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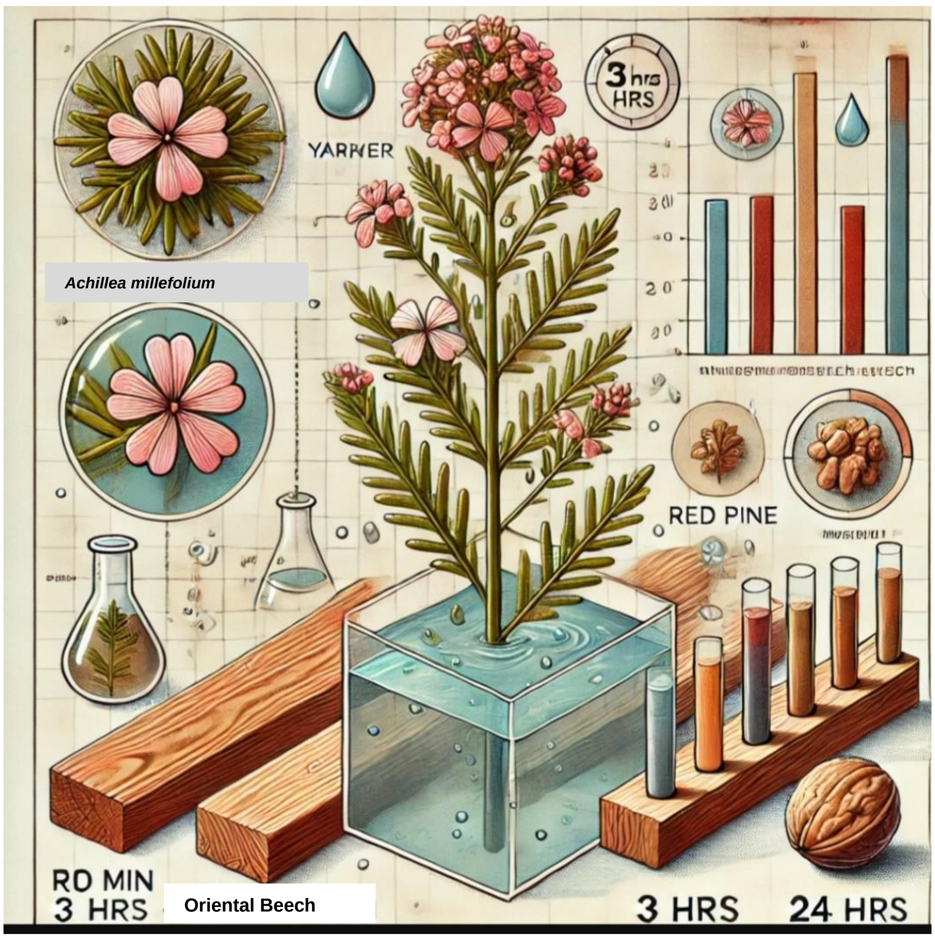
GRAPHICAL ABSTRACT



Assessment of Extracts and Hydrosol from Yarrow as Wood Preservative and Its Effects on Physical Performance

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This study aimed to assess the applicability of the extract and hydrosol obtained from the yarrow (*Achillea millefolium*) plant, which has grown widely in places where the Mediterranean climate prevails, as an impregnation agent for wooden materials. Red pine *(Pinus brutia)*, oriental beech *(Fagus orientalis)*, and walnut *(Juglans regia)* were selected as test samples of wood. An immersion method was used for the impregnation process that was performed for different time periods, 30 min (short), 3 h, (medium), and 24 h (long). Following the impregnation process, test samples were soaked in water for 6, 24, 48, 72, and 96 h to determine some physical properties of wooden material (retention, specific gravity, shrinkage, swelling, and water uptake). The results revealed that the highest retention after yarrow extract impregnation was achieved with red pine at 10% hydrosol concentration (2.29%) in a 30 min period whereas the lowest retention was observed with walnut material at 10% hydrosol concentration (1.17%) within a 24 h period. Yarrow extract did not have a significant effect on the physical properties of impregnated wooden materials; however, it was argued that the hydrosol was effective in the dimensional stability of all test samples due to its water-repellent properties.

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Keywords: Wood preservative; Yarrow plant; Impregnation; Ecology; Retention

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INTRODUCTION

Wood has been a fundamental material for human use since ancient times, primarily meeting shelter needs and finding applications in countless other areas (Çağlayan 2020). Its inherent properties, such as naturalness, diverse texture, color, and form, combined with ease of processability, have made wood a preferred choice over alternatives such as steel, concrete, and iron (Karadağ *et al.* 2017). These unique attributes make wood not only a versatile material for construction and design but also a cornerstone among today's renewable natural resources. However, wood's organic nature also presents certain vulnerabilities, including susceptibility to decay, pests, and environmental degradation. These limitations pose significant challenges to maintaining its structural and aesthetic qualities over time, particularly as finished wooden products endure prolonged usage. The rapidly increasing global population, coupled with unsustainable forest consumption, heightens the urgency to protect and preserve wood to ensure its long-term usability and environmental sustainability (Bayraktar and Kesik 2022). In response, researchers and industries are increasingly focused on enhancing wood's durability and resistance to decomposition through protective treatments that remain compatible with ecological concerns. Developing natural wood preservatives, such as those derived from organic compounds, presents a promising pathway for minimizing harmful chemical use and aligning preservation techniques with environmental and human health priorities.

Wood impregnation techniques play a critical role in enhancing the material's durability, resistance to decay, and protection against pests, thereby ensuring its prolonged usability and structural integrity. These techniques are generally divided into three categories: methods that create protective layers on the surface, non-pressure methods, and pressure-based methods. Protective surface treatments, such as charring and mechanical layer applications, provide a physical barrier against environmental and biological factors. Non-pressure methods, including brushing, spraying, dipping, hot-and-cold open tank immersion, diffusion, and osmosis, allow chemicals to penetrate the wood without the need for external pressure, making these techniques cost-effective and accessible. In contrast, pressure-based methods, such as full-cell and empty-cell processes, involve placing wood in sealed tanks where preservatives are forced into the material under high pressure, resulting in deeper and more uniform penetration. Commonly used industrial preservatives include copper-based compounds, creosote, and borates, which effectively protect wood from fungal decay, insect infestations, and moisture damage. These impregnation methods and materials have been continuously refined through modern research, ensuring enhanced performance and alignment with environment (Kılıç 2008).

Yarrow (*Achillea millefolium*) is one of the oldest known medicinal plants, widely recognized for its versatile applications and rich chemical composition. The plant contains a variety of bioactive compounds, including achilleine, apigenin, azulene, camphor, coumarin, inulin, menthol, quercetin, rutin, and salicylic acid. Among these, quercetin stands out as the primary structure with dye properties. Additionally, studies by Karamenderes (2002), Kotan (2010), and Kordali (2009) have confirmed the antibacterial properties of yarrow, highlighting its potential as a natural protective agent. While yarrow is commonly utilized in fields such as medicine and agriculture, its potential use as a surface coating and impregnation agent for wood materials represents a promising innovation. As an organic substance, yarrow plant extract offers a sustainable and environmentally friendly alternative to traditional chemical-based preservatives. Its natural antimicrobial and decay-resistant properties make it particularly suitable for protecting wood against biological degradation. When combined with water-based varnishes, yarrow extract aligns with health and environmental standards, enhancing its appeal for industrial applications. This unique combination of ecological compatibility and effectiveness underscores yarrow's potential to serve as a preferred natural impregnation material in the forestry and wood industries.

Wooden material is exposed to the harmful effects of biotic and abiotic factors due to its structural properties. Therefore, it should be further treated with natural preservatives, as alternatives to synthetic chemicals, both to prevent degradation and to provide an aesthetic appearance. Due to the adverse 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 are compatible with the environment and do not contain hardeners. There is a need to determine the exposure limit values of chemicals that can be used in organic materials, within scientific methods and environmental procedures. Plant-based preservatives used in the protection of wood and applied to wood through various methods are gradually gaining value today (Atılgan 2022). The extended useful life of wood material by using protection techniques due to developing technology, its ease of shaping, resistance to disasters (fire and earthquake), and improved physical-mechanical properties (Çağlayan 2020), naturality, diversified texture-color-form, processability, and the superior properties against many other materials have increased the use of wooden materials (Karadağ *et al.* 2017). It is of great importance to develop environmentally compatible, natural protective materials as well as methods that will prolong the useful life of wood, as well as to protect, repair, and improve its durability (Bayraktar and Kesik 2022).

