Evaluation of Oleander (*Nerium oleander* L.) Plant Extract and Hydrosol as a Protective Agent on Wood Material and Its Effects on Physical Performance

Tahsin Cetin * and Zeynep Kalayci

This study explored the applicability of oleander (*Nerium oleander* L.) extract and hydrosol as protective agents for wood materials. The research examined their effects on the physical properties of red pine (*Pinus brutia*), Oriental beech (*Fagus orientalis*), and walnut (*Juglans regia*) following an impregnation process. Wood samples were treated with oleander-based solutions using the dipping method and then subjected to water immersion for various durations to assess retention, specific gravity, shrinkage, swelling, and water uptake. The results indicated that while oleander extract had no significant impact on wood retention, hydrosol enhanced water resistance and dimensional stability. However, the use of mordant increased shrinkage percentages, particularly in Oriental beech and walnut at prolonged exposure times. These findings suggest that hydrosol-based treatments can contribute to improving wood durability, offering an environmentally friendly alternative for wood preservation.

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INTRODUCTION

Among renewable natural resources, wood holds a significant place due to its aesthetic appeal, workability, and structural versatility. However, its preservation is crucial to maintain its durability and functionality, particularly when exposed to environmental factors such as moisture, ultraviolet (UV) radiation, fungal decay, and insect attacks. Impregnation treatments, which serve as surface and protective processes, play a vital role in extending the lifespan of wood materials by improving their resistance against physical and biological degradation. These treatments help preserve the natural properties of wood, including its aesthetics, color stability, durability, and resistance to burning.

Since ancient times, humans have preferred wood materials for both indoor and outdoor applications (Çağlayan 2020). Wood's natural texture, diverse color variations, and ability to be shaped easily provide advantages over other construction and furnishing materials such as steel, concrete, and iron, making it indispensable in various industries (Karadağ *et al.* 2017). However, the increasing scarcity of wood due to deforestation, global warming, and forest fires has heightened the importance of efficient wood preservation methods. Research on wood protection has expanded significantly, with a growing interest in both chemical and organic methods. In particular, eco-friendly impregnation techniques that utilize natural plant-based preservatives have gained considerable attention due to increasing concerns over the environmental and human health impacts of conventional chemical treatments.

The oleander plant (*Nerium oleander* L.) is an evergreen shrub commonly found in Mediterranean climates. It has been widely studied for its bioactive compounds, which exhibit antibacterial, antifungal, and antioxidant properties. While traditionally known for its medicinal and toxicological effects, recent studies have explored its potential applications in material preservation. The extraction of bioactive compounds from the oleander plant is typically carried out through processes such as solvent extraction and hydrodistillation. These methods yield both oleander extract, which contains concentrated bioactive components, and hydrosol, a water-based byproduct that retains some of the plant's essential properties. Hydrosol is often used in natural preservation techniques due to its antimicrobial and hydrophobic characteristics.

The importance of plant-based preservatives used in wood preservation and applied through various methods is increasing (Atılgan 2022). With technological advancements, improvements in wood preservation techniques have enhanced its durability, workability, and resistance to environmental factors such as moisture, UV exposure, and biological decay. Wood's structural characteristics, such as its lightweight nature and high strength-to-weight ratio, make it a preferred material in certain applications compared to steel, concrete, and iron (Karadağ *et al.* 2017; Çağlayan 2020). Additionally, in seismic-prone regions, wood structures have demonstrated superior performance due to their flexibility, energy absorption capacity, and ability to dissipate seismic forces more effectively than brittle materials such as concrete (Ceccotti 2008; Popovski and Karacabeyli 2012; Tesfamariam 2022; You *et al.* 2023). However, while wood offers advantages in certain applications, material selection depends on specific engineering requirements, environmental conditions, and intended use. These developments have positioned wood as a superior material compared to others (Karadağ *et al.* 2017; Çağlayan 2020). Various protective processes, including impregnation, varnishing, and painting, are essential for ensuring the long-term usability of wood and wood-based products (Vardanyan *et al.* 2015).

Several studies have investigated the effectiveness of plant-derived extracts in wood protection. Research has demonstrated that natural extracts can enhance wood's resistance to aging (UV) (Atılgan 2009; Atılgan *et al.* 2011; Peker *et al.* 2012), improve dimensional stability (Atılgan *et al.* 2013), increase retention capacity (Atılgan *et al.* 2013), and influence mechanical properties such as bending resistance and modulus of elasticity (Atılgan *et al.* 2017). Additionally, plant-based treatments have been found to impact surface characteristics, including roughness (Atılgan *et al.* 2018), gloss, and paint adhesion (Atılgan 2009; Göktaş *et al.* 2013), while also providing resistance to fungal decay (Göktaş *et al.* 2008). Further scientific investigations have explored changes in wood's physical properties before and after treatments such as impregnation, accelerated aging (Vardanyan *et al.* 2015), and UV-cured varnish applications, with specific focus on hardness, color stability, and surface adhesion (Gürleyen *et al.* 2017; Atılgan 2022).

When other studies were examined; Atilgan and Peker (2012) stated that they obtained the highest retention amount (42.4 kg/m^3) by impregnating beech wood with a mixture of cement and borax with a concentration of 9%, while the lowest retention amount was found in yellow pine (1% ammonium tetraflu borate). Sarıca (2006) impregnated eastern beech wood with borax and found that the highest retention amount (29.6 kg/m^3) was found in sessile oak wood. Özçifçi *et al.* (2009) determined the highest retention amount in yellow pine (19.4 kg/m^3 to 21.8%) and the lowest retention amount in oak wood

(8.74 kg/m³ to 9.15%). These experimental studies may vary when different wood species and impregnants are used. In another study by Kılıç (2012), beech and spruce woods were impregnated with silicone and it was found that the specific gravity values did not change significantly compared to the control groups. While the specific gravity of spruce wood was 0.44 g/cm³ in control samples, this value ranged between 0.43 to 0.56 g/cm³ in impregnated samples. Gür (2003) reported that the density values increased by impregnating yellow pine and red pine woods with various substances. Var *et al.* (2017) impregnated red pine wood with various geothermal waters and reported that no significant change was observed in density and tangential expansion. Var and Kaplan (2019) impregnated red pine wood with geothermal waters and found that the density increased 16.6%. Bak *et al.* (2023) impregnated beech and Scots pine wood with fluorinated silica nanoparticles and reported that this treatment provided positive effects on swelling, water uptake, and equilibrium moisture content. In another study conducted by Çetin *et al.* in 2024, after yarrow extract impregnation, the highest retention was achieved in red pine in 30 min at 10% hydrosol concentration (2.29%), while the lowest retention was achieved in walnut material at 10% hydrosol concentration (1.17%) and observed in 24 h period. Yarrow extract had no significant effect on the physical properties of impregnated wood materials; However, it has been suggested that the hydrosol is effective in the dimensional stability of all test samples due to its water-repellent properties (Çetin and Kalayci 2025).

In the context of this study, the oleander plant's potential as a protective agent for wood materials was evaluated. The research investigated the applicability of oleander extract and hydrosol for enhancing wood's physical performance, particularly in terms of water uptake, dimensional stability, and resistance to shrinkage and swelling. The study aimed to determine whether oleander-based treatments can serve as a viable, eco-friendly alternative to conventional wood preservatives, offering improved protection against moisture-related deterioration and environmental degradation.

In a study where lacquer derived from resins was used as a coating on the surface of wood materials, it was observed that this application helped extend the lifespan and protect the surface of the wood while improving its color and gloss properties. Adhesion tests were also performed (Atılgan *et al.* 2022; Atılgan and Atar 2023). Another study aimed to develop natural dyes for wood products that are harmless to the environment and human health. It determined color change values using extracts from tea (*Camellia sinensis*) and applied water-based varnish to wooden samples to ensure the durability of the produced dye and evaluated surface roughness (Atılgan *et al.* 2013, 2018).

Paints with high solvent content, such as nitrocellulose-based, two-component polyurethane-based, or acid-based paints, are now being replaced by environmentally and human-friendly alternatives (Jocham *et al.* 2011). Plant-derived products are frequently discussed among policymakers, researchers, and industry professionals due to their potential to mitigate the adverse effects of indoor pollution on human health (Salthammer *et al.* 2002). Governments are increasing protective measures as public demand grows for materials that support human and environmental health (Tsatsaroni *et al.* 1998; Kamel *et al.* 2005). According to Kızıl (2005), producing natural dyes, varnishes, and preservatives today enables the development of eco-friendly and healthy products. Unprotected wood surfaces exposed to the environment deteriorate much faster (Evans *et al.* 1996). Sunlight (particularly ultraviolet rays) and water (through direct rainfall and humidity) are among the primary elements causing damage to wood in outdoor environments (Hon 2001; Can 2018). The durability of an organic coating refers to its ability to withstand adverse natural conditions throughout its service life (Gheno *et al.* 2016).

The aim of this study was to evaluate the potential of oleander (*Nerium oleander* L.) extract and hydrosol as environmentally friendly impregnation agents for enhancing the durability of wood materials. The research focuses on assessing their effectiveness in improving physical performance, which in this context refers to wood's dimensional stability, water uptake resistance, shrinkage, and swelling behavior after impregnation. Since conventional wood preservatives often contain synthetic chemicals that may pose risks to human and environmental health, plant-based alternatives are being explored as sustainable solutions. Oleander extract and hydrosol, which are known for their bioactive properties such as antifungal and hydrophobic effects, were selected to examine their role in preserving wood against moisture-related deterioration and dimensional changes. The study investigated how these natural impregnation agents influence the long-term stability and protective capacity of wood materials, particularly against water-induced degradation.

EXPERIMENTAL

Materials

Oleander plant and extraction process

The oleander (*Nerium oleander* L.) plant used in this work was from Muğla province, Turkey. For the extraction process, shade-dried leaves and flowers of the oleander plant were used, as these parts contain a high concentration of bioactive compounds. The hot water extraction method was employed, as indicated in Table 1, where the plant material was mixed with water at 90 °C for 120 min. After extraction, the solution was filtered to separate the solid residues, and the obtained liquid phase was divided into oleander extract and hydrosol fractions. The hydrosol, which contains volatile water-soluble compounds, was collected as a byproduct of the distillation process.

Oleander is a toxic plant species that has been traditionally used for medicinal purposes despite its toxic alkaloids and glycosides. Its chemical composition includes flavonoids, tannins, saponins, and cardiac glycosides, which exhibit antifungal, antibacterial, and hydrophobic properties. These compounds are of particular interest in this study, as they may contribute to the protective role of oleander extract and hydrosol in enhancing wood durability against moisture-related deterioration and microbial attack (Fig. 1).

Fig. 1. Oleander plant

For the preparation of oleander extract, the conditions under which the extraction process were carried out from shade-dried colourants are given in Table 1. At the end of the time, the dyed water was filtered with filter paper and the solid pulp was separated from the parts.

Mordant was added to the dyed solutions at the ratios shown in Table 2. In the mordanting process, grape vinegar (*Vinum acetum*) was chosen as the mordant due to its natural composition and ability to enhance the adhesion of the plant-based extract to the wood surface. Vinegar, primarily composed of acetic acid, facilitates the penetration of bioactive compounds into the wood fibers by altering the surface properties and improving the interaction between the extract and the wood matrix. Additionally, the acidic nature of vinegar aids in the fixation of tannins, flavonoids, and other phenolic compounds, which are known for their antimicrobial and hydrophobic properties, thereby enhancing the protective efficacy of the oleander extract (Singh and Singh 2018).

Compared to synthetic mordants, grape vinegar is a more environmentally friendly alternative, avoiding the use of metal-based mordants such as alum or iron sulfate, which may introduce toxicity concerns in treated materials. Studies have demonstrated that vinegar-based mordants can improve the retention of plant-based dyes and extracts on various surfaces, including textiles and wood, by stabilizing the chemical interactions between tannins and lignocellulosic materials (Trotman 1984). By selecting grape vinegar as the mordant in this study, the aim was to promote an eco-friendly and non-toxic wood treatment approach, aligning with the increasing demand for sustainable preservation techniques.

The oleander hydrosol used in this study was obtained through a steam distillation process. For this, shade-dried leaves and flowers of the oleander plant were selected due to their high concentration of bioactive compounds, such as flavonoids, tannins, saponins, and cardiac glycosides, which contribute to the protective effects of the extract. During the distillation process, a stainless-steel distillation unit was used, where 500 g of dried plant material was placed in the boiling chamber. Water was heated at 100 °C, generating steam that carried volatile and water-soluble compounds from the plant material into a condenser. The steam was then cooled and collected in a separation flask, where the essential oil and hydrosol were separated. The hydrosol, containing water-soluble phytochemicals, was collected as a byproduct of this process and stored in sterile, light-resistant glass containers to preserve its stability. This method ensures that the hydrosol retains antimicrobial and hydrophobic properties, which are essential for its role in enhancing the durability and moisture resistance of wood materials.

Table 1. Conditions Required for Dye Extraction

Coloring Agent	Water/Plant (g)/(g)	Temperature (°C)	Duration (min)
Oleander	10/1	90	120

Table 2. Ratios of Dying Solution + Mordant Mixture

Extract	Mordant	Mixture (%)
- Dying plant extract (oleander) - Hydrosol (oleander)	Control	0
	Vinegar	10

Hydrosol can be defined as a water-based solution obtained during the distillation of herbs. This process aims at the separation of plant extracts and essential oils using a boiling kettle at a temperature between 90 and 120°. During distillation, the essence of the plant is separated by water vapour, and as this vapour condenses, hydrosol is formed in a separate chamber. The vapour passes through a condenser to rise upwards and be cooled. The vapour is then converted into water and collected as essential oil in a large container, while the hydrosol, which carries the plant's distinctive odour, accumulates at the bottom. No observable amount of oil was recovered from the hydrosol. Figure 2 below shows the plant distillation machine boiler (retorting machine) used to obtain oleander hydrosol.

