statistical evaluation that there was no significant difference between the color change values of alder heartwood, alder sapwood and beech heartwood groups. Total color changes were listed to be beech> Scotch pine>spruce>alder for all impregnated wood samples, and Scotch pine>spruce>beech>alder for all nonimpregnated sapwood and heartwood samples in Muğla, respectively. Furthermore, it can be concluded that according to the evaluation range for color change in Tab. 2, all nonimpregnated wood samples exhibited greater color changes than impregnated wood samples.

Tab. 6: Color change values of test samples.

Region	Wood		L^*_{first}	a^*_{first}	b^*_{first}	L^*_{last}	a^*_{last}	b^*_{last}	ΔL^*	Δa^*	Δb^*	ΔE^*
Mixed	Scotch pine	Sapwood	79.16	5.24	26.42	50.99	1.22	4.49	28.17	4.01	21.93	36.25^{g}
		Impregnated sapwood	56.98	2.19	22.25	51.66	2.87	11.98	5.31	-0.68	10.26	13.78^{bc}
		Heartwood	80.08	6.08	28.34	51.26	1.30	4.39	28.81	4.78	23.95	38.11^{g}
	Spruce	Sapwood	79.51	4.90	20.66	53.31	1.39	4.96	26.20	3,51	15.70	30.87^{f}
		Impregnated sapwood	53.77	3.33	21.17	53.68	2.45	14.25	0.09	0.88	6.91	7.58^{a}*
		Heartwood	82.59	4.45	22.16	55.49	1.27	4.53	27.10	3.19	17.64	32.52^{f}
	Beech	Sapwood	68.67	7.08	22.99	52.13	1.78	6.68	16.54	5.30	16.31	24,55^{de}
		Impregnated sapwood	56.63	4.98	22.29	56.90	0.75	6.69	-0.28	4.24	15.60	16.75^{c}
		Heartwood	69.46	7.75	21.48	51.74	2.03	6.78	17.72	5.72	14.70	24.22^{d}
	Alder	Sapwood	70.89	7.75	23.90	54.16	2.56	8.58	16.74	5.19	15.32	23.73^{d}
		Impregnated sapwood	54.98	5.32	18.87	55.74	1.12	8.42	-0.76	4.20	10.46	11.57^{b}*
		Heartwood	72.11	8.28	22.06	50.81	1.92	6.57	21.30	6.36	15.49	27, 58^{e}

Note: 6< ΔE <12 High color change, ΔE >12 Completely different colors. Different letters on the same line indicate statistical difference ($p < 0.05$).

As can be seen in Tab. 6, for Çanakkale in the mixed region, the surface of alder heartwood for 3rd years appeared more reddish (Δ*a**,+) color while the surface of impregnated Scotch pines showed greenish (Δ*a**,-) color. All wood samples gave positive Δ*b** results and their surfaces turned to yellowish. Generally, Δ*b** results of impregnated wood samples were found lower than those of the nonimpregnated wood samples. Similarly, the lower *ΔL** values were also obtained from impregnated wood samples compared to non-impregnated wood samples. The highest Δ*L** value was found to be 28.81 for Scotch pine heartwood and lighter color was observed on the sample surface. The Δ*E** values were ranged from 7.58 to 38.11. The highest Δ*E** values (38.11 and 36.25) were found in Scotch pine heartwood and sapwood samples having the same homogeneity groups. The lowest Δ*E** value was determined for impregnated spruce wood to be 7.58. Considering the 3rd year samples in the Çanakkale experimental area, Δ*E** values were ordered to be beech> Scotch pine>alder>spruce for all impregnated wood samples, Scotch pine>spruce>beech>alder for all sapwood samples and Scotch pine>spruce>alder>beech for all heartwood samples. The nonimpregnated sapwood and heartwood samples showed notable high color change compared to impregnated wood samples.

Tab. 7: Color change values of test samples.