Using plant extracts to preserve wooden materials is an environmentally friendly option. The chemical content of such extracts, which are usually obtained from plant extracts or natural minerals, is minimal. Impregnation is a process applied to improve the durability of wood (Bi *et al.* 2024). However, plant extracts are generally not compatible with the chemicals used during the impregnation process applied to wood (Kirker *et al.* 2024). Therefore, impregnation with plant extracts and non-wood forest products may not have a significant effect on the durability and longevity of wooden materials. However, there are many scientific studies that reveal effective results in terms of color, brightness, and antimicrobial effects (Stanciu *et al.* 2024).

Applying protective treatments (impregnation, varnishing, and painting) to wood and wood-based products is essential for their long-term and efficient use (Vardanyan *et al.* 2015). Certain scientific tests have been performed following the application of natural dyes obtained from plants on wooden material surfaces. These tests include accelerated aging (UV) (Atılgan 2009; Atılgan *et al.* 2011; Peker *et al.* 2012), dimensional stability (Atılgan *et al.* 2013), retention (Atılgan *et al.* 2013), bending strength and the effect on elasticity modulus (Atılgan *et al.* 2017), roughness (Atılgan *et al.* 2018), gloss, paint adhesion (Atılgan 2009; Göktaş *et al.* 2013), and resistance against fungi (Göktaş *et al.* 2008). There are further scientific studies in the literature that examine the changes in various physical properties before or after the application of certain procedures such as impregnation (Toker *et al.* 2009), bleaching (Kesik *et al.* 2015), aging (Vardanyan *et al.* 2015), oscillatory hardness, color, gloss, and surface adhesion in UV protected varnish layers (Gürleyen *et al.* 2015; Atılgan 2017).

For the purpose of a study where food lacquer obtained from resins was used as a coating material on the upper surface of wooden materials, it was determined that this material helps wood to have a longer useful life and protects the surface. Surfaces suitable for medicine and food contact are obtained and the color and gloss properties and adhesion have been examined (Atılgan *et al.* 2022; Atılgan and Atar 2023). In another study aiming to develop natural coloring agents that can be used for coloring wooden materials, harmless to the environment and human health, a coloring agent was prepared from the wastes of the tea (*Camellia sinensis*) plant derived during the processing in factories, and the color change values were determined (Atılgan *et al.* 2013). Then, assuming that the adhesion of the produced paint would be strong, the permanence of the paint ensured by applying water-based varnish on the wooden samples and the surface roughness was measured (Atılgan *et al.* 2018). In other studies conducted by Atılgan (2023a,b), water-based impregnation based on linseed oil, teak oil, and silane-siloxane were used as a wood protection agent in 100% concentrations and impregnation was applied by dipping method in different periods for 30 min (short), 3 h (medium), and 24 h (long). Following the impregnation process, test samples were soaked in water for 6, 24, 48, 72, and 96 h to determine some physical properties of wooden material (retention, specific gravity, shrinkage, swelling, and water uptake) (Atılgan 2023a,b). In another study, where medicinal aromatic plant extract was used as an impregnation and antimicrobial material, a mixture of borax and ferula plant extract was impregnated into the wood material at a concentration of 3%, and then the anatomical properties of the wooden material were examined. No adhesion of the dye solution was observed in the tracheid and trachea cells, which perform the transmission function, however it was observed that the dye solution adheres to the walls of the storage cells and forms a bond (Atılgan 2023c).

The utilization of environmentally friendly and sustainable materials has gained significant attention in recent years. Biological impregnation techniques contribute to the degradation of various bacteria and fungi in natural environments. Chitosan microspheres impregnated with the natural dye curcuma were investigated under specific conditions to evaluate their effectiveness. The impregnation process was conducted in an aqueous medium at pH levels of 9.0, 9.5, and 10.0, and the presence of the dye within the microspheres was analyzed using capillary electrophoresis. Microspheres impregnated at pH 10.0 underwent further characterization through infrared spectroscopy, optical microscopy, scanning electron microscopy, and thermal analysis. The adsorption process facilitated the incorporation of the dye into the chitosan microspheres, which subsequently released the dye in acidic solutions at pH levels ranging from 1.0 to 5.0. Regardless of the pH, the dye release was completed within 3 hours, with most microspheres dissolving in under 1 hour. The release mechanism was found to align with the Super Case II transport release model, demonstrating the microspheres' potential for controlled dye delivery in varying pH environments (Parize 2009).

The use of human and environmentally friendly materials has been increasing in recent years. These biological impregnations help the process of breaking down various bacteria/fungi in the natural environment. Resin/natural dyes prevent the growth of fungus as they reduce the amount of water in the wood to below 10% (Koski 2008; Tomak 2011). Atılgan (2023) applied silane-siloxane based, water-based impregnation on some types of wooden materials by dipping method and observed that dimensional stability was achieved in all experiment groups compared to control samples due to its water-repellent effect.

High solvent content, nitrocellulose-based, two-component polyurethane-based, or acid-based paints are now used as paints and are harmful to humans and the environment (Jocham *et al.* 2011). Organic products are frequently considered by managers, researchers, and professionals of the industry due to the negative effects of indoor pollution on human health (Salthammer *et al.* 2002). As the demand for materials harmless to human and environmental health increases, states are also increasing protective measures (Tsatsaroni *et al.* 1998; Kamel *et al.* 2005). Kızıl (2005) argued that environmentally friendly and healthy products will emerge with the production of natural dyes, varnishes, and preservatives. The surface of wood exposed to environmental influences without any preservatives deteriorates faster (Evans *et al.* 1996). Sunlight (especially sun and ultraviolet light) and water (direct exposure to precipitation and humidity) are common elements that damage wood materials outdoors (Hon 2001; Can 2018). The durability of an organic coating refers to its resistance to adverse conditions in the natural environment throughout its useful life (Gheno *et al.* 2016).

The use of plant-based preservatives in wood treatment has garnered significant attention due to increasing ecological awareness and the need for sustainable alternatives to chemical agents. This study stands out by focusing on the potential of yarrow (*Achillea millefolium*) extract and hydrosol as innovative impregnation agents for wooden materials. Yarrow's rich chemical composition, coupled with its antibacterial and decay-resistant properties, makes it a promising candidate for enhancing wood's durability and resistance to environmental degradation. By utilizing environmentally friendly and non-toxic plant-based compounds, this research aims to reduce reliance on synthetic chemicals and promote the development of safer and more sustainable preservation techniques. The primary objective of this study is to evaluate the physical performance and retention efficacy of yarrow-based preservatives across various wood types, contributing to the advancement of eco-compatible wood protection strategies.

This study aims to contribute to science with a human and environmentally respectful product to be used as an impregnation agent on wooden materials. For this purpose, yarrow plant extract and hydrosol, developed from products obtained from plant extracts by taking health, safety, and environmental problems into consideration as well as are suitable for food and drug contact, were preferred as impregnation materials.

EXPERIMENTAL

Materials

Yarrow (*Achillea millefolium*) is a sharp-smelling plant with yellow and white flowers that has been used to cure various ailments since ancient times. It is a plant species that grows in temperate regions. The conditions under which the extraction process will be carried out from shade-dried coloring agents, to prepare the yarrow extract, are shown in Table 1. At the end of the process, dyed water was filtered through filter paper and separated from the solid pulp. Mordant substance was then added to the dyed solutions in the proportions exhibited in Table 2. Only grape vinegar (*Vinum acetum*) was preferred in the mordanting process to ensure retention naturally. The workflow process of the study is given in Fig. 1 as visual steps.

The yarrow extract and hydrosol were prepared under controlled conditions to maximize their efficacy as impregnation agents. The plant material was shade-dried to preserve its active compounds and subjected to an extraction process at 90°C for 120 minutes, using a 10:1 water-to-plant ratio. This meticulous preparation ensured the retention of its bioactive properties, such as its antimicrobial and water-repellent effects, which are critical for improving wood's dimensional stability and resistance to environmental effect. The combination of yarrow-based impregnation materials with different wood types provides a unique opportunity to assess their compatibility and effectiveness. Yarrow's natural decay resistance and its compatibility with water-based varnishes make it an excellent candidate for sustainable wood treatment. Moreover, its suitability for applications involving food and drug contact expands its potential utility in specialized industries.