Fig. 2. Plant distillation machine (retorting machine)

Methods

Impregnation method

The impregnation process was carried out by immersion method, which is one of the non-pressurised methods under the conditions specified in ASTM D1413-76 (1976). For this purpose, (2 x 2 x 3) cm^3 sized wood samples were immersed in oleander plant extract solution at normal atmospheric pressure for the following periods. The samples were rendered completely dry before and after impregnation to determine the impregnant retention and to prevent the wood from being affected by moisture.

Preparation of test samples and impregnation application method

Red pine (*Pinus brutia.*), Oriental beech (*Fagus orientalis* L.), and walnut (*Juglans regia* L.) were selected as the most commonly used trees in the furniture and wood industry in Turkey. The test samples were obtained from 1st class wood material, with smooth fibres, without knots, cracks, tulle formation and growth defects, without colour and density difference, without reaction wood, without fungal and insect damage, with annual rings perpendicular (radial) to the surfaces and from the sapwood parts. The samples used for solution absorption and net dry matter content were prepared with a length of 3 cm parallel to the fibres, a width of 2 cm parallel to the rays, and a thickness of 2 cm tangential to the annual rings (Bozkurt *et al.* 1993; Akyürekli 2003). In the impregnation process, air-dried wood samples were impregnated by dipping method (short term: 30 min, medium term: 3 h, long term: 24 h). At the end of the impregnation process, the excess impregnation solution on the surface of the specimens was removed with a paper towel and the test specimens were immediately weighed wet. The samples were then kept in an oven at 50 ± 3 °C until they reached constant weight. The exact dry weight (g) the samples were redetermined on a precision balance with an accuracy of 0.01 (TSE 345 2012). The length of the samples was also determined.

Before impregnation, all wood samples were oven-dried at 103 ± 2°C until they reached a constant weight, following the standard procedure for wood drying. After the impregnation process, samples were again oven-dried at 50 ± 3°C to remove excess moisture while preventing structural degradation due to high-temperature exposure. The drying conditions were selected based on standard wood treatment practices to ensure accurate weight measurements before and after impregnation. For each formulation of the plant solution, a total of 195 wood samples were used, making up 5 samples per wood type (red pine, Oriental beech, walnut) to ensure statistical validity in the experimental setup. Additionally, to clarify terminology in the text, the phrase "air-dried wood samples" refers to the initial condition before oven-drying, while "completely dry before and after impregnation" indicates the standardized oven-drying process to remove moisture before testing. This ensures consistency in the explanation of sample preparation procedures.

Dimensional stability (shrinking/swelling) and water-uptake

Water uptake and dimensional stability (contraction/expansion) tests of the samples were carried out according to ISO 13061-1 (2017). The samples, whose full dry weight and length were previously determined, were kept in distilled water for 6, 24, 48, 72 and 96 h under laboratory conditions (Bozkurt *et al.* 1993). At the end of each soaking period, the samples were removed from the water, dried with a paper towel, and weighed. The lengths of the samples kept in water for 6, 24, 48, 72, and 96 h were determined. Tangential direction, radial direction, longitudinal water uptake ratio (WU), and dimensional stability (contraction/expansion) values (DS) of the samples were determined using Eqs. 1 and 2 (Atılgan 2023b),

$$\text{WU}\ (\%) = (M_2 - M_1) / M_1 \times 100 \tag{1}$$

$$\text{DS}\ (\%) = (L_2 - L_1) / L_1 \times 100 \tag{2}$$

where M_1 is the initial full dry weight (g), M_2 is the weight of the sample taken out of the water after each period (g), L_1 is the length of fully dry sample before immersion in water (mm), and L_2 is the length of the wet sample after being immersed in water (mm).

Specific Gravity (Air Dry/Oven Dry) and Retention

Procedures were carried out based on TS ISO 13061-1 (2021) and TS ISO 13061-2 (2021) standards in determining air dry and oven dry specific gravities. The retention amount of oleander extract in wood material was determined by means of Eq. 3 (Atılgan 2023b),

$$R\ (\%) = (M_{\text{oes}} - M_{\text{oeö}}) / M_{\text{oeö}} \times 100 \tag{3}$$

where R (%) is the retention percentage, M_{oes} is the oven dry weight (g) after impregnation, and $M_{\text{oeö}}$ is the full dry weight (g) before impregnation. The terms "tangential direction," "radial direction", and "longitudinal water uptake ratio" refer to the three primary anatomical directions of wood:

- **Tangential water uptake**: Expansion or absorption occurring along the growth rings.
- **Radial water uptake**: Movement of moisture perpendicular to the growth rings, from the pith outward.
- **Longitudinal water uptake**: Water movement along the grain direction, parallel to the fiber structure of the wood.

Data Analysis

In this study, MANOVA and Duncan tests were selected as the primary statistical methods to evaluate the effects of impregnation parameters (wood type, impregnation duration, and solution concentration) on the physical performance of wood. MANOVA was employed to analyze the simultaneous effect of multiple independent variables on dependent physical properties, allowing for the identification of statistically significant differences across groups. The Duncan post-hoc test was then utilized to further distinguish differences between specific treatment groups, ensuring a detailed comparison of experimental conditions.

Multiple analysis of variance (MANOVA) method was used to analyse the data obtained in the study to determine the effect of groups (tree species, time, concentration, and duration time) on each parameter. Duncan Multiple Comparison Test was preferred for pairwise comparisons of groups. The results were presented as mean ± standard deviation and the statistical significance level was determined as $p < 0.05$. The MANOVA tables and graphical visualisations were used to show whether there were significant differences between the data. The statistical significance level is taken as 0.05. The SPSS 26 program was used for the statistical analysis of the data collected in the study.

RESULTS AND DISCUSSION

In this part of the study, the physical performance values obtained from the application of 10% hydrosol, 10% hydrosol + mordant, 10% extract, and 10% extract + mordant to red pine, Oriental beech, and walnut wood materials at different impregnation times are presented. Air dry specific gravity and full dry specific gravity values of red pine, oriental beech and walnut wood samples impregnated with 10% hydrosol, 10% hydrosol + mordant, 10% extract, and 10% extract + mordant are presented in the following tables.

Table 3 presents the results of the MANOVA for air-dried specific gravity values. The results of the analysis revealed that only wood species (A) had a significant effect on specific gravity ($F(2, 78) = 442.530$, $p < 0.05$). The factors time (B) and concentration (C), as well as their double and triple interactions, were not statistically significant ($p > 0.05$). This suggests that specific gravity was highly dependent on tree species, but variables such as time and concentration or their interactions had no significant effect on this trait.

Table 3. Multiple Variance Analysis Results for Air Dry Specific Gravity Values

Factor	Degrees of Freedom	Sum of Squares	Mean Squares	F	p
Woods (A)	2	1.483	0.742	442.530	**0.000***
Time (B)	2	0.000	0.000	0.061	0.940
Concentration (C)	3	0.005	0.002	0.943	0.424
A * B	4	0.006	0.002	0.953	0.438
A * C	6	0.007	0.001	0.702	0.649
B * C	6	0.010	0.002	0.999	0.432
A * B * C	12	0.022	0.002	1.074	0.393
Error	78	0.131	0.002		
Total	117	44.264			

*Significant at $p < 0.05$ level

Table 4 shows the air-dry specific gravity values and their homogeneity groups (HG) obtained for different wood species, time periods, and concentration types. According to the findings, there were significant differences in specific gravity among tree species. Red pine had the lowest average specific gravity value with 0.43, while Oriental beech (0.68) and walnut (0.69) had the highest values and were in the same homogeneity group (A). No differences were observed between the mean specific gravity values for the time variable and concentration types; all groups were classified in the same homogeneity group (A) with values of 0.60 or 0.61. These results indicate that air-dry specific gravity was highly dependent on the wood species. Its graphical representation is also given in Figs. 3, 4, and 5.

Table 4. Air Dry Specific Gravity Values Obtained According to Wood Type, Time, and Concentration Type

	Procedure	**$\bar{x}$**	**HG**
Wood Type	Red Pine	0.43	B
	Oriental Beech	0.68	A
	Walnut	0.69	A
Time	0 h	0.61	A
	30 min	0.60	A
	3 h	0.60	A
	24 h	0.60	A
Concentration	Control (%)	0.61	A
	10% Hydrosol	0.60	A
	10% Hydrosol + Mordant	0.60	A
	10% Extract	0.60	A
	10% Extract + Mordant	0.61	A

$\bar{x}$ Arithmetic mean, HG: Homogeneity group

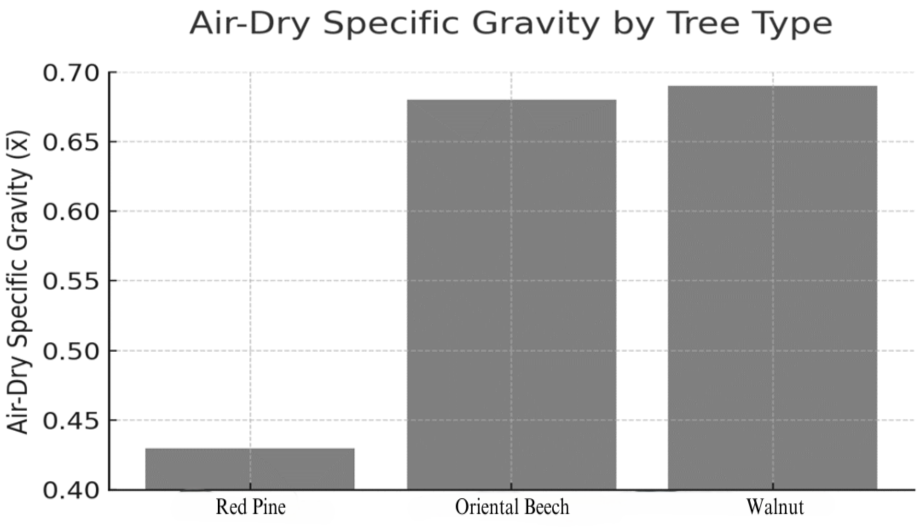

Fig. 3. Air-dry specific gravity by tree type

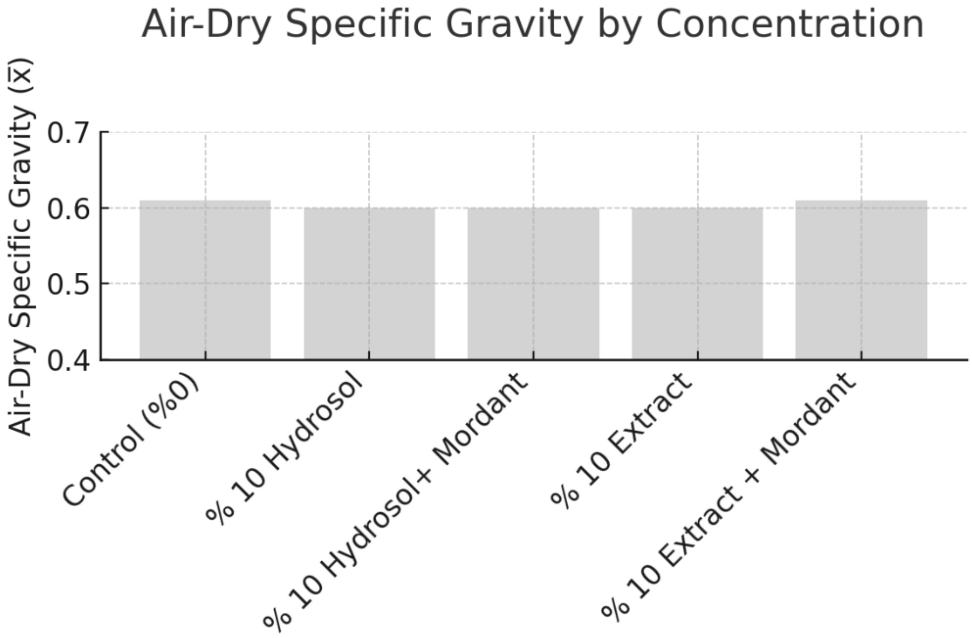

Fig. 4. Air-dry specific gravity by concentration

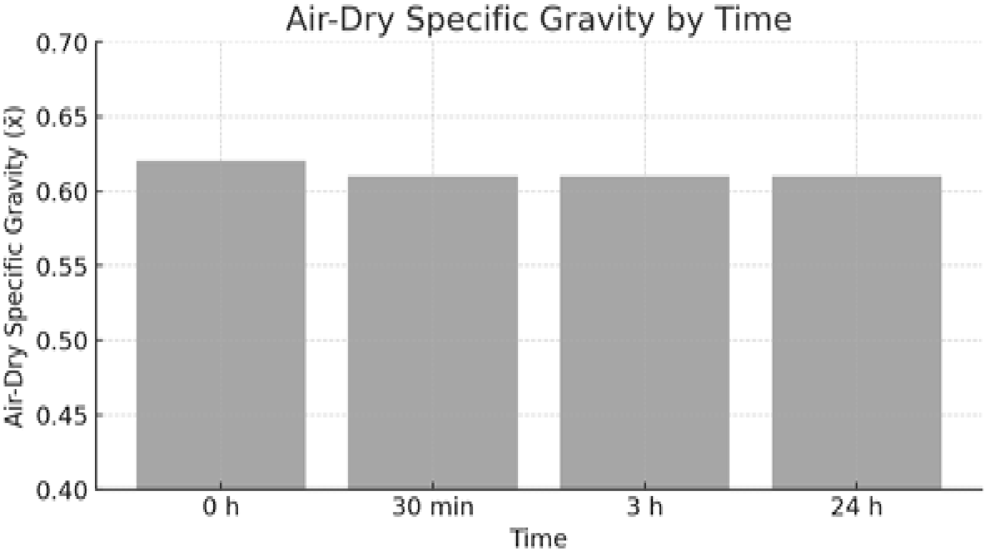

Fig. 5. Air-dry specific gravity by time

Table 5 presents the results of multiple analysis of variance for the dry specific gravity values. The analysis showed that only wood species (A) had a significant effect on specific gravity (F(2, 78) = 730.204, $p < 0.05$).