Region	Wood		L^*_{first}	a^*_{first}	b^*_{first}	L^*_{last}	a^*_{last}	b^*_{last}	ΔL^*	Δa^*	Δb^*	ΔE^*
Terrestrial	Scotch pine	Sapwood	78.45	5.69	26.23	54.25	1.11	5.49	24.19	4.58	20.74	32.31^{ef}
		Impregnated sapwood	56.35	2.63	23.26	47.11	4.17	16.94	9.24	-1.55	6.32	11.76^{b}*
		Heartwood	80.71	5.74	28.09	55.59	1.02	5.13	25.12	4.72	22.96	34.38^{f}
	Spruce	Sapwood	77.21	5.77	20.32	57.25	0.99	5.64	19.96	4.78	14.68	25.48^{d}
		Impregnated sapwood	54.82	3.21	21.03	52.44	2.63	16.63	2.38	0.58	4.40	6.16^{a}*
		Heartwood	81.56	4.78	22.67	57.12	1.34	5.31	24.44	3.44	17.37	30.34^{e}
	Beech	Sapwood	68.27	7.27	23.02	55.26	0.96	5.51	13.01	6.31	17.52	23.93^{d}
		Impregnated sapwood	56.15	4.87	22.58	57.61	0.24	7.80	-1.47	4.62	14.77	16.16^{c}
		Heartwood	63.93	8.90	21.33	58.17	0.87	5.35	5.76	8.03	15.98	18.89^{c}
	Alder	Sapwood	67.92	9.54	23.66	55.76	1.15	5.60	12.16	8.39	18.06	23.78^{d}
		Impregnated sapwood	54.79	5.03	19.14	56.95	0.77	9.39	-2.15	4.26	9.74	11.53^{b}*
		Heartwood	70.52	9.09	22.29	54.70	1.17	5.31	15.82	7.93	16.97	25.42^{d}

Note: 6< ΔE <12 High color change, ΔE* >12 Completely different colors. Different letters on the same line indicate statistical difference ($p < 0.05$).*

As can be observed from Tab. 7, it was found that the Δ*a** values were positive except for impregnated Scotch pine samples for the terrestrial region (Elazığ). The high Δ*a** value (8.39) was found for alder sapwood sample. While, this positive highest value means more reddish color compared to other samples, negative Δ*a** value (-1.55) for impregnated Scotch pine means greenish color. Tab. 7 shows that all wood types showed yellowish surfaces with positive Δ*b** values. The high Δ*b** value was determined in Scotch pine heartwood sample. It was found that Δ*L**values of impregnated wood samples were lower than those of nonimpregnated wood samples. The highest Δ*E** value was found to be 34.38 for the Scotch pine heartwood, while the lowest Δ*E** value was determined to be 6.16 for the impregnated spruce wood at the end of test period in Elazığ. Comparing the total change values of the all wood samples in this region, it can be seen that the lower color change values were obtained with, especially, impregnated samples. Additionally, according to total color change range stated in Tab. 2, it can be said that especially nonimpregnated wood samples having a higher ΔE^*value than 12 were classified as samples with a completely different color. Evaluating all results in this study, it can be concluded that different intensities of the color changes were detected in the measurements made on the wood samples that were in contact with the soil in different climates for 3 years. As can be seen from Tabs. 4, 5, 6 and 7, all color parameters showed notable changes depend on the climate type/region, the wood type and, part of wood.

The most color change was observed in Çanakkale throughout the research. The climate parameters in Çanakkale are higher than the others. Climate data are presented in the research as monthly averages. Thus, the data are reasonably near to one another. The transitions between the climatic factors, however, are abrupt in the mixed climate (Çanakkale), and this has a negative impact on the test samples as well. The weather events that occur in those climate types are adequate to explain the color change, even though it is difficult to describe the differences between the various climate types clearly (Rüther and Jelle 2013). In all study regions with various climates, the Scotch pine sapwood in non-impregnated sapwoods showed the maximum color change. The Scotch pine heartwoods had the greatest color change. It could also be related to wood density. It was discovered that there was a significant correlation between wood density and color change for natural weathering (Feist and Mraz 1978, Sell and Feist 1986). According to the Delucise et al. (2016) blackening and dulling are observed in all of the wood types left in soil contact. Barcik et al. (2015) recorded that a completely different color formation was observed in all nonimpregnated woods according to the total color change evaluation criterion.