Table 1. Conditions Required for Dye Extraction

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

Table 2. Ratios of Dying Solution + Mordant Mixture

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

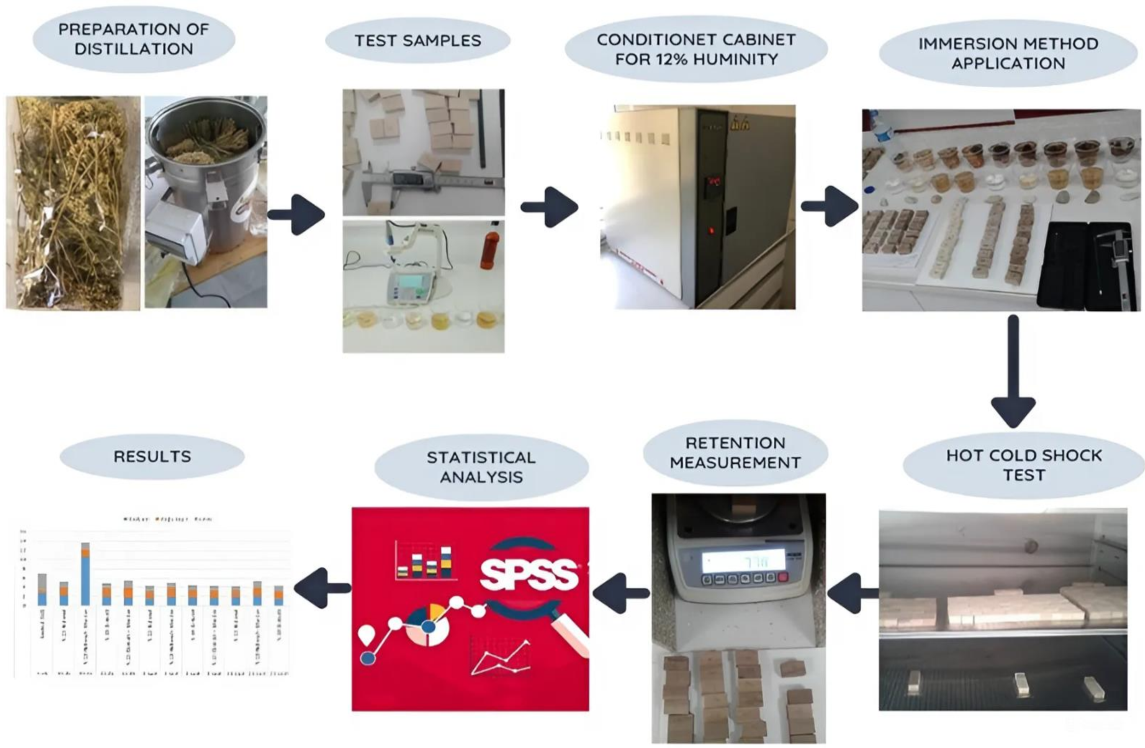

Fig. 1. Workflow process

Method

Impregnation method

The impregnation process was carried out under the conditions specified in ASTM–D 1413-76 (1976) by the immersion method, which is one of the methods that does not require the application of pressure. For this purpose, wood samples prepared in dimensions of (2×2×3) cm were left in the solution containing the extract of the yarrow plant under normal atmospheric pressure for the periods specified below. To determine the retained amount of the impregnation material and to prevent the wood from being affected by moisture, the samples were completely dried before and after impregnations.

Preparation of test samples

The sample preparation process was the first and essential step in the experimental methodology, ensuring consistency and reliability of results. Red pine (*Pinus brutia*), oriental beech (*Fagus orientalis* L.), and walnut (*Juglans regia* L.) were selected as the test wood species due to their common usage and distinct properties in the wood industry. The samples were prepared using high-quality, first-class wood, specifically sapwood, chosen for its smooth fibers and absence of defects such as knots, cracks, fungal damage, or growth irregularities. Red pine (*Pinus brutia*), oriental beech (*Fagus orientalis* l.), and walnut (*Juglans regia* l.) were selected from the most commonly used trees in the Turkish furniture and wood industry.

Test samples were prepared using first class wood and from sapwood parts with smooth fibers, without any knots or cracks, without tulle formation and growth defects, without any color and density differences, without any reaction wood, not subjected to fungal and insect damage, with annual rings perpendicular (radial) to the surface. The samples used to find the amount of solution absorption and net dry matter were prepared with a length of 3 cm parallel to the fibers, a width of 2 cm parallel to the core rays, and a thickness of 2 cm tangential to the annual rings (Bozkurt *et al.* 1993; Akyürekli 2003).

Impregnation Method

For the impregnation process, air-dried wood samples were impregnated using the immersion method (short term: 30 min, mid-term: 3 h, long term: 24 h). At the end of the impregnation process, the excess solution on the surface of the samples was removed with a paper towel and the test samples were weighed immediately while they were still wet. The samples were then kept in an oven at 50 ± 3 °C until they reached a constant weight. Their exact dry weight (g), and dimensions (mm) were determined again on a precision balance with an accuracy of 0.01 (TSE 345 2012).

The extraction of compounds from the yarrow plant (*Achillea millefolium*) was conducted under controlled laboratory conditions to ensure the retention of its bioactive properties. The plant material, consisting of dried leaves and flowers, was first shade-dried to preserve its chemical composition, including key compounds such as quercetin, rutin, and salicylic acid, which are crucial for its antibacterial and decay-resistant properties. The extraction process involved preparing a 10:1 water-to-plant ratio by weight. The plant material was immersed in distilled water and heated to 90 °C for 120 min. This process facilitated the release of the plant's bioactive constituents into the aqueous medium. Following the extraction, the liquid was filtered through Whatman filter paper to separate the extract from the solid residues, ensuring a clear solution suitable for subsequent impregnation tests. To enhance the extract's stability and effectiveness, the solution was treated with a natural mordant—grape vinegar—in specified proportions to ensure better retention on wooden surfaces. This additional step was aimed at improving the interaction between the wood and the extract, particularly in terms of adhesion and long-term durability. The resulting extract and hydrosol were stored in airtight containers at room temperature until use in the impregnation experiments. This detailed extraction method ensured that the yarrow-based solutions retained their functional properties, making them effective for wood preservation and aligning with the study's goals of utilizing eco-friendly and sustainable materials.

Dimensional Stability (Shrinking/Swelling) and Water-Uptake

Water uptake (WU) and dimensional stability (DS, Shrinking/Swelling) tests of the samples were conducted according to the ISO 13061-1 (2017) standards. The samples, whose exact dry weight and dimensions were previously determined, were soaked 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 taken out of the water, dried with paper towels, and weighed. The dimensions of the samples soaked in water for 6, 24, 48, 72, and 96 h were also measured. Tangential direction, radial direction, longitudinal direction WU as well as DS (Shrinking/Swelling) values of the samples were then determined by the following 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 dimensions of fully dry sample before immersion in water (mm), and L_2 is the dimensions 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 fully dry specific gravities. The retention amount of yarrow extract in wood material was determined by the following Eq. 3 (Atılgan 2023b),

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

where R (%) is the retention efficiency, M_{oes} is the oven dry weight (gr) after impregnation, and $M_{oeö}$ is the oven dry weight (gr) before impregnation.

The impregnation process was carried out using the immersion method. A non-pressure technique chosen due to its simplicity, cost-effectiveness, and compatibility with natural impregnation materials. This method followed the ASTM-D 1413-76 (1976) standards to ensure consistency and reliability in experimental procedures. The prepared wood samples, measuring 2 × 2 × 3 cm, were fully dried before the impregnation process to eliminate moisture and standardize their initial weight and dimensions. For the impregnation, air-dried samples of red pine (*Pinus brutia*), oriental beech (*Fagus orientalis* L.), and walnut (*Juglans regia* L.) were submerged in solutions containing yarrow extract and hydrosol at concentrations of 10%. The immersion times were categorized into three durations: short-term (30 min), mid-term (3 h), and long-term (24 h), to investigate the effect of exposure time on the retention and performance of the impregnation agents.

After the immersion period, excess solution on the surface of the samples was carefully removed using paper towels to avoid inconsistencies in weight measurements. The impregnated samples were then oven-dried at 50 ± 3 °C until they reached a constant weight. The exact dry weight and dimensions of the samples were recorded to calculate the retention values and assess physical performance properties such as dimensional stability, shrinkage, swelling, and water uptake.