Table 5. Multiple Variance Analysis Results for Fully Dry Specific Gravity Values

Factor	Degrees of Freedom	Sum of Squares	Mean Squares	F	p
Woods (A)	2	1.341	0.670	730.204	**0.000***
Time (B)	2	0.001	0.001	0.569	0.568
Concentration (C)	3	0.001	0.000	0.297	0.827
A * B	4	0.003	0.001	0.801	0.528
A * C	6	0.006	0.001	1.010	0.425
B * C	6	0.005	0.001	0.833	0.548
A * B * C	12	0.011	0.001	1.006	0.451
Error	78	0.072	0.001		
Total	117	40.120			

*Significant at $p < 0.05$ level

The factors time (B) and concentration (C), as well as their double and triple interactions, had no significant effect on specific gravity ($p > 0.05$). These results suggest that whole-dry specific gravity values were highly dependent on wood species, but variables, such as time and concentration, or their interactions had no significant effect on this value.

Table 6 presents the whole dry specific gravity values and homogeneity groups (HG) obtained for different wood species, time periods, and concentration types. The results show that tree species had a significant difference on specific gravity. Red pine had the lowest mean specific gravity value of 0.41 and was classified in homogeneity group (HG) B, while Oriental beech (0.65) and walnut (0.66) had the highest values and were classified in the same group (A). In terms of time, hour 0 (0.59) had the highest mean, while the other time periods (30 min, 3 h, 24 h) showed similar results, but partial differences were observed between homogeneity groups (*e.g.*, 3 h and 24 h were both in groups A and B).

Table 6. Fully Dry Specific Gravity Values Obtained According to Wood Type, Time, and Concentration Type

	Procedure	$\bar{x}$	HG
Wood Type	Red Pine	0.41	B
	Oriental Beech	0.65	A
	Walnut	0.66	A
Time	0 h	0.59	A
	30 min	0.57	B
	3 h	0.57	AB
	24 h	0.58	AB
Concentration	Control (%)	0.59	A
	10% Hydrosol	0.57	AB
	10% Hydrosol + Mordant	0.57	B
	10% Extract	0.57	AB
	10% Extract + Mordant	0.57	AB

$\bar{x}$: Arithmetic mean, HG: Homogeneity group

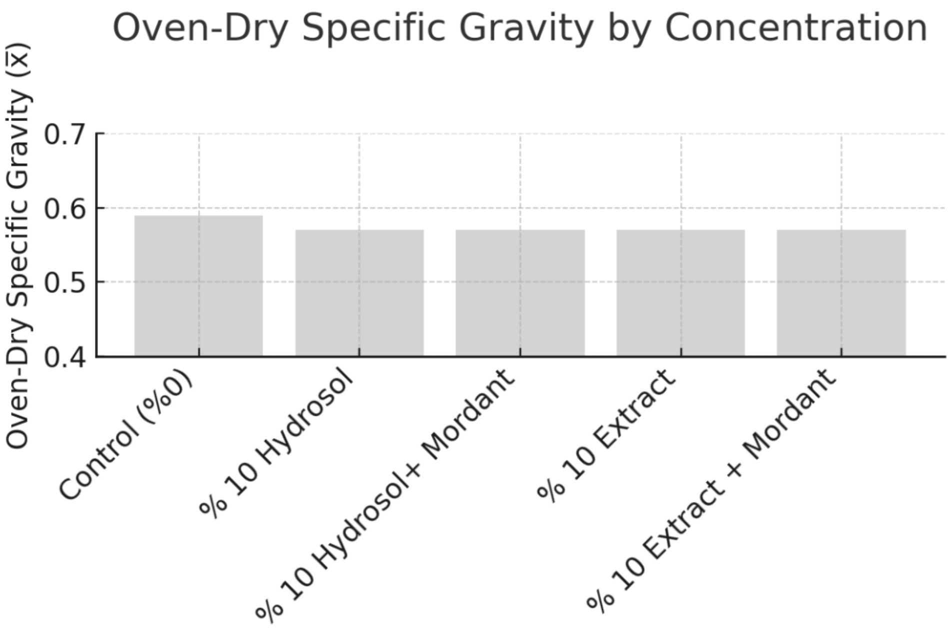

Fig. 6. Oven-dry specific gravity by concentration

No major differences in specific gravity were also observed between the concentration types, although the 10% Hydrosol+Mordan group (0.57) showed the lowest value and was classified only in group B. Overall, these findings suggest that whole-dry specific gravity values were highly dependent on wood species, but time and concentration factors had a more limited effect on this property. Its graphical representation is also given below Figs. 6, 7, and 8.

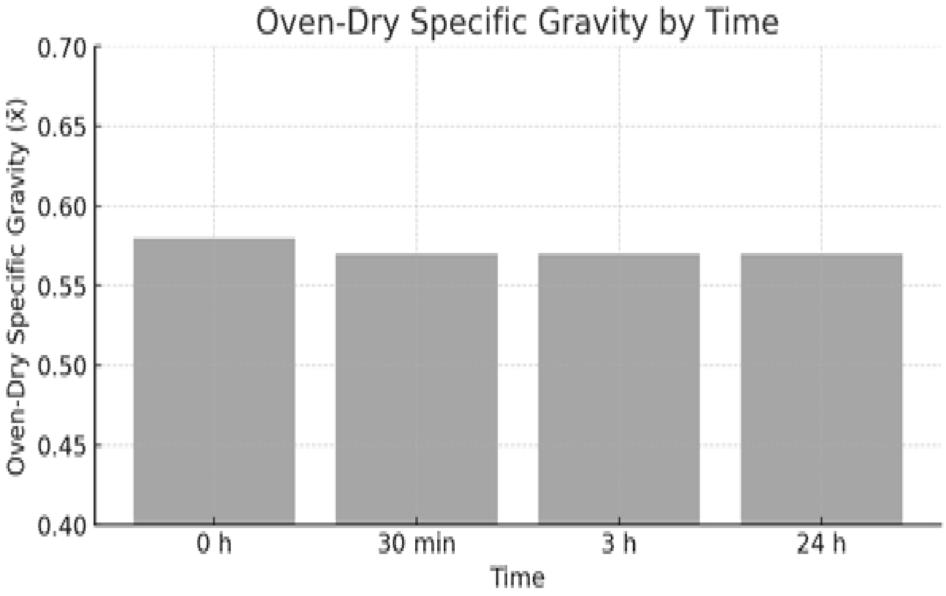

Fig. 7. Oven-dry specific gravity by time

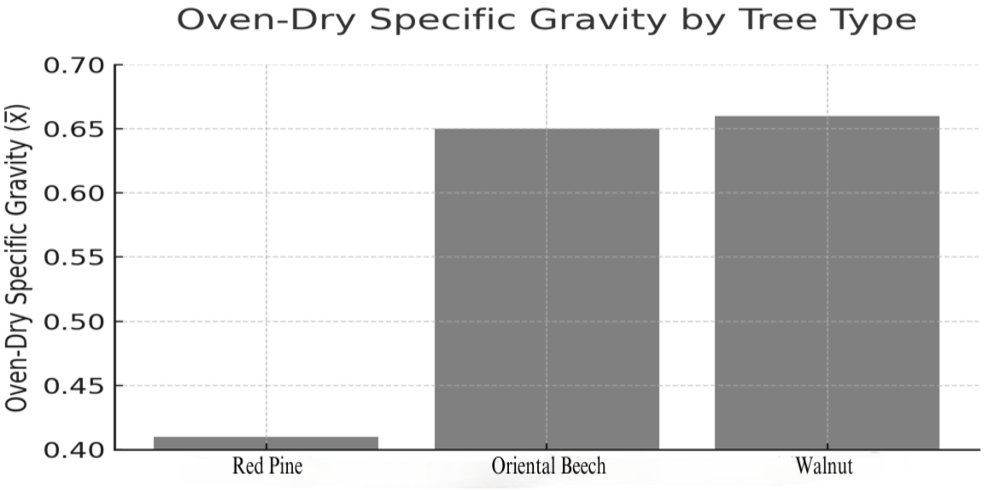

Fig. 8. Oven-dry specific gravity by tree type

Table 7 shows that air dry and complete dry specific gravity values differed according to wood species, impregnation time, and oleander impregnant concentrations. Red pine had the lowest values in both specific gravity types (0.40 to 0.44) and all treatments were in the same homogeneity group (C). Oriental beech showed the highest value in air-dried specific gravity with 10% Extract + Mordant (0.78) and was classified in group (A), while in whole-dried specific gravity most of the treatments had high values and were generally classified in group (A). Walnut showed the highest air-dry specific gravity value (0.71) for the control group (0%) and was classified in group (AB), while the whole-dry specific gravity values were generally classified in group (A). In general, Oriental beech and walnut showed high specific gravity values, while red pine showed low values.

Table 7. Duncan Test Results for Air Dry Specific Gravity and Oven Dry Specific Gravity Values

Wood Type	Impregnation Time	Impregnation Agent Concentrations from Oleander	Air Dry Specific Gravity			Oven Dry Specific Gravity		
			$\bar{x}$	SS	Duncan (HG)	$\bar{x}$	SS	Duncan (HG)
Red pine	0 h	Control (0%)	0.43	0.00	C	0.42	0.01	C
	30 min	10% Hydrosol	0.43	0.02	C	0.41	0.02	C
	30 min	10% Hydrosol + Mordant	0.43	0.02	C	0.41	0.02	C
	30 min	10% Extract	0.41	0.02	C	0.40	0.02	C
	30 min	10% Extract + Mordant	0.44	0.01	C	0.43	0.01	C
	3 h	10% Hydrosol	0.42	0.02	C	0.40	0.01	C
	3 h	10% Hydrosol + Mordant	0.42	0.01	C	0.41	0.01	C
	3 h	10% Extract	0.43	0.02	C	0.41	0.02	C
	3 h	10% Extract + Mordant	0.44	0.01	C	0.41	0.02	C
	24 h	10% Hydrosol	0.43	0.02	C	0.41	0.02	C
	24 h	10% Hydrosol + Mordant	0.44	0.01	C	0.43	0.01	C
	24 h	10% Extract	0.44	0.00	C	0.42	0.00	C
	24 h	10% Extract + Mordant	0.44	0.00	C	0.42	0.00	C

Oriental beech	0 h	Control (0%)	0.69	0.00	B	0.66	0.01	A
	30 min	10% Hydrosol	0.67	0.01	B	0.64	0.01	A
	30 min	10% Hydrosol + Mordant	0.69	0.00	B	0.67	0.00	A
	30 min	10% Extract	0.66	0.02	B	0.63	0.02	B
	30 min	10% Extract + Mordant	0.78	0.17	A	0.65	0.02	A
	3 min	10% Hydrosol	0.69	0.04	B	0.66	0.04	A
	3 min	10% Hydrosol + Mordant	0.69	0.03	B	0.65	0.03	A
	3 min	10% Extract	0.70	0.01	B	0.67	0.02	A
	3 min	10% Extract + Mordant	0.65	0.01	B	0.62	0.00	B
	24 h	10% Hydrosol	0.69	0.03	B	0.65	0.03	A
	24 h	10% Hydrosol + Mordant	0.70	0.02	B	0.64	0.02	A
	24 h	10% Extract	0.66	0.02	B	0.62	0.02	B
	24 h	10% Extract + Mordant	0.70	0.01	B	0.66	0.01	A
Walnut	0 h	Control (0%)	0.71	0.02	AB	0.69	0.02	A
	30 min	10% Hydrosol	0.66	0.03	B	0.64	0.03	A
	30 min	10% Hydrosol + Mordant	0.66	0.06	B	0.64	0.06	A
	30 min	10% Extract	0.68	0.06	B	0.66	0.06	A
	30 min	10% Extract + Mordant	0.68	0.04	B	0.66	0.04	A
	3 h	10% Hydrosol	0.70	0.01	B	0.68	0.01	A
	3 h	10% Hydrosol + Mordant	0.69	0.03	B	0.67	0.04	A
	3 h	10% Extract	0.69	0.07	B	0.66	0.08	A
	3 h	10% Extract + Mordant	0.70	0.05	B	0.68	0.05	A
	24 h	10% Hydrosol	0.70	0.04	B	0.67	0.04	A
	24 h	10% Hydrosol + Mordant	0.63	0.02	B	0.61	0.02	B
	24 h	10% Extract	0.69	0.05	B	0.68	0.05	A
	24 h	10% Extract + Mordant	0.67	0.06	B	0.65	0.06	A

HG Homogeneity group: Means in the same column marked with a different letter are statistically different from each other ($p < 0.05$)

Table 8 shows the results of multiple variance analysis for retention values. According to the results of the analysis, none of the factors or interactions between factors had a statistically significant effect on retention ($p > 0.05$). Tree species (A), time (B) and concentration (C) factors did not reach significance level with F(2, 78) = 1.454 ($p = 0.240$), F(3, 78) = 0.046 ($p = 0.987$) and F(3, 78) = 1.175 ($p = 0.325$), respectively. Binary and ternary interactions also did not show a significant effect on retention ($p > 0.05$).