In the study, the highest color change was observed in the impregnated beech samples for all regions. Even though most of the impregnated samples showed a substantial color change, the impregnated test samples were the group in which the lowest color change value was recorded. The wood had a green tint when it was first impregnated with CCB, but after three years of soil contact testing, the specimens turned a softer, paler shade of green. It is thought that the copper ratio between 20-50% in the content of the CCB impregnation material used in the study has a reducing effect on lignin degradation. Can and Sivrikaya (2019) impregnated Scotch pine wood with various impregnation materials and measured the total color change. As a result, the least color change was measured in the samples treated with ACQ (Ammonium copper quat) chemical. In particular, wood material impregnated with copper and chromium chemicals exhibit the better performance in outdoor conditions (Feist 1984, Williams 2005). In a study, the resistance of wood materials impregnated with CCA, ACQ 1900, ACQ 2200, Tanalith E and Wolmanit CX-8 materials against accelerated outdoor testing was investigated. It has been determined that CCA and ACQ 1900 are the most effective substances in preventing color change in wood material (Temiz 2005). Also, according to Gralier et al. (2000), copper amine impregnation greatly reduces color change as it prevents the degradation of lignin on the surface due to UV light and rain (Özgenç and Yıldız 2012).

Tab. 3 indicates that Scotch pine heartwood had the greatest color change value. Tomak et al. (2014) stated that the color change is higher in coniferous tree woods than in deciduous tree woods. Similarly, it has been stated in studies that this situation occurs depending on the chemical composition of wood species and the difference in lignin content (Mitsui 2004, Deka et al. 2008, Temiz et al. 2006, Srinivas and Pandey 2012, Yıldız et al. 2013). In the study, color change was higher in spruce heartwood and sapwood test samples as well as in Scotch pine test samples. Şahin (2002) reports that the darkening of color in coniferous woods is higher than in deciduous trees and has a positive relationship with exposure time. Lignin, which contains aromatic, phenolic, carbonyl and carboxylic groups in large amounts, has a much better light absorption feature than carbohydrates (hemicellulose, cellulose). Therefore, lignin has the potential to react more by interacting more with UV rays. As a result of these complex photochemical reactions, its polymeric structure may be degraded to a certain extent. The chemical components in the structures of deciduous tree and coniferous tree woods are different in terms of both ratio and content. Coniferous tree woods generally have 2-10% more lignin. These differences in lignin structure and ratios show that deciduous tree and coniferous tree woods can interact with different sensitivities to photochemical reactions. Therefore, it is an expected situation that the degree of color change is different due to the external factors that deciduous tree and coniferous tree woods are exposed to. In addition, free radicals formed on the surface during the decomposition of wood can interact with the oxygen in the atmosphere and cause color change on the surfaces (Şahin 2002).

The beech samples showed the greatest color change among the test samples that had been impregnated. In a study conducted with impregnated wood samples, the most color change was observed in beech samples impregnated with sodium borate solution. The impregnation process slightly changes the color of the wood material and increases the surface roughness. Sanding before impregnation is recommended for less color change and surface roughness (Söğütlü and Döngel 2009).

In this study, alder sapwoods, except Muğla, exhibited lower color change values than heartwoods. In a study that was conducted, alder sapwood treated to heat treatment was reported to have less color change than alder heartwood (Balçık and Özdemir 2017).

CONCLUSION

In applications where color change is important and more aesthetic values are at the forefront, beech wood can be recommended because it changes color much less than other types. However, if applications are desired to be made with coniferous wood species, impregnation is required. In the study, color change was found to be low in impregnated products. However, it should be taken into consideration that the impregnation process will bring an additional cost. It is recommended to carry out new studies by applying different surface treatments on impregnated or non-impregnated samples.

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