Data Analysis

Multiple variance analysis was used to compare the groups (wood, time, concentration, and time/duration of soaking in water) for each parameter. Duncan's multiple range test (DMRT) was preferred for pairwise comparison of each group. Results obtained are presented as mean ± standard deviation. The statistical significance level is taken as 0.05. 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, 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.

The findings obtained regarding the air-dry specific gravity and oven 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 tables below.

The results presented in Tables 3 and 4 revealed that there was a significant difference between wood species based on the results obtained regarding air-dry specific gravity values; however, no significant differences were observed between wood species in terms of impregnation time and impregnation materials. Considering the differences between wood species, the highest air-dry specific gravity values were observed in oriental beech and walnut wood. In addition, the interaction of wood species and impregnation had a significant influence on the dry specific gravity.

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	1.357	0.678	141.018	**0.000***
Time (B)	2	0.010	0.005	1.046	0.356
Concentration (C)	3	0.014	0.005	0.997	0.399
A * B	4	0.021	0.005	1.111	0.357
A * C	6	0.019	0.003	0.642	0.696
B * C	6	0.024	0.004	0.832	0.549
A * B * C	12	0.054	0.005	0.939	0.514
Error	78	0.375	0.005		
Total	117	42.278			

*Significant at $p < 0.05$ level

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

	Procedure	$\bar{x}$	HG
Wood Type	Red Pine	0.43	B
	Oriental Beech	0.67	A
	Walnut	0.66	A
Time	0 h	0.60	A
	30 min	0.59	A
	3 h	0.60	A
	24 h	0.57	A
Concentration	Control (%)	0.60	A
	10% Hydrosol	0.59	A
	10% Hydrosol + Mordant	0.57	A
	10% Extract	0.60	A
	10% Extract + Mordant	0.59	A

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

The results presented in Tables 3 and 4 revealed that there was a significant difference between wood species based on the results obtained regarding oven dry specific gravity values; however, no significant differences were observed between wood species in terms of impregnation time and impregnation materials. Considering the differences between wood species, the highest oven dry specific gravity values were observed in walnut woods. In addition, it was concluded that the interaction of wood type and impregnation time had a significant impact on the oven dried specific gravity.

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

Factor	Degrees of Freedom	Sum of Squares	Mean Squares	F-value	P-value
Woods (A)	2	1.351	0.676	958.827	**0.000***
Time (B)	2	0.000	0.000	0.290	0.749
Concentration (C)	3	0.002	0.001	0.841	0.476
A * B	4	0.010	0.002	3.468	**0.012***
A * C	6	0.004	0.001	1.010	0.425
B * C	6	0.002	0.000	0.576	0.749
A * B * C	12	0.010	0.001	1.185	0.309
Error	78	0.055	0.001		
Total	117	39.877			

*Significant at $p < 0.05$ level

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

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

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

The results of the Duncan's multiple range test (DMRT), which was performed to determine which groups caused the differences, are presented in Table 5. The table indicates that the highest air-dry specific gravity value was observed on walnut wood after 3 h of impregnation time using 10% hydrosol + mordant ($\bar{x}$ = 0.71). Furthermore, the lowest air-dry specific gravity value was observed on red pine after 30 min and 24 h of impregnation time using 10% hydrosol ($\bar{x}$ = 0.41). The highest fully dry specific gravity value was observed on walnut wood after 3 h and 24 h of impregnation time using 10% hydrosol + mordant ($\bar{x}$ = 0.69).

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

Wood Type	Impregnation Time	Impregnation Agent Concentrations Obtained from Yarrow	Air Dry Specific Gravity			Oven Dry Specific Gravity		
			$\bar{x}$	SD	Duncan (HG)	$\bar{x}$	SD	Duncan (HG)
Red pine	0 h	Control (0%)	0.42	0.01	B	0.40	0.01	D
	30 min	10% Hydrosol	**0.41**	0.02	B	0.40	0.02	D
	30 min	10% Hydrosol + Mordant	0.43	0.01	B	0.41	0.01	D
	30 min	10% Extract	0.43	0.02	B	0.41	0.02	D
	30 min	10% Extract + Mordant	0.42	0.02	B	0.40	0.02	D
	3 h	10% Hydrosol	0.43	0.01	B	0.41	0.00	D
	3 h	10% Hydrosol + Mordant	0.43	0.03	B	0.41	0.03	D
	3 h	10% Extract	0.43	0.01	B	0.42	0.01	D
	3 h	10% Extract + Mordant	0.43	0.02	B	0.42	0.02	D
	24 h	10% Hydrosol	0.41	0.01	B	0.40	0.01	D
	24 h	10% Hydrosol + Mordant	0.43	0.01	B	0.42	0.01	D
	24 h	10% Extract	0.44	0.02	B	0.43	0.02	D
	24 h	10% Extract + Mordant	0.43	0.00	B	0.41	0.01	D
Oriental beech	0 h	Control (%0)	0.69	0.00	A	0.66	0.01	ABC
	30 min	10% Hydrosol	0.69	0.04	A	0.66	0.04	ABC
	30 min	10% Hydrosol + Mordant	0.67	0.01	A	0.65	0.02	ABC
	30 min	10% Extract	0.70	0.00	A	0.67	0.00	ABC
	30 min	10% Extract + Mordant	0.68	0.04	A	0.65	0.04	ABC
	3 h	10% Hydrosol	0.69	0.04	A	0.66	0.03	ABC
	3 h	10% Hydrosol + Mordant	0.65	0.01	A	0.62	0.02	C
	3 h	10% Extract	0.67	0.02	A	0.65	0.03	ABC
	3 h	10% Extract + Mordant	0.65	0.02	A	0.62	0.02	C
	24 h	10% Hydrosol	0.65	0.01	A	0.63	0.01	BC
	24 h	10% Hydrosol + Mordant	0.65	0.02	A	0.63	0.02	C
	24 h	10% Extract	0.67	0.02	A	0.64	0.03	ABC
	24 h	10% Extract + Mordant	0.68	0.04	A	0.65	0.04	ABC
Walnut	0 h	Control (%0)	0.70	0.06	A	0.68	0.06	AB
	30 min	10% Hydrosol	0.67	0.04	A	0.65	0.04	ABC
	30 min	10% Hydrosol + Mordant	0.65	0.02	A	0.62	0.02	C
	30 min	10% Extract	0.68	0.02	A	0.66	0.02	ABC
	30 min	10% Extract + Mordant	0.65	0.01	A	0.63	0.01	BC
	3 h	10% Hydrosol	0.68	0.02	A	0.65	0.03	ABC
	3 h	10% Hydrosol + Mordant	**0.71**	0.03	A	0.69	0.02	A

	3 h	10% Extract	0.67	0.06	A	0.65	0.06	ABC
	3 h	10% Extract + Mordant	0.70	0.01	A	0.68	0.01	AB
	24 h	10% Hydrosol	0.68	0.03	A	0.67	0.03	ABC
	24 h	10% Hydrosol + Mordant	0.47	0.40	B	0.69	0.03	A
	24 h	10% Extract	0.69	0.03	A	0.67	0.03	ABC
	24 h	10% Extract + Mordant	0.65	0.05	A	0.63	0.04	BC