Table 8. Multiple Variance Analysis Results for Retention Value

Factor	Degrees of Freedom	Sum of Squares	Mean Squares	F	p
Woods (A)	2	8.739	4.370	1.454	0.240
Time (B)	3	0.414	0.138	0.046	0.987
Concentration (C)	3	10.599	3.533	1.175	0.325
A * B	6	0.708	0.118	0.039	1.000
A * C	6	18.192	3.032	1.009	0.426
B * C	6	1.073	0.179	0.060	0.999
A * B * C	12	0.852	0.071	0.024	1.000
Error	78	234.447	3.006		
Total	117	476.278			

*Significant at $p < 0.05$ level

Table 9 shows the retention values and homogeneity groups (HG) obtained for different wood species, time periods and concentration types. The results show that all treatments were in the same homogeneity group (A), thus there was no statistically significant difference between the retention values. Its graphical representation is also given below Figs. 9, 10, and 11.

Table 9. Retention Values Obtained According to Wood Type, Time, and Concentration

	Procedure	$\bar{x}$	HG
Wood Type	Red pine	1.04	A
	Oriental beech	1.44	A
	Walnut	1.45	A
Time	0 h	0.47	A
	30 min	1.08	A
	3 h	1.51	A
	24 h	1.56	A
Concentration	Control (0%)	1.15	A
	10% Hydrosol	1.30	A
	10% Hydrosol + Mordant	1.37	A
	10% Extract	1.48	A

$\bar{x}$: Arithmetic mean, HG: Homogeneity group

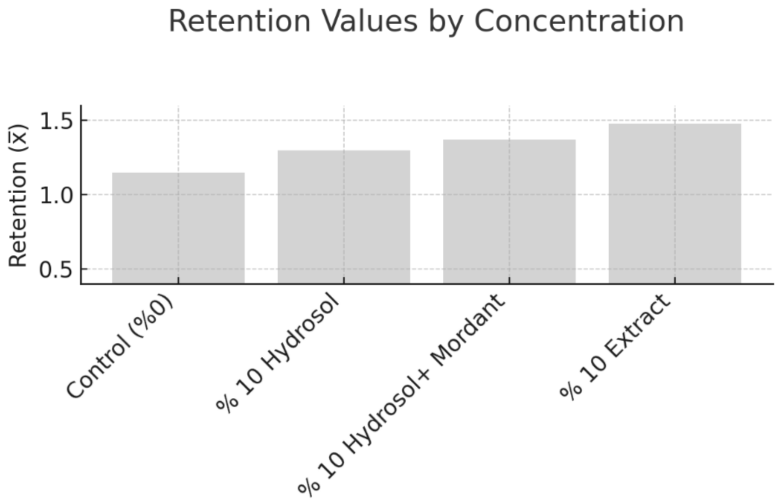

Fig. 9. Retention values by concentration

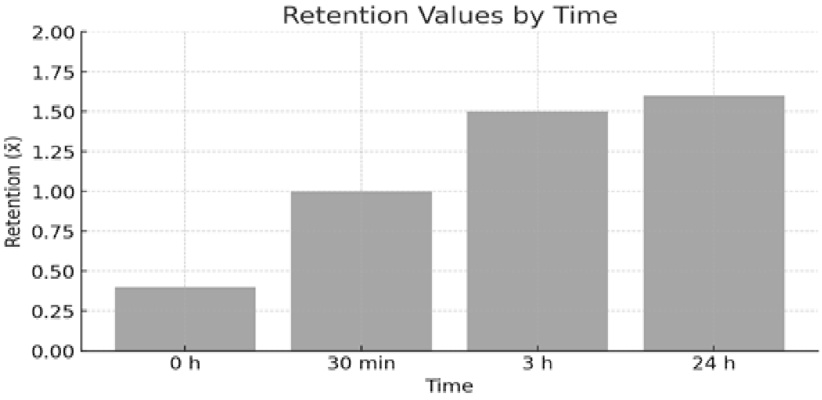

Fig. 10. Retention values by time

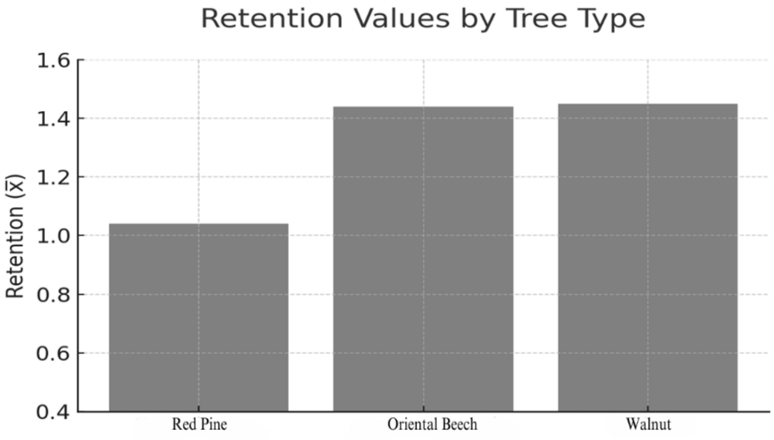

Fig. 11. Retention values by wood type

Table 10 shows the results of Duncan’s test for retention values according to wood species, impregnation times, and oleander impregnant concentrations. According to the results, all wood species and treatments were in the same homogeneity group (A), which means that there is no statistically significant difference between the treatments.

Table 10. Duncan Test Results for Retention (%) Values

Wood Type	Impregnation Time	Oleander Impregnating Agent Concentrations	Retention (%)		
			$\bar{x}$	St. Sp.	Duncan (HG)
Red pine	30 min	10% Hydrosol	1.62	0.81	A
	30 min	10% Hydrosol + Mordant	0.86	0.98	A
	30 min	10% Extract	0.87	0.26	A
	30 min	10% Extract + Mordant	1.27	0.12	A
	3 h	10% Hydrosol	1.57	0.72	A
	3 h	10% Hydrosol + Mordant	1.99	0.36	A
	3 h	10% Extract	1.73	0.32	A
	3 h	10% Extract + Mordant	1.66	0.30	A
	24 h	10% Hydrosol	1.90	0.24	A
	24 h	10% Hydrosol + Mordant	2.03	0.45	A
	24 h	10% Extract	1.49	0.15	A
	24 h	10% Extract + Mordant	1.98	0.24	A
Oriental beech	30 min	10% Hydrosol	1.00	0.15	A
	30 min	10% Hydrosol + Mordant	1.08	0.18	A
	30 min	10% Extract	1.11	0.16	A
	30 min	10% Extract + Mordant	0.99	0.14	A
	3 h	10% Hydrosol	1.42	0.07	A
	3 h	10% Hydrosol + Mordant	1.72	0.13	A
	3 h	10%Extract	1.46	0.13	A
	3 h	10% Extract + Mordant	1.45	0.14	A
	24 h	10% Hydrosol	1.19	0.22	A
	24 h	10% Hydrosol + Mordant	1.73	0.01	A
	24 h	10% Extract	1.53	0.33	A
	24 h	10% Extract + Mordant	1.40	0.22	A
Walnut	30 min	10% Hydrosol	1.15	0.11	A
	30 min	10% Hydrosol + Mordant	1.04	0.16	A
	30 min	10% Extract	0.91	0.15	A
	30 min	10% Extract + Mordant	1.03	0.07	A
	3 h	10% Hydrosol	1.34	0.12	A
	3 h	10% Hydrosol + Mordant	1.29	0.03	A
	3 h	10% Extract	1.28	0.15	A
	3 h	10% Extract + Mordant	1.18	0.12	A
	24 h	10% Hydrosol	1.17	0.17	A
	24 h	10% Hydrosol + Mordant	1.56	0.19	A
	24 h	10% Extract	1.33	0.29	A
	24 h	10% Extract + Mordant	1.44	0.07	A

HG: Homogeneity group: Means in the same column marked with a different letter are statistically different from each other ($p < 0.05$)

Table 11 shows the results of multiple analysis of variance for water uptake change value. According to the results of the analysis, among the main factors analysed, tree species (A) (F(2, 390) = 919,145, $p < 0.05$), times (B) (F(2, 390) = 8,986, $p < 0.05$), concentration (C) (F(3, 390) = 4,251, $p < 0.05$), and duration time (D) (F(4, 390) = 147,202, $p < 0.05$) had a statistically significant effect on water uptake change. In addition, some double and triple interactions were also significant. For example, Tree Species and Times (F(4, 390) = 3,081, p = 0.016), Tree Species and Concentration (F(6, 390) = 4,511, $p < 0.05$), and (Times and Concentration) (F(6, 390) = 11,957, $p < 0.05$) interactions were significant on water uptake change. However, higher order interactions, especially triple and quadruple interactions, did not make a significant difference ($p > 0.05$).

Table 11. Multiple Variance Analysis Results for Water Uptake Value

Factor	Degrees of Freedom	Sum of Squares	Mean Sq	F	p
Woods (A)	2	187537.310	93768.655	919.145	**0.000***
Times (B)	2	1833.417	916.709	8.986	**0.000***
Concentration (C)	3	1300.978	433.659	4.251	**0.006***
Standby time (D)	4	60068.680	15017.170	147.202	**0.000***
A * B	4	1257.285	314.321	3.081	**0.016***
A * C	6	2761.073	460.179	4.511	**0.000***
A * D	8	1670.111	208.764	2.046	**0.040***
B * C	6	7318.687	1219.781	11.957	**0.000***
B * D	8	170.220	21.277	0.209	0.989
C * D	12	265.418	22.118	0.217	0.998
A * B * C	12	3799.351	316.613	3.104	**0.000***
A * B * D	16	182.979	11.436	0.112	1.000
A * C * D	24	293.599	12.233	0.120	1.000
B * C * D	24	431.634	17.985	0.176	1.000
A * B * C * D	48	498.730	10.390	0.102	1.000
Error	390	39786.736	102.017		
Total	585	2578148.827			

* Significant at p< 0.05 level

Table 12 presents the water uptake values and their homogeneity groups (HG) obtained for different tree species, time periods, concentration types, and duration times. In terms of tree species, red pine (85.38) exhibited the highest water uptake value and is in homogeneity group (A), while Oriental beech (59.36) and walnut (41.28) had lower values and are classified in groups (B) and (C), respectively. When the time variable was analysed, 0 h (60.69), 30 min (61.30) and 3 h (60.39) showed similar values and were in the same homogeneity group (B). However, 24 h (64.67) time differed from the others and was in group (A). Among the concentration types, the Control (0%) and 10% Hydrosol groups (60.69 and 60.76) were in the same group (B), while 10% Hydrosol+Mordan (64.53) was in group (A) with a higher value. 10% Extract (62.45) group was classified in two groups as (AB). The duration time variable showed significant differences. The shortest time of 6 h (45.77) had the lowest water uptake value and was classified in group (A), while the water uptake values increased as the time increased and reached the highest value with 96 h (76.93) and was classified in group (E). These findings revealed that the water uptake values showed significant changes depending on the tree species, time intervals, type of concentration applied and duration time. Especially the duration time played a critical role in the increase of water uptake values. Its graphical representation is also given below Figs. 12, 13, 14, and 15.

Table 12. Water Uptake Values Obtained According to Wood Type, Time, and Concentration

	Procedure	$\bar{x}$	HG
Wood Type	Red pine	85,38	A
	Oriental beech	59,36	B
	Walnut	41,28	C
Time	0 h	60,69	B
	30 min	61,30	B
	3 h	60,39	B
	24 h	64,67	A
Concentration	Control (0%)	60,69	B
	10% Hydrosol	60,76	B
	10% Hydrosol+ Mordant	64,53	A
	10% Extract	62,45	AB
	10% Extract +Mordant	60,75	B
Standby Time	6 h	45,77	A
	24 h	55,72	B
	48 h	61,84	C
	72 h	69,80	D
	96 h	76,93	E

$\bar{x}$: Arithmetic mean, HG: Homogeneity group

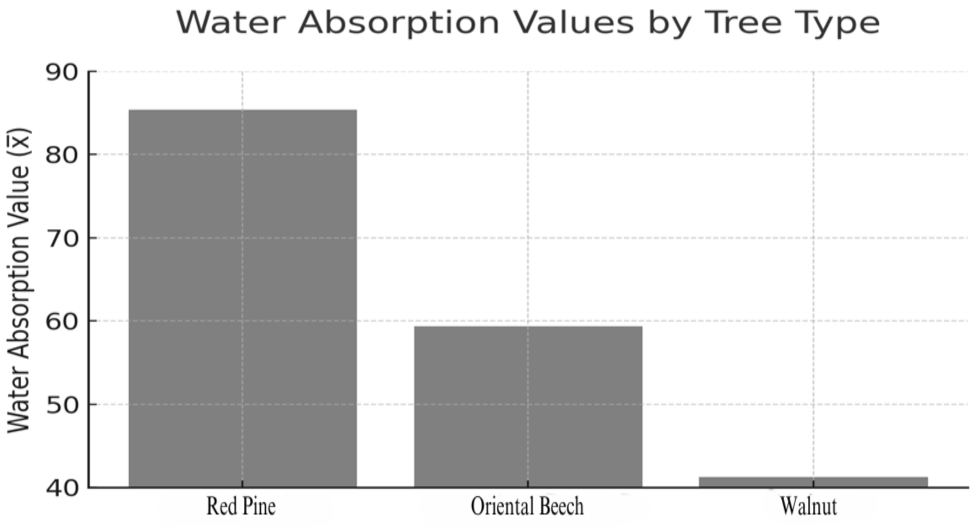

Fig. 12. Water uptake values obtained according to wood (tree) type

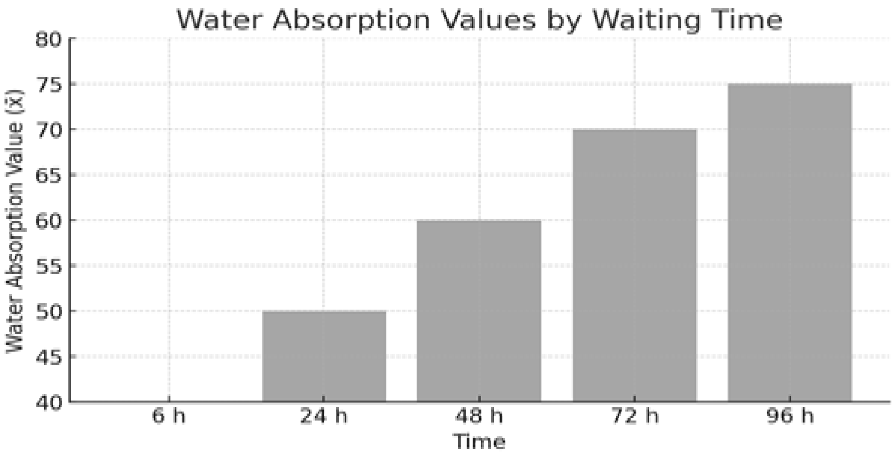

Fig. 13. Water uptake values obtained according to duration time

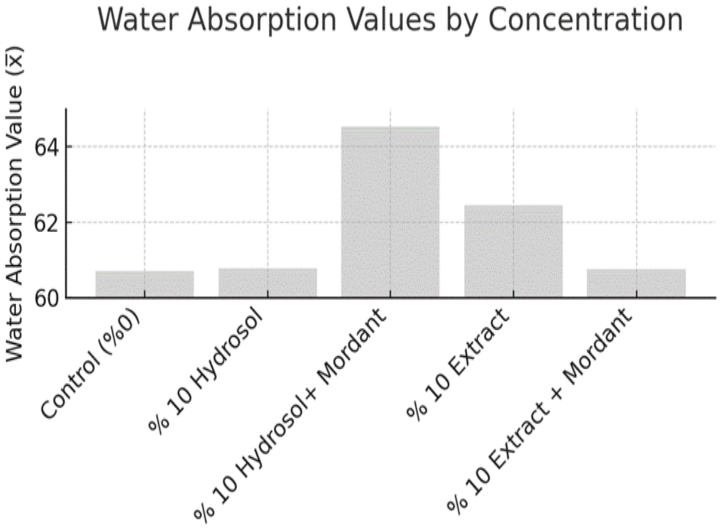

Fig. 14. Water uptake values obtained according to concentration

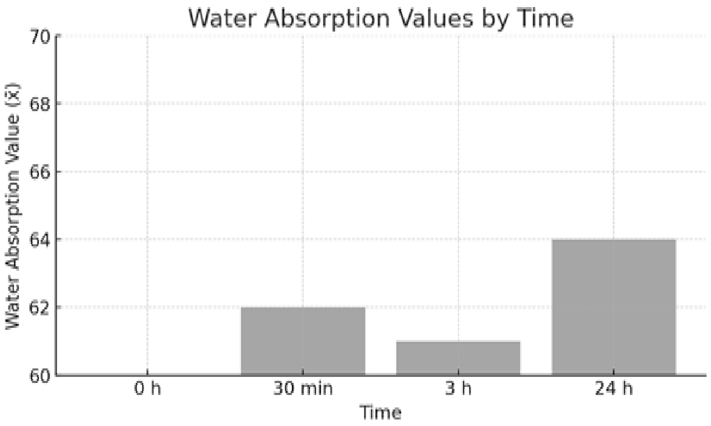

Fig. 15. Water uptake values obtained according by time

Table 13 shows the values of water uptake change at different time periods according to wood species, impregnation times, and oleander impregnant concentrations. Red pine had the highest water uptake change values compared to the other species at all time periods, especially in the control group, reaching 121.2% at the end of 96 h. Oriental beech showed moderate water uptake change values and reached 79.6% at the end of 96 h with 10% Hydrosol+Mordan. Walnut had the lowest water uptake change values and reached 44.5% at the end of 96 h for the control group. In all wood species, concentrations containing Mordant and longer duration times generally led to an increase in the water uptake change. A significant increase in water uptake percentages was observed as the duration time increased, especially between 72 and 96 h. These results indicate that the change in water uptake varies depending on both wood species and impregnation time and concentration.

Table 13. Values Regarding Water Uptake

Wood Type	Impregnation Time	Impregnation Agent Concentrations Obtained from Oriental	Water Uptake (%)				
			6 h	24 h	48 h	72 h	96 h
Red pine	0 min	Control (0%)	83.11	90.96	94.88	109.25	121.24
	30 min	10% Hydrosol	63.94	71.76	81.15	91.19	100.74
	30 min	10% Hydrosol+ Mordant	63.05	70.54	73.60	84.54	97.02
	30 min	10% Extract	67.36	75.08	79.12	89.84	98.83
	30 min	10% Extract + Mordant	73.16	79.06	84.44	96.54	109.85
	3 h	10% Hydrosol	57.82	64.86	67.43	72.76	81.38
	3 h	10% Hydrosol + Mordant	59.28	67.99	72.10	79.47	96.87
	3 h	10% Extract	80.23	86.21	92.10	103.27	113.40
	3 h	10% Extract + Mordant	72.26	79.03	84.83	99.85	109.06
	24 h	10% Hydrosol	75.86	81.46	87.13	99.48	109.69
	24 h	10% Hydrosol + Mordant	74.92	82.42	102.38	110.80	113.23
	24 h	10% Extract	66.36	77.50	84.63	92.08	96.98
	24 h	10% Extract + Mordant	63.93	69.82	76.00	91.75	103.14
Oriental beech	0 min	Control (0%)	30.24	45.61	49.36	57.37	64.26
	30 min	10% Hydrosol	45.90	55.01	57.42	64.48	71.43
	30 min	10% Hydrosol+ Mordant	48.37	58.68	61.26	68.89	73.35
	30 min	10% Extract	37.62	49.78	53.20	58.74	67.40
	30 min	10% Extract + Mordant	38.31	50.57	54.20	64.47	68.68
	3 h	10% Hydrosol	48.14	57.23	60.50	67.88	71.98
	3 h	10% Hydrosol + Mordant	45.48	56.45	60.09	67.88	71.71
	3 h	10% Extract	49.54	57.76	60.78	68.76	73.26
	3 h	10% Extract + Mordant	42.17	52.34	56.04	62.61	69.96
	24 h	10% Hydrosol	55.90	60.19	64.29	72.98	75.26
	24 h	10% Hydrosol + Mordant	55.91	64.44	72.92	77.98	79.65

	24 h	10% Extract	46.25	55.79	60.98	67.17	71.89
	24 h	10% Extract + Mordant	38.31	52.90	56.82	64.13	69.82
Walnut	0 min	Control (0%)	18.30	26.87	34.73	39.61	44.53
	30 min	10% Hydrosol	26.23	40.72	49.95	56.00	62.09
	30 min	10% Hydrosol+ Mordant	26.10	39.53	48.67	54.28	60.16
	30 min	10% Extract	23.20	35.87	43.73	50.00	55.75
	30 min	10% Extract + Mordant	22.50	35.17	43.57	49.78	56.23
	3 h	10% Hydrosol	18.74	28.90	35.74	40.57	47.36
	3 h	10% Hydrosol + Mordant	22.50	34.95	43.05	48.25	56.20
	3 h	10% Extract	24.47	38.09	46.93	52.67	57.78
	3 h	10% Extract + Mordant	20.68	32.20	39.47	44.74	49.35
	24 h	10% Hydrosol	21.66	32.28	39.07	45.42	54.33
	24 h	10% Hydrosol + Mordant	30.53	45.58	54.29	60.02	68.34
	24 h	10% Extract	22.69	34.02	42.23	48.66	52.34
	24 h	10% Extract + Mordant	23.87	35.42	42.66	48.06	55.82

HG Homogeneity group: Means in the same column marked with a different letter are statistically different from each other ($p < 0.05$)

Table 14 shows the results of MANOVA for the expansion (swelling) value. According to the results of the analysis, among the main factors analysed, tree species (A) (F(2, 390) = 141,065, $p < 0.05$), times (B) (F(2, 390) = 18,805, $p < 0.05$), concentration (C) (F(3, 390) = 6,833, $p < 0.05$), and duration time (D) (F(4, 390) = 28,267, $p < 0.05$) had a statistically significant effect on the expansion values. In addition, some interactions were also significant. Tree Species and Duration time (A * D) (F(8, 390) = 10,804, $p < 0.05$), Time and Concentration (B * C) (F(6, 390) = 4,151, $p < 0.05$), and Tree Species, Time and Concentration (A * B * C) (F(12, 390) = 2,516, $p < 0.05$) interactions showed a significant effect on expansion. However, other double, triple, and quadruple interactions were not significant ($p > 0.05$). It can be stated that especially tree species, time, and duration time variables have significant effects on expansion.

Table 14. Multiple Variance Analysis Results for Swelling

Factor	Degrees of Freedom	Sum of Squares	Mean Squares	F	p
Woods (A)	2	1474.814	737.407	141.065	**0.000***
Time (B)	2	196.607	98.304	18.805	**0.000***
Concentration (C)	3	107.149	35.716	6.833	**0.000***
Standby Time (D)	4	591.059	147.765	28.267	**0.000***
A * B	4	16.560	4.140	0.792	0.531
A * C	6	53.115	8.853	1.693	0.121
A * D	8	451.806	56.476	10.804	**0.000***
B * C	6	130.206	21.701	4.151	**0.000***
B * D	8	19.172	2.397	0.458	0.885
C * D	12	26.708	2.226	0.426	0.953
A * B * C	12	157.842	13.153	2.516	**0.003***
A * B * D	16	53.983	3.374	0.645	0.846
A * C * D	24	83.649	3.485	0.667	0.884

B * C * D	24	51.936	2.164	0.414	0.994
A * B * C * D	48	116.726	2.432	0.465	0.999
Error	390	2038.692	5.227		
Total	585	164149.281			

*Significant at $p < 0.05$ level

Table 15 shows the expansion (swelling) values and homogeneity groups (HG) obtained for different tree species, time periods, concentration types, and duration times. In terms of tree species, Oriental beech (18.37) had the highest expansion value and was classified in group (A), while red pine (16.62) and walnut (14.35) had lower values and were classified in groups (B) and (C,) respectively. When the time variable was evaluated, 0 h (17.07) and 24 h (17.11) reached the highest expansion value and were in the same homogeneity group (A); 30 min (16.44) and 3 h (15.63) had lower values and were in groups (B) and (C), respectively. Among the Concentration Types, the Control group (0%) (17.1) had the highest value and was classified in group (A). The 10% Hydrosol (16.77) and 10% Hydrosol+Mordan (16.85) groups had similar values and were classified in groups (AB). Next, 10% Extract (16.19) and 10% Extract+Mordan (15.76) had lower values and were classified in groups (BC) and (C), respectively. In the duration time variable, the shortest period of 6 h (14.57) had the lowest expansion value and was in group (C), while the expansion values increased as the duration time increased.

Table 15. Swelling Obtained According to Wood Type, Time, and Concentration

	Procedure	**$\bar{x}$**	**HG**
Wood Type	Red pine	16.62	B
	Oriental beech	18.37	A
	Walnut	14.35	C
Time	0 h	17.07	A
	30 min	16.44	B
	3 h	15.63	C
	24 h	17.11	A
Concentration	Control (0%)	17.07	A
	10% Hydrosol	16.77	AB
	10% Hydrosol + Mordant	16.85	AB
	10% Extract	16.19	BC
	10% Extract + Mordant	15.76	C
Standby Time	6 h	14.57	C
	24 h	16.39	B
	48 h	16.42	B
	72 h	17.32	A
	96 h	17.53	A

$\bar{x}$: Arithmetic Mean, HG: Homogeneity group

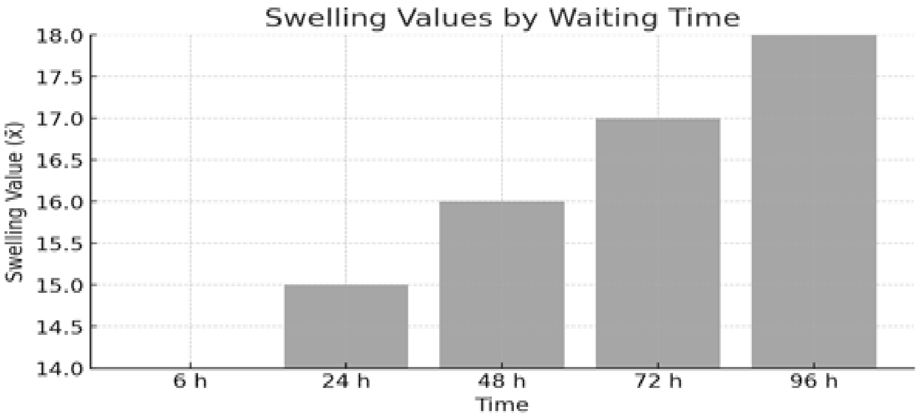

Fig. 16. Swelling values by duration time

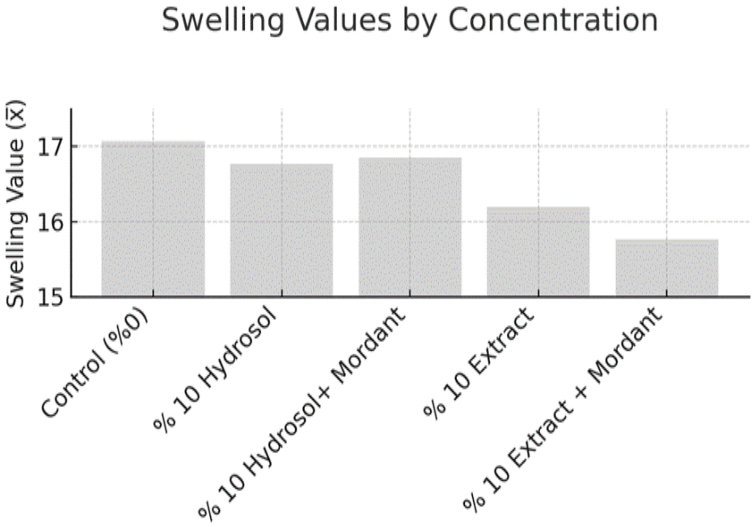

Fig. 17. Swelling values by concentration

The longest period of 96 h (17.53) showed the highest value and was in group (A). These findings show that expansion values show significant differences depending on tree species, time intervals, type of concentration applied and duration time, and especially duration time has a significant effect on expansion. Its graphical representation is also given below Figs. 16, 17, 18, and 19.