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

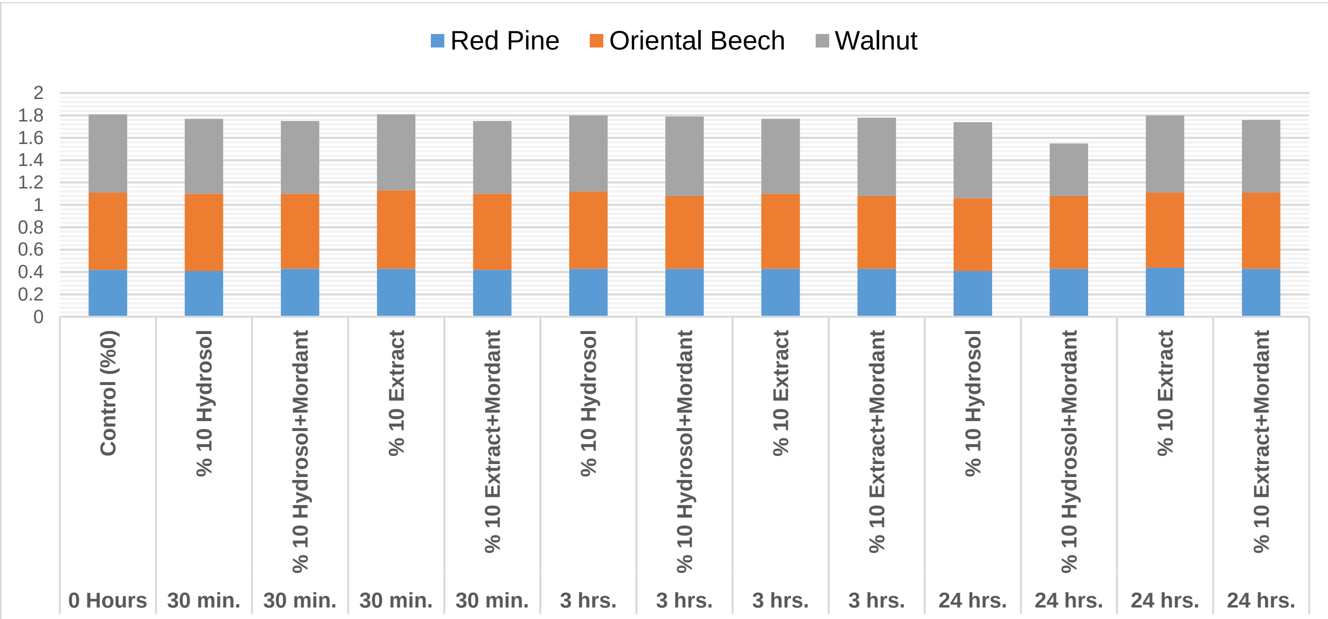

Fig. 2. Air dry specific gravity

Tables 6, 7, 8, and Fig. 2, present the findings regarding the retention values of red pine, oriental beech, and walnut wood impregnated time with 10% hydrosol, 10% hydrosol + mordant, 10% extract, and 10% extract + mordant for different periods of time.

Table 6 presents the results obtained regarding the retention values, indicating that no significant difference was observed between 10% hydrosol, 10% hydrosol + mordant, 10% extract, and 10% extract + mordant materials used as different impregnation time techniques on different wooden material types ($p > 0.05$).

Table 10 reveals that the highest retention was observed when red pine wood was impregnated for 30 min using 10% hydrosol + mordant ($\bar{x}$=10.58 gr.). In addition, the lowest retention was observed when walnut wood was impregnated for 24 h using 10% hydrosol ($\bar{x}$= 1.17 gr.).

Table 8. Multiple Variance Analysis Results for Retention Value

Factor	Degrees of Freedom	Sum of Squares	Mean Squares	F-value	p-value
Woods (A)	2	26.317	13.158	1.453	0.240
Time (B)	2	19.391	9.695	1.071	0.348
Concentration (C)	3	24.692	8.231	0.909	0.441

A * B	4	25.047	6.262	0.692	0.600
A * C	6	39.204	6.534	0.722	0.633
B * C	6	29.955	4.992	0.551	0.767
A * B * C	12	76.076	6.340	0.700	0.747
Error	78	706.131	9.053		
Total	117	1377.725			

*Significant at $p < 0.05$ level

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

	Procedure	$\bar{x}$	HG
Wood Type	Red pine	2.58	A
	Oriental beech	1.47	A
	Walnut	1.56	A
Time	0 h	2.31	A
	30 min	2.43	A
	3 h	1.51	A
	24 h	1.56	A
Concentration	Control (0%)	1.53	A
	10% Hydrosol	2.66	A
	10% Hydrosol + Mordant	1.53	A
	10% Extract	1.61	A
	10% Extract + Mordant	2.31	A

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

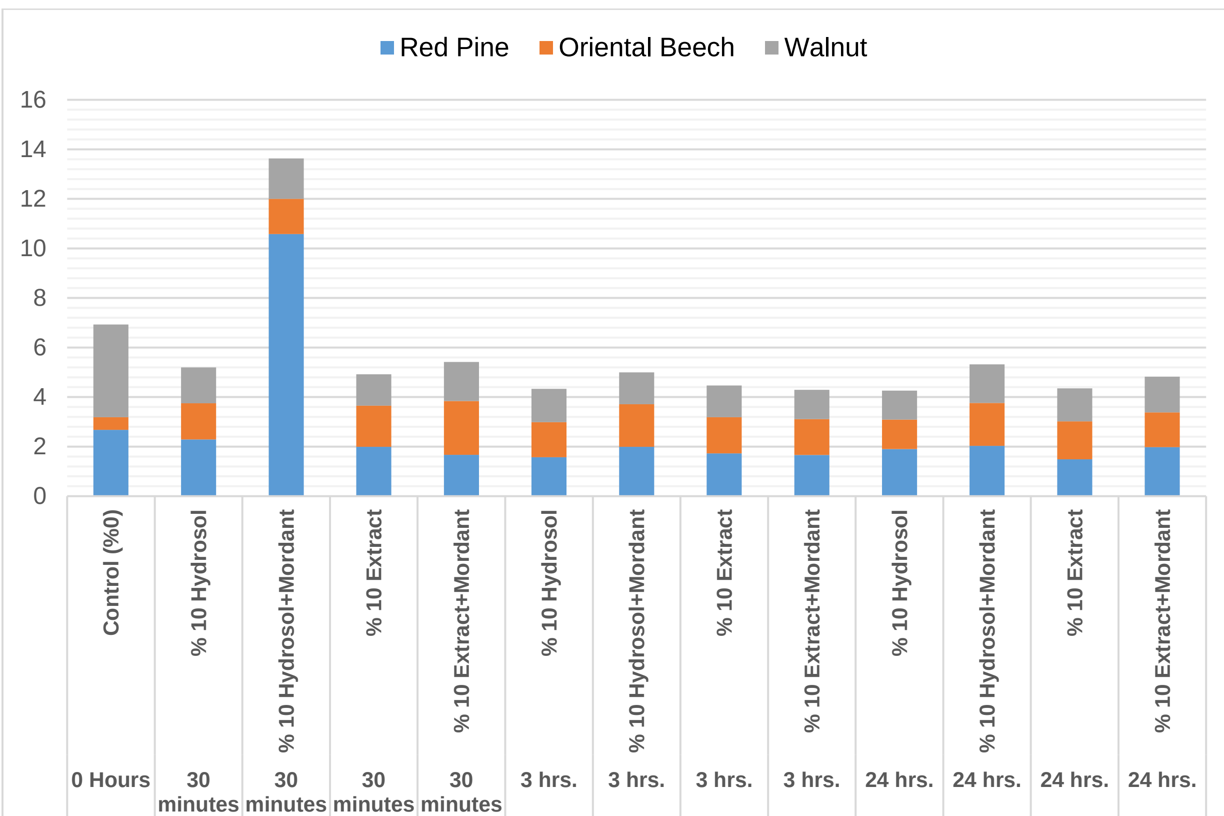

Fig. 3. Retention ratio (%)

Tables 9, 10, 11, and Fig. 3. reveal that there were significant differences regarding water uptake between wood species, the time/duration of impregnation time, and time/duration of soaking in water. However, no significant difference was observed in terms of the impregnation time materials used. It was further argued that the interactions of wood type, time, and the concentrations used had a significant impact on the WU values. In terms of wood type, the highest WU was observed in red pine, whilst the lowest value was observed in walnut. In terms of time/duration of impregnation, the highest WU was observed in 30 min, whilst the lowest was observed in 24 h. In terms of time/duration of soaking in water time, the highest WU was observed in 96 h, whilst the lowest was observed in 6 h. Atılgan and Peker (2012) impregnated the wooden material obtained from beech with cement + borax (9% concentration) and obtained the highest retention value (42.4 kg/m³), while they observed lowest value with Scots pine (1% ammonium tetrafluoro borate concentrate). Sarıca (2006) impregnated oriental beech wood with borax and determined the highest retention with sessile oak wood impregnated with maximum (29.6 kg/m³) boric acid. In a study examining the total retention amounts and retention (%) in wooden materials impregnated with tea plant extract, the highest retention was observed in beech (6.75%) and the lowest in iroko wood (1.58%), while the highest total retention value was observed with beech (100.6 kg/m^3) and the lowest in iroko (31.3 kg/ m^3). These results are parallel to the results of this study.