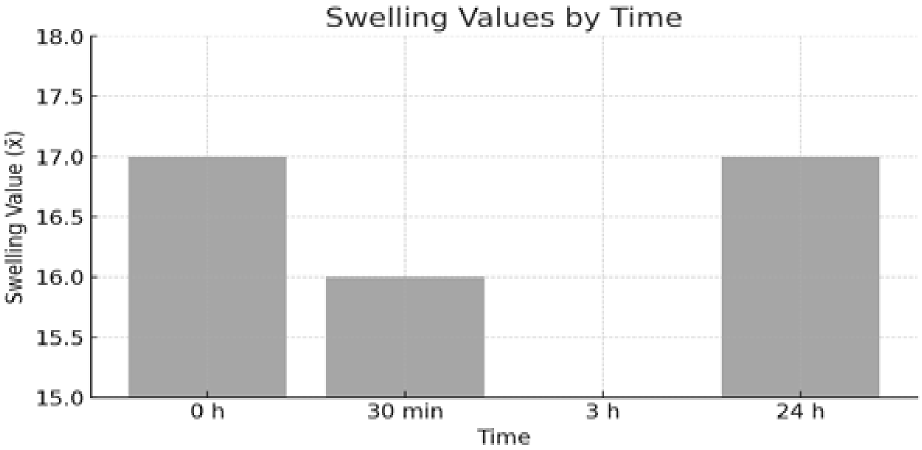

Fig. 18. Swelling values by time

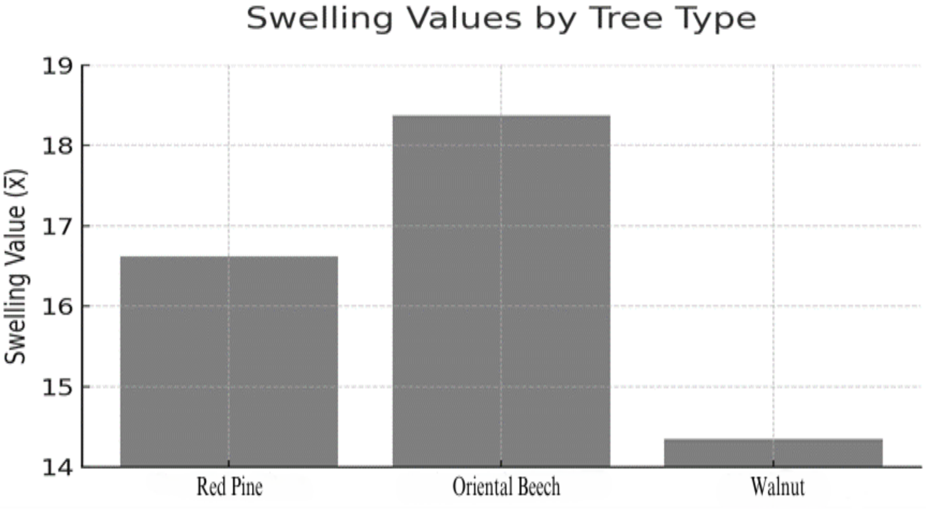

Fig. 19. Swelling values by wood (tree) type

Table 16 shows the values of expansion (swelling) change at different time periods according to different wood species, impregnation times, and oleander impregnant concentrations. Red pine expansion percentages were generally within a constant range in all treatments reaching 19.7% at 96 h in the control group. Oriental beech reached the highest expansion, with the 10% Hydrosol+Mordan treatment and showed a value of 20.6% at the end of 96 h. Walnut had generally lower expansion values and reached 16.3% at 96 h for the control group. Concentrations containing mordant and long duration times (72 to 96 h) contributed to the increasing trend in expansion in all tree species. In particular, the mordant combinations had an increasing effect on swelling values in Oriental beech and red pine, while this effect was more limited in walnut. These findings suggest that the change in expansion varied depending on tree species, duration time, and concentrations used.

Table 16. Values Regarding Swelling

Wood Type	Impregnation Time	Impregnation Agent Concentrations Obtained from Oleander	Swelling (%)				
			6 h	24 h	48 h	72 h	96 h
Red pine	0 h	Control (0%)	19.20	19.34	18.57	19.28	19.66
	30 min	10% Hydrosol	16.91	17.01	16.94	16.97	17.13
	30 min	10% Hydrosol + Mordant	16.51	16.72	16.72	16.64	16.43
	30 min	10% Extract	16.12	16.80	16.87	16.82	16.07
	30 min	10% Extract + Mordant	16.35	15.81	16.63	16.58	16.52
	3 h	10% Hydrosol	16.17	17.04	16.57	17.14	16.67
	3 h	10% Hydrosol + Mordant	16.15	17.08	16.02	16.22	16.59
	3 h	10% Extract	15.78	16.51	16.32	16.03	15.83
	3 h	10% Extract + Mordant	12.04	12.43	11.92	12.35	11.07
	24 h	10% Hydrosol	17.03	16.91	16.89	17.78	16.99
	24 h	10% Hydrosol + Mordant	17.71	18,19	17.71	18.08	17.84
	24 h	10% Extract	16.10	17.84	16.57	16.76	16.63
	24 h	10% Extract + Mordant	17.32	16.74	17.42	17.53	17.47
Oriental beech	0 h	Control (0%)	14.97	19.02	19.05	19.77	19.50
	30 min	10% Hydrosol	16.89	18.32	18.16	19.32	18.56
	30 min	10% Hydrosol + Mordant	18.45	19.86	19.91	20.65	20.56
	30 min	10% Extract	15.61	16.93	17.06	17.54	17.95
	30 min	10% Extract + Mordant	16.05	18.36	18.57	19.45	19.10
	3 h	10% Hydrosol	17.75	18.55	18.82	18.76	18.54
	3 h	10% Hydrosol + Mordant	16.60	18.08	18.56	19.04	18.32
	3 h	10% Extract	17.55	18.89	19.62	19.54	19.40
	3 h	10% Extract + Mordant	14.13	15.54	15.61	15.73	15.89
	24 h	10% Hydrosol	19.36	19.49	19.51	19.35	19.22
	24 h	10% Hydrosol + Mordant	18.26	19.81	18.88	19.09	19.43
	24 h	10% Extract	16.81	18.07	19.28	19.03	18.54
	24 h	10% Extract + Mordant	16.31	19.39	19.35	20.50	19.74
Walnut	0 h	Control (0%)	9.53	12.81	13.85	15.16	16.27
	30 min	10% Hydrosol	11.07	14.58	15.54	16.75	16.64
	30 min	10% Hydrosol + Mordant	10.37	14.03	15.07	15.92	16.71
	30 min	10% Extract	10.10	12.62	14.47	15.02	16.25
	30 min	10% Extract + Mordant	9.84	13.88	14.87	15.80	16.79
	3 h	10% Hydrosol	9.18	12.82	14.39	15.58	17.75
	3 h	10% Hydrosol + Mordant	9.70	13.52	14.24	15.27	16.52
	3 h	10% Extract	10.62	14.86	14.90	16.75	19.47
	3 h	10% Extract + Mordant	9.84	13.67	14.62	16.05	17.44
	24 h	10% Hydrosol	10.94	14.54	15.24	17.53	17.54
	24 h	10% Hydrosol + Mordant	12.43	14.88	15.46	16.36	17.68
	24 h	10% Extract	11.08	14.36	14.56	16.34	18.11
	24 h	10% Extract + Mordant	11.29	14.08	15.73	16.83	16.66

HG Homogeneity group: Means in the same column marked with a different letter are statistically different from each other ($p < 0.05$)

Table 17 shows the results of MANOVA for shrinkage value. According to the results of the analysis, among the main factors analysed, tree species (A) (F(2, 390) = 104.414, $p < 0.05$), times (B) (F(2, 390) = 8.962, $p < 0.05$), and duration time (D) (F(4, 390) = 13.772, $p < 0.05$) had a statistically significant effects on shrinkage values. However, the effect of the concentration (C) factor was not significant ($p = 0.095$). In addition, the interactions between some factors were also significant. In particular, the interactions of Tree Species and Times (A * B) (F(4, 390) = 3.605, $p < 0.05$), Tree Species and Concentration (A * C) (F(6, 390) = 4.859, $p < 0.05$), and Tree Species and Duration Time (A * D) (F(8, 390) = 5.549, $p < 0.05$) showed a significant effect on shrinkage. Furthermore, the interaction of Times and Concentration (B * C) (F(6, 390) = 3,081, $p < 0.05$) was also significant. However, most of the triple and quadruple interactions were not significant ($p > 0.05$).

These findings show that the shrinkage values were significantly affected by both the main factors, such as tree species, time, and duration time, and the interactions between certain factors. Especially, tree species and duration time variables played a significant role on shrinkage.

Table 17. Multiple Variance Analysis Results of Shrinkage

Factor	Degrees of Freedom	Sum of Squares	Mean Squares	F	p
Woods (A)	2	1726.448	863.224	104.414	**0.000***
Times (B)	2	148.189	74.094	8.962	**0.000***
Concentration (C)	3	52.948	17.649	2.135	0.095
Standby Time (D)	4	455.421	113.855	13.772	**0.000***
A * B	4	119.220	29.805	3.605	**0.007***
A * C	6	241.009	40.168	4.859	**0.000***
A * D	8	366.997	45.875	5.549	**0.000***
B * C	6	152.811	25.468	3.081	**0.006***
B * D	8	32.435	4.054	0.490	0.863
C * D	12	42.886	3.574	0.432	0.950
A * B * C	12	176.234	14.686	1.776	0.050
A * B * D	16	78.585	4.912	0.594	0.889
A * C * D	24	124.401	5.183	0.627	0.915
B * C * D	24	91.111	3.796	0.459	0.988
A * B * C * D	48	194.784	4.058	0.491	0.998
Error	390	3224.255	8.267		
Total	585	101255.205			

*Significant at $p < 0.05$ level

Table 18 shows the shrinkage values and homogeneity groups (HG) obtained for different tree species, time periods, concentration types, and duration times. In terms of tree species, Oriental beech (14.66) had the highest shrinkage value and was classified in group (A), while red pine (13.11) had an intermediate value and was classified in group (B). Walnut (10.17) showed the lowest value and was classified in group (C). Regarding the time variable, 30 min (13.11) showed the highest value and was classified in group (A). Other time periods showed lower levels of contraction values. For example, 3 h (11.94) showed the lowest value and was classified in group (C), while 24 h (12.98) had a medium value and was classified in group (AB). When Concentration Types were analysed, no significant difference was found between all groups. Control group (0%) (12.27), 10% Hydrosol (12.57), 10% Hydrosol+Mordan (12.81), 10% Extract (12.25), and 10% Extract+Mordan (13.10) were in the same homogeneity group (A). Duration time variable created significant differences in shrinkage values. The shortest duration time of 6 h (11.03) showed the lowest value and was in group (C). As the duration time increased, the shrinkage values increased, and the longest duration time of 96 h (13.63) reached the highest value and was classified in group (A). Its graphical representation is also given below Figs. 20, 21, 22, and 23.

These findings indicate that the shrinkage values were significantly affected by the factors of tree species and duration time and that the shrinkage values tended to increase with increasing duration time. In addition, the effect of concentration types on shrinkage was limited.