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

Wood Type	Impregnation Time	Impregnation Agent	Retention (%)		
			Mean	St. Sp.	Duncan (HG)
Red pine	30 min	10% Hydrosol	2.29	0.53	B
	30 min	10% Hydrosol + Mordant	1.58	1.57	A
	30 min	10% Extract	1.99	0.21	B
	30 min	10% Extract + Mordant	1.67	0.30	B
	3 h	10% Hydrosol	1.57	0.72	B
	3 h	10% Hydrosol + Mordant	1.99	0.36	B
	3 h	10% Extract	1.73	0.32	B
	3 h	10% Extract + Mordant	1.66	0.30	B
	24 h	10% Hydrosol	1.90	0.24	B
	24 h	10% Hydrosol + Mordant	2.03	0.45	B
	24 h	10% Extract	1.49	0.15	B
	24 h	10% Extract + Mordant	1.98	0.24	B
Oriental beech	30 min	10% Hydrosol	1.46	0.17	B
	30 min	10% Hydrosol + Mordant	1.42	0.24	B
	30 min	10% Extract	1.66	0.22	B
	30 min	10% Extract + Mordant	2.17	0.43	B
	3 h	10% Hydrosol	1.42	0.07	B
	3 h	10% Hydrosol + Mordant	1.72	0.13	B
	3 h	10%Extract	1.46	0.13	B
	3 h	10% Extract + Mordant	1.45	0.14	B
	24 h	10% Hydrosol	1.19	0.22	B
	24 h	10% Hydrosol + Mordant	1.73	0.01	B
	24 h	10% Extract	1.53	0.33	B
	24 h	10% Extract + Mordant	1.40	0.22	B
Walnut	30 min	10% Hydrosol	1.45	0.05	B
	30 min	10% Hydrosol + Mordant	1.63	0.20	B
	30 min	10% Extract	1.27	0.04	B

	30 min	10% Extract + Mordant	1.58	0.19	B
	3 h	10% Hydrosol	1.34	0.12	B
	3 h	10% Hydrosol + Mordant	1.29	0.03	B
	3 h	10% Extract	1.28	0.15	B
	3 h	10% Extract + Mordant	1.18	0.12	B
	24 h	10% Hydrosol	1.17	0.17	B
	24 h	10% Hydrosol + Mordant	1.56	0.19	B
	24 h	10% Extract	1.33	0.29	B
	24 h	10% Extract + Mordant	1.44	0.07	B

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

Table 11. Multiple Variance Analysis Results for Water Uptake Value

Factor	Degrees of Freedom	Sum of Squares	Mean Sq	F	p
Woods (A)	2	248006.378	124003.189	1825.040	**0.000***
Times (B)	2	9805.537	4902.769	72.157	**0.000***
Concentration (C)	3	365.224	121.741	1.792	0.148
Standby time (D)	4	69701.496	17425.374	256.461	**0.000***
A * B	4	6649.646	1662.412	24.467	**0.000***
A * C	6	2535.182	422.530	6.219	**0.000***
A * D	8	789.832	98.729	1.453	0.173
B * C	6	1445.928	240.988	3.547	**0.002***
B * D	8	625.524	78.191	1.151	0.328
C * D	12	529.252	44.104	0.649	0.800
A * B * C	12	10149.930	845.827	12.449	**0.000***
A * B * D	16	148.255	9.266	0.136	1.000
A * C * D	24	654.159	27.257	0.401	0.995
B * C * D	24	411.046	17.127	0.252	1.000
A * B * C * D	48	681.665	14.201	0.209	1.000
Error	390	26498.724	67.945		
Total	585	2836557.475			

*Significant at $p < 0.05$ level

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

	Procedure	$\bar{x}$	HG
Wood Type	Red pine	92.75	A
	Oriental beech	59.02	B
	Walnut	41.46	C
Time	0 h	61.26	C
	30 min	69. 02	A
	3 h	65.93	B
	24 h	58.84	D
Concentration	Control (0%)	61.26	A
	10% Hydrosol	64.36	A
	10% Hydrosol+ Mordant	64.16	A
	10% Extract	65.99	A
	10% Extract +Mordant	63.88	A
Standby Time	6 h	43.62	E
	24 h	60.80	D
	48 h	66.70	C
	72 h	72.99	B
	96 h	77.59	A

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

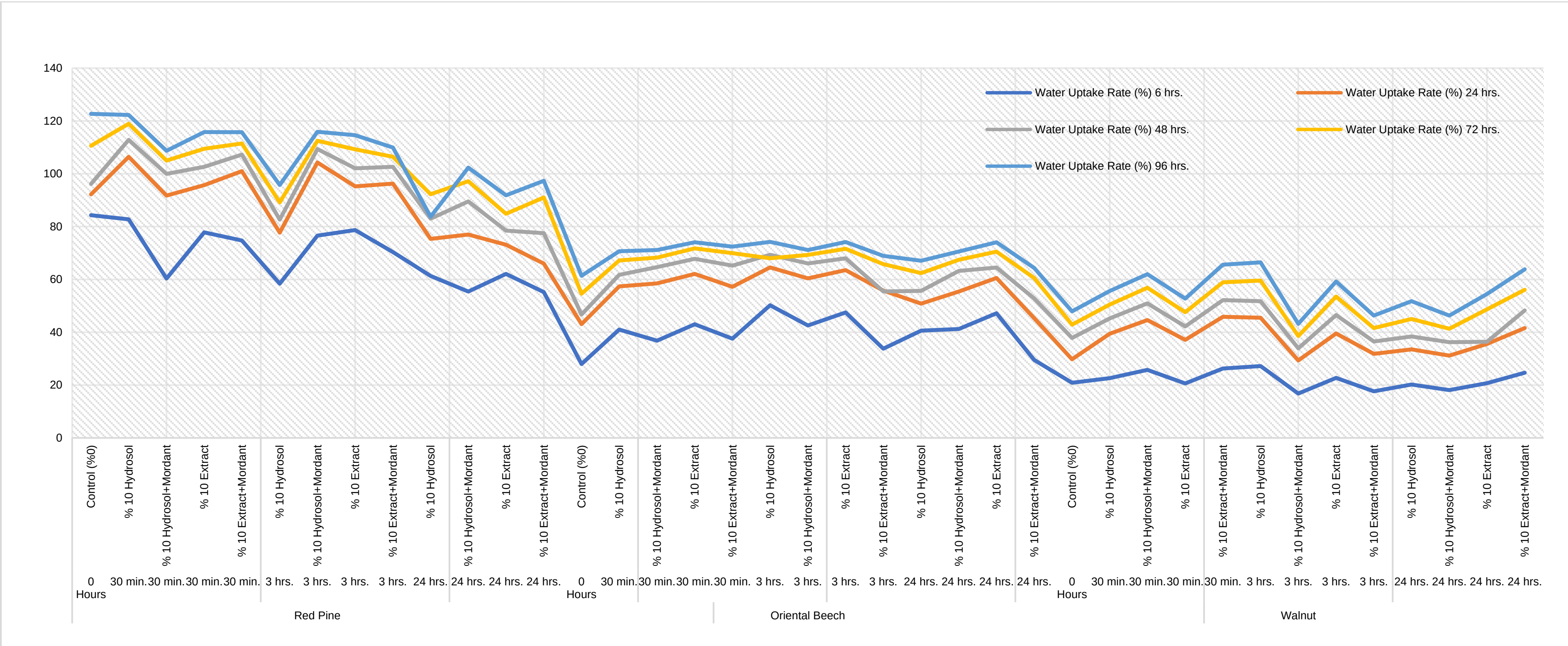

Fig. 3. Water uptake ratio (%)

Table 13 reveals that the highest WU was observed with the red pine wood control sample at 96 h ($\bar{x}$ = 10.58 gr.). The lowest water uptake was observed with the walnut wood impregnated with 10% hydrosol + mordant for 3 h ($\bar{x}$ = 16.79 gr.). In addition, the highest WU was generally observed with red pine whilst the lowest water uptake was observed with walnut wood.

Table 13. Values Regarding Water Uptake

Wood Type	Impregnation Time	Impregnation Agent Concentrations Obtained from Yarrow	Water Uptake (%)				
			6 h	24 h	48 h	72 h	96 h
Red pine	0 min	Control (%0)	**84.31**	92.20	96.14	110.62	122.68
	30 min	% 10 Hydrosol	82.75	106.42	112.83	118.93	122.25
	30 min	% 10 Hydrosol+ Mordant	60.34	91.73	99.95	104.99	108.70
	30 min	% 10 Extract	77.82	95.69	102.61	109.48	115.77
	30 min	% 10 Extract + Mordant	74.72	101.01	107.26	111.46	115.76
	3 h	% 10 Hydrosol	58.40	77.71	82.66	89.17	95.76
	3 h	% 10 Hydrosol + Mordant	76.60	104.27	109.39	112.51	115.89
	3 h	% 10 Extract	**78.69**	95.22	102.07	109.28	114.60
	3 h	% 10 Extract + Mordant	70.34	96.25	102.64	106.43	109.91
	24 h	% 10 Hydrosol	61.33	75.35	82.98	92.27	83.70
	24 h	% 10 Hydrosol + Mordant	55.39	76.97	89.55	97.17	102.33
	24 h	% 10 Extract	62.11	73.13	78.47	84.87	91.86
	24 h	% 10 Extract + Mordant	55.22	65.97	77.50	91.01	97.34
Oriental beech	0 min	Control (%0)	27.95	43.05	46.74	54.61	61.38
	30 min	% 10 Hydrosol	41.04	57.35	61.73	67.16	70.65
	30 min	% 10 Hydrosol+ Mordant	36.80	58.50	64.65	68.25	71.13
	30 min	% 10 Extract	43.02	62.07	67.78	71.74	74.06
	30 min	% 10 Extract + Mordant	37.57	57.19	65.20	69.96	72.44
	3 h	% 10 Hydrosol	50.21	64.55	69.35	68.01	74.21
	3 h	% 10 Hydrosol + Mordant	42.58	60.40	66.03	69.28	71.14
	3 h	% 10 Extract	47.51	63.52	67.98	71.62	74.18
	3 h	% 10 Extract + Mordant	33.79	55.77	55.46	65.80	68.94
	24 h	% 10 Hydrosol	40.62	50.84	55.69	62.40	67.06
	24 h	% 10 Hydrosol + Mordant	41.20	55.39	63.20	67.45	70.56
	24 h	% 10 Extract	47.21	60.56	64.48	70.52	74.07
	24 h	% 10 Extract + Mordant	29.50	45.33	52.79	60.55	64.37
Walnut	0 min	Control (%0)	20.87	29.75	37.84	42.85	47.88
	30 min	% 10 Hydrosol	22.63	39.43	45.24	50.49	55.63
	30 min	% 10 Hydrosol+ Mordant	25.76	44.64	50.96	56.84	62.01
	30 min	% 10 Extract	20.61	37.10	42.22	47.62	52.73
	30 min	% 10 Extract + Mordant	26.26	45.83	52.17	58.89	65.60
	3 h	% 10 Hydrosol	27.17	45.48	51.74	59.57	66.44
	3 h	% 10 Hydrosol + Mordant	**16.79**	29.32	33.91	38.58	43.18
	3 h	% 10 Extract	22.75	39.55	46.51	53.50	59.23
	3 h	% 10 Extract + Mordant	17.65	31.80	36.48	41.60	46.33
	24 h	% 10 Hydrosol	20.23	33.50	38.39	45.01	51.77
	24 h	% 10 Hydrosol + Mordant	18.10	31.13	36.25	41.32	46.30

	24 h	% 10 Extract	20.74	35.57	36.38	48.65	54.48
	24 h	% 10 Extract + Mordant	24.66	41.58	48.29	56.10	63.83

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

Tables 14, 15, and 16 reveal that there were significant differences regarding swelling between tree species, the time/duration of impregnation, and time/duration of soaking in water. However, no significant difference was observed in terms of the impregnation materials used.

Table 14. Multiple Variance Analysis Results for Swelling

Factor	Degrees of Freedom	Sum of Squares	Mean Squares	F	p
Woods (A)	2	758.098	379.049	25.509	**0.000***
Time (B)	2	119.552	59.776	4.023	**0.019***
Concentration (C)	3	96.848	32.283	2.173	0.091
Standby Time (D)	4	875.896	218.974	14.736	**0.000***
A * B	4	105.280	26.320	1.771	0.134
A * C	6	265.015	44.169	2.972	**0.008***
A * D	8	462.121	57.765	3.887	**0.000***
B * C	6	149.269	24.878	1.674	0.126
B * D	8	92.009	11.501	0.774	0.626
C * D	12	187.422	15.619	1.051	0.401
A * B * C	12	181.510	15.126	1.018	0.431
A * B * D	16	167.350	10.459	0.704	0.791
A * C * D	24	300.251	12.510	0.842	0.682
B * C * D	24	346.985	14.458	0.973	0.501
A * B * C * D	48	690.666	14.389	0.968	0.536
Error	390	5795.159	14.859		
Total	585	152567.024			

*Significant at p< 0.05 level

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

	Procedure	$\bar{x}$	HG
Wood Type	Red pine	15.28	B
	Oriental beech	17.21	A
	Walnut	14.18	C
Time	0 h	15.09	AB
	30 min	15.97	A
	3 h	14.93	B
	24 h	15.88	A
Concentration	Control (0%)	15.09	A
	10% Hydrosol	15.63	A

	10% Hydrosol + Mordant	15.01	A
	10% Extract	16.21	A
	10% Extract + Mordant	15.53	A
Standby Time	6 h	13.33	C
	24 h	15.15	B
	48 h	15.54	B
	72 h	16.74	A
	96 h	17.01	A

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

In addition, it was concluded that the interaction between the wood type and the concentration used, and the wood type and the time/duration of soaking in water had a significant effect on the swelling. In terms of wood type, the highest swelling was observed in oriental beech, whilst the lowest was observed in walnut. In terms of time/duration of impregnation time the highest swelling was observed in 30 min and 24 h whilst the lowest was observed in 3 h. In terms of time/duration of soaking in water, the highest swelling was observed at 72 h and 96 h, whilst the lowest swelling was observed at 6 h.

Table 16 reveals that the highest swelling was observed in the oriental beech samples impregnated with 10% extract at the 72 h ($\bar{x}$ = 36.65 gr.). In addition, the highest swelling values were generally observed in oriental beech samples.

Tables 17, 18, and 19 reveal that there were significant differences regarding shrinkage between tree species, concentration, and time/duration of soaking in water. However, no significant difference was observed in terms of the time/duration of impregnation time. It was further argued that the interactions of wood type, time, and the concentrations used had a significant impact on the shrinkage. In terms of wood type, the highest shrinkage was observed in oriental beech. In terms of impregnation materials used, the highest shrinkage was observed with 10% Extract + Mordant while the lowest shrinkage was observed with 10% Extract. In terms of time/duration of soaking in water, the highest shrinkage was observed at 48 h, 72 h, and 96 h, while the lowest shrinkage was observed at 6 h.

Table 16. Values Regarding Swelling

Wood Type	Impregnation Time	Impregnation Agent Concentrations Obtained from Yarrow	Swelling (%)				
			6 h	24 h	48 h	72 h	96 h
Red pine	0 h	Control (0%)	15.34	15.47	14.70	15.45	15.79
	30 min	10% Hydrosol	15.70	15.05	15.10	15.23	17.84
	30 min	10% Hydrosol + Mordant	15.02	15.58	15.09	16.03	15.56
	30 min	10% Extract	16.27	15.69	14.97	15.81	16.77
	30 min	10% Extract + Mordant	15.30	15.47	14.10	14.40	15.43
	3 h	10% Hydrosol	14.98	14.81	14.92	15.16	14.98
	3 h	10% Hydrosol + Mordant	15.36	16.37	15.69	14.98	15.66
	3 h	10% Extract	14.90	15.29	14.71	14.45	14.75
	3 h	10% Extract + Mordant	14.51	15.73	14.83	15.26	15.80
	24 h	10% Hydrosol	14.95	14.90	14.18	14.01	15.05
	24 h	10% Hydrosol + Mordant	14.73	15.70	15.11	15.44	14.82
	24 h	10% Extract	15.24	16.19	6.68	15.58	26.27
	24 h	10% Extract + Mordant	14.86	14.91	14.69	14.66	14.92
Oriental beech	0 h	Control (0%)	12.85	16.78	16.79	17.49	17.23
	30 min	10% Hydrosol	17.14	8.18	20.04	19.56	20.15
	30 min	10% Hydrosol + Mordant	15.00	17.70	18.19	18.13	18.27
	30 min	10% Extract	16.60	19.32	19.29	19.37	20.58
	30 min	10% Extract + Mordant	14.39	17.79	17.85	17.93	18.31
	3 h	10% Hydrosol	16.57	17.42	18.03	17.89	17.86
	3 h	10% Hydrosol + Mordant	3.14	15.09	14.68	14.97	15.24
	3 h	10% Extract	16.24	14.68	17.81	18.37	18.49
	3 h	10% Extract + Mordant	13.73	14.83	17.07	17.46	17.87
	24 h	10% Hydrosol	16.11	16.46	16.82	16.71	16.90
	24 h	10% Hydrosol + Mordant	15.73	17.17	17.64	17.74	15.98
	24 h	10% Extract	17.99	18.40	18.17	**36.65**	18.68
	24 h	10% Extract + Mordant	13.63	17.81	18.64	19.82	19.16
Walnut	0 h	Control (0%)	9.68	12.97	14.02	15.33	16.44
	30 min	10% Hydrosol	9.57	13.97	15.12	16.30	16.81
	30 min	10% Hydrosol + Mordant	11.05	14.27	15.12	16.73	16.80
	30 min	10% Extract	9.36	13.21	14.95	15.57	16.74
	30 min	10% Extract + Mordant	13.06	15.01	16.14	16.90	17.47
	3 h	10% Hydrosol	11.37	15.32	16.22	16.78	18.50
	3 h	10% Hydrosol + Mordant	8.56	12.12	13.23	14.56	15.10
	3 h	10% Extract	9.76	12.88	14.48	15.23	15.86
	3 h	10% Extract + Mordant	8.91	12.02	13.76	14.53	16.12
	24 h	10% Hydrosol	11.19	13.54	13.99	15.47	16.32
	24 h	10% Hydrosol + Mordant	10.27	15.27	14.78	15.65	16.27
	24 h	10% Extract	9.96	10.98	14.79	15.41	15.90
	24 h	10% Extract + Mordant	11.04	16.65	13.58	16.00	16.72