Table 18. Shrinkage Values Obtained According to Wood Type, Time, and Concentration

	Procedure	$\bar{x}$	**HG**
Wood Type	Red pine	13.11	B
	Oriental beech	14.66	A
	Walnut	10.17	C
Time	0 h	12.27	BC
	30 min	13.11	A
	3 h	11.94	C
	24 h	12.98	AB
Concentration	Control (0%)	12.27	A
	10% Hydrosol	12.57	A
	10% Hydrosol+ Mordant	12.81	A
	10% Extract	12.25	A
	10% Extract + Mordant	13.10	A
Standby Time	6 h	11.03	C
	24 h	12.64	B
	48 h	12.52	B
	72 h	13.43	A
	96 h	13.63	A

$\bar{x}$: Arithmetic mean, HG: Homogeneity group

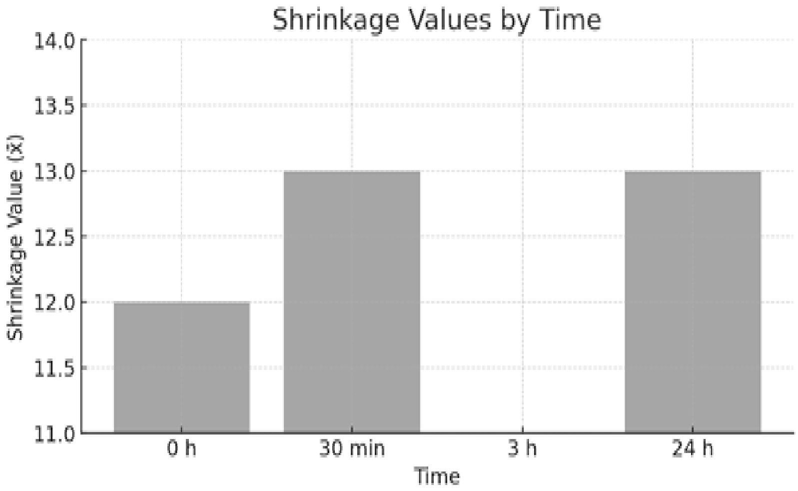

Fig. 20. Shrinkage values by time

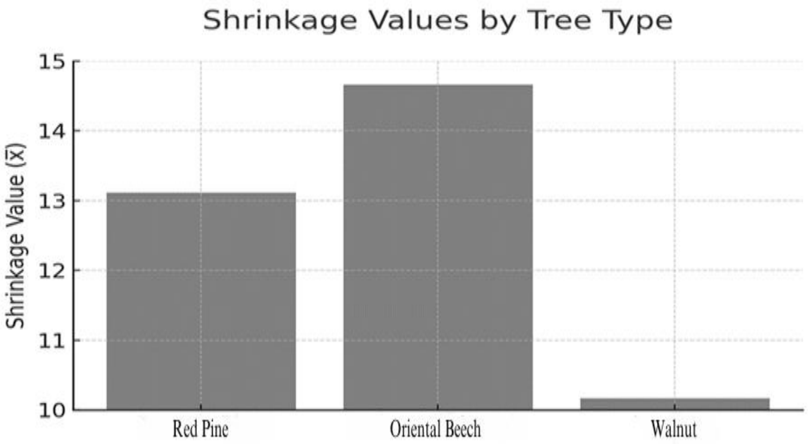

Fig. 21. Shrinkage values by tree type

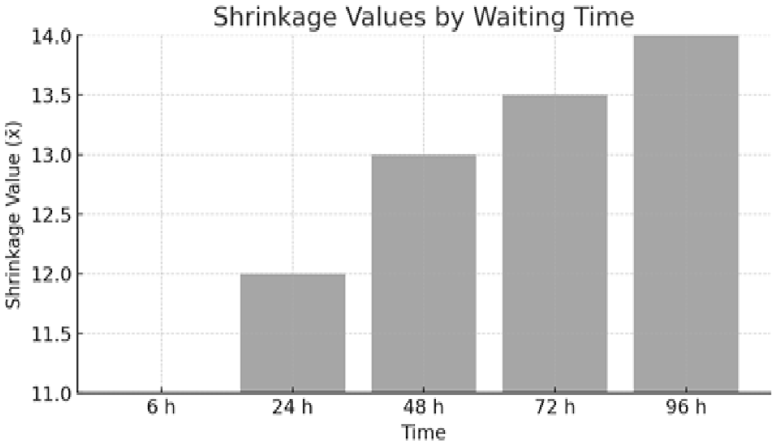

Fig. 22. Shrinkage values by standby time

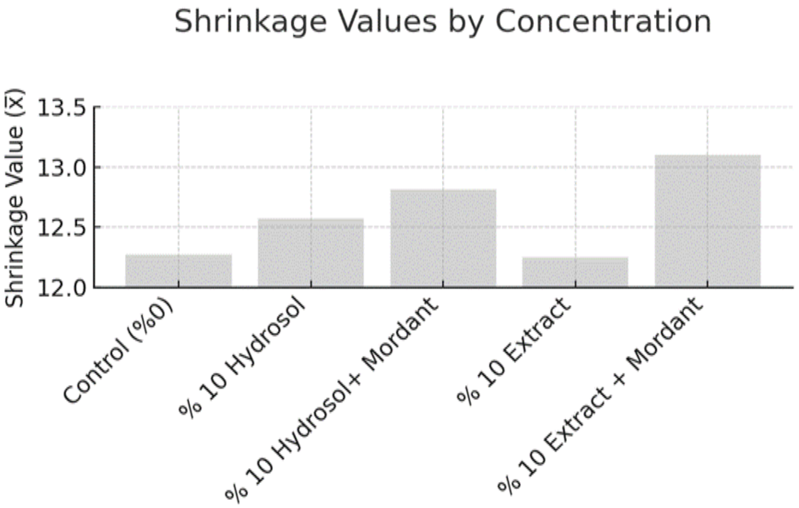

Fig. 23. Shrinkage values by concentration

Table 19 shows the changes in shrinkage values at various time periods according to different wood species, impregnation times, and oleander impregnant concentrations. Red pine showed a generally stable trend in shrinkage values and showed shrinkage between 12.1% and 13.9%. Oriental beech had higher shrinkage values, reaching 16.0% after 96 h, especially with 10% Hydrosol+Mordan. Walnut was generally characterised by lower shrinkage values, but it reached a high value of 18.4% after 96 h with 10% Extract + Mordant. In all wood species, an increase in shrinkage ratios was observed as the duration time increased, and maximum values were obtained especially at 72 and 96 h. Treatments containing mordant generally resulted in higher shrinkage values. These findings indicate that the shrinkage values varied depending on both wood species, impregnation times, and concentration type and that the addition of mordant had an increasing effect on shrinkage.

Table 19. Duncan Test Results for Shrinkage Values

Wood Type	Impregnation Time	Impregnation Agent Concentrations Obtained from Oleander	Shrinkage Obtained (%)				
			6 h	24 h	48 h	72 h	96 h
Red pine	0 h	Control (0%)	13.4	13.60	12.93	13.59	13.94
	30 min	10% Hydrosol	13.0	13.19	13.09	13.09	13.26
	30 min	10% Hydrosol + Mordant	13.0	13.31	13.22	13.15	12.99
	30 min	10% Extract	12.7	13.42	13.47	13.42	12.72
	30 min	10% Extract + Mordant	13.2	12.72	13.42	13.36	13.33
	3 h	10% Hydrosol	12.4	13.22	12.81	13.27	12.89
	3 h	10% Hydrosol + Mordant	12.4	13.14	12.25	12.45	12.73
	3 h	10% Extract	13.2	13.89	13.76	13.48	13.28
	3 h	10% Extract + Mordant	12.0	12.44	11.96	12.37	11.26
	24 h	10% Hydrosol	13.0	12.94	12.90	13.68	12.99
	24 h	10% Hydrosol + Mordant	13.0	13.45	13.07	13.40	13.15
	24 h	10% Extract	12.8	14.34	13.31	13.46	13.32
	24 h	10% Extract + Mordant	13.4	13.00	13.57	13.60	13.59
	0 h	Control (0%)	10.7	14.10	14.07	14.63	14.44

Oriental beech	30 min	10% Hydrosol	13.9	15.08	14.97	15.92	15.29
	30 min	10% Hydrosol + Mordant	14.2	15.39	15.43	16.05	16.02
	30 min	10% Extract	12.3	13.49	13.61	14.01	14.40
	30 min	10% Extract + Mordant	12.7	14.72	14.90	15.64	15.36
	3 h	10% Hydrosol	14.2	14.87	15.10	15.06	14.84
	3 h	10% Hydrosol + Mordant	13.5	14.75	15.13	15.49	14.95
	3 h	10% Extract	13.5	14.68	15.28	15.23	15.09
	3 h	10% Extract + Mordant	11.8	13.06	13.13	13.25	13.41
	24 h	10% Hydrosol	14.7	14.84	14.86	14.81	14.67
	24 h	10% Hydrosol + Mordant	14.9	16.19	15.43	15.61	15.89
	24 h	10% Extract	14.0	15.09	16.18	15.90	15.54
	24 h	10% Extract + Mordant	12.9	15.51	15.42	16.40	15.78
Walnut	0 h	Control (0%)	6.07	9.08	10.00	11.18	12.16
	30 min	10% Hydrosol	722	10.39	11.22	12.28	12.18
	30 min	10% Hydrosol + Mordant	6.25	9.57	10.49	11.23	11.91
	30 min	10% Extract	6.01	8.30	9.98	10.43	11.53
	30 min	10% Extract + Mordant	12.3	15.91	16.77	17.53	18.41
	3 h	10% Hydrosol	4.54	7.90	9.32	10.36	12.32
	3 h	10% Hydrosol + Mordant	5.34	8.83	9.46	10.37	11.46
	3 h	10% Extract	5.95	9.76	14.39	11.42	13.77
	3 h	10% Extract + Mordant	5.60	9.13	9.93	11.18	12.43
	24 h	10% Hydrosol	6.00	9.24	9.84	11.86	11.89
	24 h	10% Hydrosol + Mordant	8.93	11.10	11.61	12.38	13.54
	24 h	10% Extract	6.43	9.40	9.55	11.13	12.63
	24 h	10% Extract + Mordant	7.28	9.82	11.22	12.21	12.04

The findings from the study reveal significant insights into the effects of various impregnation treatments using oleander extract and hydrosol on wood materials. First, the analysis indicates that specific physical properties, such as density and retention, were influenced more by the wood type than by impregnation duration or concentration. For instance, red pine exhibited the lowest average specific gravity, while Oriental beech, and walnut showed significantly higher values, indicating that wood species played a critical role in determining these characteristics. In contrast, impregnation duration and concentration had limited or no statistically significant impact on these properties.

Water uptake and dimensional changes, such as swelling and shrinkage, were found to depend heavily on the type of wood, the impregnation agent used, and the soaking duration. Hydrosol-treated samples showed better water repellency and dimensional stability than those treated with extract. Oriental beech demonstrated higher water uptake and swelling compared to red pine and walnut, especially when hydrosol-mordant combinations were used. This highlights the potential of hydrosol-based treatments for enhancing dimensional stability in wood, though their effects vary across different wood types.

The findings of this study align with and expand upon previous research examining the effects of plant-based impregnation agents on wood properties. Atılgan *et al.* (2013) demonstrated that natural extracts, particularly those containing tannins and flavonoids, improved wood’s resistance to moisture absorption and dimensional stability. Similarly, in this study, oleander hydrosol exhibited water-repellent properties, contributing to reduced swelling and shrinkage, which is consistent with prior research on plant-derived preservatives (Göktaş *et al.* 2008; Peker *et al.* 2012).

Moreover, studies by Karadağ *et al.* (2017) and Çağlayan (2020) reported that the impregnation of wood with plant-based solutions had no significant effect on retention percentages, suggesting that the absorption capacity of bio-based solutions is primarily influenced by wood species rather than treatment concentration. The results obtained in this study are in line with these findings, as the oleander extract treatment did not significantly affect retention ($p>0.05$), reinforcing the idea that botanical-based impregnation treatments may have limited penetration ability depending on wood porosity and composition.

Additionally, the impact of mordant on shrinkage values has been previously discussed in wood preservation studies (Gheno *et al.*, 2016). It has been reported that acidic mordants, including vinegar-based solutions, can lead to increased contraction in wood fibers, which correlates with the observed increase in shrinkage, particularly in Oriental beech and walnut in this study. This finding supports prior work by Hon (2001) and Evans *et al.* (1996), which highlighted that acidic treatments can modify cell wall structure and influence dimensional stability.

Overall, these results contribute to the existing literature by demonstrating that oleander-based treatments, particularly hydrosol, can provide moderate protective effects against moisture-related degradation, with potential for application in sustainable wood preservation. However, the findings also indicate that mordant addition may introduce unwanted dimensional changes, suggesting that further refinements in treatment formulations are needed to optimize their protective efficacy.

Shrinkage behavior also varied significantly among wood species and impregnation treatments. Oriental beech and walnut exhibited greater shrinkage over prolonged soaking periods, with mordant combinations amplifying this effect. Notably, walnut, typically less prone to shrinkage, reached high shrinkage values under certain extract and mordant combinations. These findings emphasize that while mordant can improve adhesion and water resistance, it may also exacerbate shrinkage, especially under extended exposure to moisture. Overall, the results underscore the need to consider wood species and specific treatment conditions when optimizing impregnation processes for enhanced physical performance.

In general, studies have shown similar results in wood preservation research, but differences can be observed in some studies. This study was able to obtain more meaningful results with different wood species and extract ratios and can serve as a reference for future research.

RECOMMENDATIONS

As a result of various processes with today's technology, the oleander plant can be developed as environmentally sensitive natural wood surface preservatives (impregnation) and can create new areas of use. Wood material is exposed to the harmful effects of biotic and abiotic factors and should be treated with natural preservatives alternative to chemicals to prevent degradation and gain aesthetic appearance. Due to the negative effects of solvent-based varnishes and paints on the environment and living things, it is necessary to produce, develop, apply, and expand the use of sustainable products that do not contain environmentally compatible hardeners.

It is of great importance to evaluate the oleander plant, which has a significant production potential in Turkey, as a wood surface protector in terms of ensuring economic recycling and creating a new area of use in the woodworking industry. The reactions of wooden materials treated with natural preservatives, especially to events, such as burning, is an important issue that can guide other research and is presented as a suggestion for studies to be carried out in this field. In another experiment on wood conducted by Özder *et al.* (2024), the lowest growth in terms of antimicrobial activity was found in samples with 0.1% nano boron synthetic varnish, and the highest growth was found in 0.1% water-based varnish. Thus, alternative usage opportunities can be increased using oleander hydrosol in antimicrobial experiments.

The use of herbal extracts in the field of wood preservation is also of economic importance for the producers of these substances. If natural preservatives are developed as an alternative to synthetic chemical dyes, then dye plants can become widespread in agricultural areas and create a new raw material source. Outdoor furniture and interior decoration products with herbal natural preservatives can also create an important source of economic income for the domestic and foreign markets.

Future research should focus on the detailed chemical characterization of oleander extract and hydrosol to identify bioactive compounds responsible for wood protection. Additionally, long-term durability studies under various environmental conditions, such as UV exposure, fungal decay, and extreme humidity, would provide a deeper understanding of their effectiveness. Exploring alternative natural mordants could help mitigate the shrinkage effects observed in this study. Lastly, scaling up these findings for industrial applications, including field tests on construction and furniture materials, would be essential for assessing the practical feasibility of oleander-based wood treatments.

CONCLUSIONS

This study evaluated the effectiveness of oleander (*Nerium oleander L.*) extract and hydrosol as natural impregnation agents for wood materials, focusing on their impact on dimensional stability, water uptake, and shrinkage behavior. The following conclusions were drawn from the findings:

1. Oleander-based treatments demonstrated potential as eco-friendly wood preservation agents, with hydrosol-treated samples exhibiting better water repellency and dimensional stability compared to extract-treated ones.
2. Mordant-treated wood samples generally showed higher shrinkage values, indicating that the addition of mordant may influence the physical response of wood to moisture exposure.
3. The effect of hydrosol and extract treatments varied across different wood species. While red pine exhibited relatively stable shrinkage values, Oriental beech had the highest swelling and water uptake, particularly in hydrosol-mordant combinations. Walnut demonstrated lower shrinkage overall but exhibited increased values at prolonged exposure times.
4. The findings support the viability of plant-based impregnation solutions as alternatives to synthetic wood preservatives, aligning with the growing demand for sustainable materials in the wood industry. However, further research is needed to optimize

treatment formulations and improve performance across diverse environmental conditions.

5. Future studies should explore the combination of oleander-based treatments with water-based protective coatings to assess their industrial applicability and potential economic benefits.
6. This study contributes to the theoretical framework of wood preservation by demonstrating the potential of oleander extract and hydrosol as eco-friendly impregnation agents. The findings highlight that while oleander extract had no significant impact on wood retention, hydrosol exhibited water-repellent properties, contributing to improved dimensional stability. These results align with previous research on plant-based preservatives and offer a new perspective on the use of bioactive compounds in wood protection.
7. From a practical standpoint, the study underscores the viability of oleander-derived hydrosol as a natural alternative to synthetic wood preservatives, particularly in reducing water uptake and swelling effects. However, the observed increase in shrinkage with mordant treatment suggests that further refinement is necessary to optimize its application in commercial wood preservation processes. These insights can be valuable for manufacturers, researchers, and environmental policymakers seeking sustainable solutions in the wood industry.

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REFERENCES CITED

Akyürekli, Ö. (2003). *Researching Some of the Technological Properties of Impregnated Crimean Pine (Pinus nigra Arnold) Wood*, Master’s Thesis, Süleyman Demirel University, Institute of Science and Technology, Department of Forestry Engineering, Isparta, Turkey.

ASTM D1413-76 (1976). “Standard test method of testing wood preservatives by laboratory soil blocks cultures,” ASTM International, West Conshohocken, PA, USA.

Atılgan, A., Ersen, N., Ulusoy, H., Bardak, S., and Peker, H. (2013). “Possibility of using wood protection furniture industry waste teas and effect on gloss,” in: *International Caucasian Forestry Symposium*, Artvin, Turkey.

Atılgan, A., Ulusoy, H., and Peker, H. (2017). “Effects on bending strength and modulus of elasticity of plant extracts dye on some wood species,” *Research Journal of Biology Sciences E* 10(1), 10-13.

Atılgan, A. (2009). *Determination of the Color Stability of Wood Stains from Plant Extracts Under Accelerated Weathering Exposure*, Master’s Thesis, Dumlupınar University Institute of Science and Technology, Kütahya, Turkey.

Atılgan, A. (2022). *The Use of Resin Lacquer as a Surface Material on Wood Material and Antimicrobial Effects Occur*, Ph.D. Thesis, Gazi University, Institute of Science and Technology, Woodworking Industrial Engineering Department, Ankara, Turkey.

Atılgan, A. (2023a). "Effect of silane-siloxane based water-repellent impregnant on the dimensional stability of some wood species," *BioResources* 18(4), 7172-7185. DOI: 10.15376/biores.18.4.7172-7185

Atılgan, A. (2023b). "Effects of organic protective oils on the physical performance level of wooden materials in the ecological cycle," in: *Current Approaches in Agriculture, Forestry and Water Sciences*, Duvar Publishing, Sariyer Istanbul, Turkey, pp. 7-28.

Atılgan, A. (2023c). "Effects of plant extract and wood on anatomical structure in ecological environment interaction," *BioResources* 18(2), 2693-2706. DOI: 10.15376/biores.18.2.2693-2706

Atılgan, A., and Atar, M. (2023). "Environmentally friendly surface treatment agent trial on wood material and its effect on adhesion resistance," *International Journal of Advanced Natural Sciences and Engineering Research* 7(9), 254-260. DOI: 10.59287/ijanser.1545

Atılgan, A., Ersen, N., and Peker, H. (2013a). "Investigation of the coloring possibilities of the dye obtained from waste tea extracts in wooden materials," *Kastamonu University Journal of Forestry Faculty* 13(2), 268-277.

Atılgan, A., Ersen, N., and Peker, H. (2013b). "Retention values in wood species treated with tea plant extract," *Kastamonu University Journal of Forestry Faculty* 13(2), 278-286.

Atılgan, A., Göktaş, O., and Peker, H. (2011). "Natural plant extract produced the material surface of the paint timber pinar adoption," *Artvin Çoruh University, Journal of Forestry Faculty* 12(2), 139-147.

Atılgan, A., Peker, H., and Atar, M. (2021). "Application of environmentally friendly organic surface treatment agent on wood material and its effect on some surface properties Gazi University," *Journal of the Faculty of Engineering and Architecture* 37(1), 107-120. DOI: 10.17341/gazimmfd.876217

Atılgan, A., Tan, H., Ulusoy, H., and Peker, H. (2018). "Dye of waste tea extract with mordant-varnish and the effect of color changes on wood," *International Journal of Ecosystems and Ecology Science (IJEES)* 8(2), 203-212.

Atılgan, A., Ulusoy, H., Tan, H., and Peker, H. (2018). "Ecological paint use and surface roughness in wood," *Politeknik Journal* 21(3), 553-558. DOI: 10.2339/politeknik.417748

Bak, M., Takács, D., Rákosa, R., Németh, Z. I., and Németh, R. (2023). "One-step process for the fabrication of hydrophobic and dimensional stable wood using functionalized silica nanoparticles," *Forests* 14(3), article 651. DOI: 10.3390/f14030651

Bozkurt, A. Y., Göker, Y., and Erdin N. (1993). *Impregnation Technique*, İstanbul University Forest Faculty Publisher, İstanbul, Turkey.

Can, A. (2018). *Examination of the Performance of Some Impregnations Combined with Water Repellents*, Ph.D. Thesis, Bartın University, Institute of Science and Technology, Bartın, Turkey.

Çağlayan, E. S. (2020). *Wooden Structures and the Opinions of Civil Engineers / Woodworking Industry Engineers in Turkey About Multi-Storey Wooden Buildings*, Master's Thesis, Hacettepe University Institute of Science and Technology, Woodworking Industrial Engineering Department, Ankara, Turkey.

Cetin, T., and Kalaycı, Z. (2025). “Assessment of extracts and hydrosol from yarrow as wood preservative and its effects on physical performance,” *BioResources* 20(1), 1518-1546. DOI: 10.15376/BIORES.20.1.1518-1546

Evans, P. D., Thay, P. D., and Schmalzl, K. J. (1996). “Degradation of wood surfaces during natural weathering. Effects on lignin and cellulose and on the adhesion of acrylic latex primer,” *Wood Science and Technology* 40(1), 411–422. DOI: 10.1007/BF00244437

Gheno, G., Ganzerla, R., Bortoluzzi, M., and Paganica, R. (2016). “Accelerated weathering degradation behaviour of polyester thermosetting powder coating,” *Progress in Organic Coatings* 101, 90-99. DOI: 10.1016/j.porgcoat.2016.07.004

Göktaş, O., Çolak, M., Uğurlu, M., Özen, E., and Yeniocak, M., (2013). *Determination of Washing Performances (Paint Adhesion) and Color Change Values Under UV-Rapid Aging Conditions of Wooden Materials Painted with Plant Dyes Using the Ultrasonic Method* (Project No: 110 O 141), Tübitak-Tovag, Turkey.

Göktaş, O., Duru, E. M., Yeniocak, M., and Özen, E. (2008). “Determination of the color stability of an environmentally friendly wood stain derived from laurel (*Laurus nobilis* L.) leaf extracts under UV exposure,” *Forest Products Journal* 58(1/2), 77-80.

Gürleyen, T., Ayata, Ü., Gürleyen, L., Esteves, B., and ve Çakıcıer, N. (2017). “Determination of color, gloss and oscillatory hardness values in single and double layer UV system parquet varnish layers applied to Rowan (*Sorbus* L.) wood,” in: *5th International Symposium on Innovative Technologies in Engineering and Science (ISITES2017*), Baku, Azerbaijan, Turkey, pp. 1327-1336.

Hon, D. N. S. (2001). “Weathering and photochemistry of wood,” in: *Wood and Cellulose Chemistry*, D. N.-S. Hon, and N. Shiraishi (eds), Marcel Dekker, New York, NY, USA, pp. 513-546.

ISO 13061-15 (2017*)*. “Physical and mechanical properties of wood — Test methods for small clear wood specimens — Part 15: Determination of radial and tangential swelling,” International Organization for Standardization, Geneva, Switzerland.

Jocham, C., Schmidt, T. W., Wuzella, G., Teischinger, A., and Kandelbauer, A. (2011). “Adhesion improvement of powder coating on medium density fibreboard (MDF) by thermal pre-treatment,” *Journal of Adhesion Science and Technology* 25(15), 1937-1946. DOI: 10.1163/016942410X537189

Kamel, M. M., El-Shishtawy, R. M., Yussef, B. M., and Mashaly, H. (2005). “Ultrasonic assisted dyeing III. Dyeing of wool with lac as a natural dye,” *Dyes and Pigments* 65(2), 103-110. DOI: 10.1016/j.dyepig.2004.06.003

Karadağ, A. A., Korkut, D. S., Korkut, S., Köylü, G. P., and Akıncı Kesim, G. (2017). “Use of wooden materials in landscape applications in Turkey,” *İnönü University Art and Design Journal* 7(15), 83-98. DOI: 10.16950/iujad.329085

Kızıl, S. (2005). “Effect of different planting densities on some vegetative characteristics in love flower (*Reseda lutea* L.),” in: *Türkiye VI. Field Crops Congress,* Antalya, Turkey, Vol. 1, pp. 263–266.

Özder, C., Atar, M., and Atılgan, A. (2024). "Determination of the antimicrobial effect of varnishes modified with nano particles on the surface of wood materials," *BioResources* 19(4), 8935-8946. DOI: 10.15376/biores.19.4.8935-8946

Peker, H., Atılgan, A., Ulusoy, H., and Göktaş, O. (2012). “Usage opportunities of the natural dye extracted from acorn (*Quercus ithaburensis* Decaisne) in the furniture industry upper surface treatment,” *International Journal of Physical Sciences* 7(40), 5552-5558. DOI: 10.5897/IJPS12.479

Salthammer, T., Bednarek, M., Fuhrmann, F., Funaki, R., and Tanabe, S. I. (2002). "Formation of organic indoor air pollutants by UV-curing chemistry," *Journal of Photochemistry and Photobiology A: Chemistry* 152(1–3), 1-9. DOI: 10.1016/S1010-6030(02)00212-5

Singh, S. H. W. E. T. A., and Singh, D. R. (2018). "Application of natural mordants on textile," *International Journal of Applied Home Science* 5(1), 252-260.

Tesfamariam, S. (2022). "Performance-based design of tall timber buildings under earthquake and wind multi-hazard loads: Past, present, and future," *Frontiers in Built Environment* 8, article 848698.

Trotman, E. R. (1984). *Dyeing and Chemical Technology of Textile Fibres*.

TS 345 (2012). "Test methods of the effects of wood impregnations," Turkish Standardization Institute (TSE), Ankara, Turkey.

TS ISO 13061-1 (2021). "Physical and mechanical properties of wood- Test methods for small clear wood specimens – Part 1: Determination of moisture content for physical and mechanical tests," Turkish Standardization Institute (TSE), Ankara, Turkey.

TS ISO 13061-2 (2021). "Physical and mechanical properties of wood- Test methods for small clear wood specimens – Part 2: Determination of density for physical and mechanical tests," Turkish Standardization Institute (TSE), Ankara, Turkey.

Tsatsaroni, E., Liakopoulou-Kyriakides, M., and Eleftheriadis, I. (1998*)*. "Comparative study of dyeing properties of two yellow natural pigments – Effect of enzymes and protein," *Dyes and Pigments* 37(4), 307-315. DOI: 10.1016/S0143-7208(97)00069-7

Vardanyan, V., Galstian, T., and Riedl, B. (2015). "Effect of addition of cellulose nanocrystals to wood coatings on color changes and surface roughness due to accelerated weathering," *Journal of Coatings Technology and Research* 12(2), 247-258. DOI: 10.1007/s11998-014-9634-3

You, T., Teweldebrhan, B. T., Wang, W., and Tesfamariam, S. (2023). "Seismic loss and resilience assessment of tall-coupled cross-laminated timber wall building," *Earthquake Spectra* 39(2), 727-747.

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