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

Table 17. Multiple Variance Analysis Results of Shrinkage

Factor	Degrees of Freedom	Sum of Squares	Mean Squares	F	p
Woods (A)	3277.708	2	1638.854	38.690	**0.000***
Times (B)	166.547	2	83.274	1.966	0.141
Concentration (C)	451.420	3	150.473	3.552	**0.015***
Standby Time (D)	724.335	4	181.084	4.275	**0.002***
A * B	848.834	4	212.208	5.010	**0.001***
A * C	1400.175	6	233.363	5.509	**0.000***
A * D	406.938	8	50.867	1.201	0.297
B * C	1308.280	6	218.047	5.148	**0.000***
B * D	132.146	8	16.518	0.390	0.926
C * D	222.179	12	18.515	0.437	0.948
A * B * C	1598.930	12	133.244	3.146	**0.000***
A * B * D	160.184	16	10.011	0.236	0.999
A * C * D	333.717	24	13.905	0.328	0.999
B * C * D	384.083	24	16.003	0.378	0.997
A * B * C * D	771.830	48	16.080	0.380	1.000
Error	16520.001	390	42.359		
Total	112645.592	585			

*Significant at $p < 0.05$ level

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

	Procedure	$\bar{x}$	HG
Wood Type	Red pine	12.68	B
	Oriental beech	14.68	A
	Walnut	8.34	C
Time	0 h	12.27	A
	30 min	12.39	A
	3 h	11.10	A
	24 h	12.12	A
Concentration	Control (0%)	12.27	AB
	10% Hydrosol	11.77	AB
	10% Hydrosol+ Mordant	11.72	AB
	10% Extract	10.71	B
	10% Extract + Mordant	13.27	A
Standby Time	6 h	9.88	B
	24 h	11.51	AB
	48 h	11.90	A
	72 h	12.95	A
	96 h	13.26	A

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

Table 19 reveals that the highest shrinkage was observed in the oriental beech samples impregnated with 10% extract at the 24 h ($\bar{x}$ = 25.43). In contrast, the lowest shrinkage was observed in the walnut samples impregnated with 10% extract at the 3 h ($\bar{x}$ = -10.87). Furthermore, the highest shrinkage was generally observed in oriental beech samples while the least shrinkage was observed in walnut samples.

Table 19. Duncan Test Results for Shrinkage Values

Wood Type	Impregnation Time	Impregnation Agent Concentrations Obtained from Yarrow	Shrinkage Obtained (%)				
			6 h	24 h	48 h	72 h	96 h
Red pine	0 h	Control (0%)	13.49	13.60	12.93	13.59	13.94
	30 min	10% Hydrosol	12.12	11.56	11.59	11.73	13.97
	30 min	10% Hydrosol + Mordant	12.64	13.19	12.74	13.56	13.12
	30 min	10% Extract	12.91	12.48	11.80	12.53	13.41
	30 min	10% Extract + Mordant	12.46	12.66	11.43	11.70	12.60
	3 h	10% Hydrosol	12.91	12.77	12.86	13.08	12.91
	3 h	10% Hydrosol + Mordant	12.90	13.79	13.17	12.56	13.15
	3 h	10% Extract	13.20	13.59	13.02	12.81	13.11
	3 h	10% Extract + Mordant	12.39	13.48	12.65	13.04	13.54
	24 h	10% Hydrosol	11.98	11.95	11.27	11.09	12.06
	24 h	10% Hydrosol + Mordant	12.31	13.15	12.63	12.92	12.30
	24 h	10% Extract	12.45	13.31	**0.51**	12.75	19.86
	24 h	10% Extract + Mordant	13.14	13.12	12.94	12.90	13.18
Oriental beech	0 h	Control (0%)	10.73	14.10	14.07	14.62	14.44
	30 min	10% Hydrosol	13.41	-1.43	15.90	15.47	15.96
	30 min	10% Hydrosol + Mordant	13.33	15.63	16.03	15.95	16.09
	30 min	10% Extract	14.85	17.08	17.06	17.13	18.18
	30 min	10% Extract + Mordant	12.19	15.06	15.05	15.14	15.43
	3 h	10% Hydrosol	13.73	14.45	14.97	14.86	14.82
	3 h	10% Hydrosol + Mordant	-4.53	13.06	12.68	12.98	13.20
	3 h	10% Extract	13.31	11.85	14.57	15.03	15.19
	3 h	10% Extract + Mordant	21.08	21.98	23.95	24.25	24.67
	24 h	10% Hydrosol	12.61	12.91	13.23	13.13	13.31
	24 h	10% Hydrosol + Mordant	12.35	13.56	13.99	14.07	12.53
	24 h	10% Extract	14.13	14.48	14.27	25.43	14.73
	24 h	10% Extract + Mordant	10.81	14.38	15.05	16.02	15.50
Walnut	0 h	Control (0%)	6.07	9.08	10.00	11.18	12.16
	30 min	10% Hydrosol	5.54	9.55	10.57	11.62	12.03
	30 min	10% Hydrosol + Mordant	7.56	10.45	11.19	12.61	12.67
	30 min	10% Extract	4.70	8.22	9.81	10.31	11.35
	30 min	10% Extract + Mordant	7.92	9.71	10.69	11.39	11.86
	3 h	10% Hydrosol	6.32	9.88	10.67	11.14	12.70
	3 h	10% Hydrosol + Mordant	4.46	7.76	8.76	9.97	10.44
	3 h	10% Extract	-10.87	-7.64	-6.19	-5.47	-4.90
	3 h	10% Extract + Mordant	4.58	7.47	9.04	9.73	11.14
	24 h	10% Hydrosol	7.08	9.23	9.64	10.94	11.69
	24 h	10% Hydrosol + Mordant	5.56	10.06	9.65	10.44	10.95
	24 h	10% Extract	6.41	7.30	10.81	11.33	11.77
	24 h	10% Extract + Mordant	7.02	12.07	9.31	11.44	12.11

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

Atılgan and Peker (2012) reported that they achieved the highest retention amount (42.4 kg/m³) with beech impregnated with cement + borax (9% concentration) and the lowest value with Scots pine impregnated with ammonium tetrafluoro borate (1% concentration). Sarıca (2006) reported to have reached the maximum retention (29.6 kg/m³) by impregnating oriental beech with borax. Özçifçi *et al.* (2009) observed the highest retention amount with Scots pine (19.4 kg/m³ - 21.81%) and the lowest retention amount with oak wood (8.742 kg/m³ - 9.15%). Experimental studies may provide variable results with different wood types and using different impregnation materials.

In another study conducted by Kılıç (2012), beech and spruce materials were impregnated with silicone, and it was determined 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, it was observed that this value varied between 0.43 to 0.56 g/cm³ in impregnated samples. Gür (2003) reported that density values increased by impregnating Scots pine and red pine wood with various substances. Var *et al.* (2017) impregnated red pine (*P. brutia* Ten.) wood with various geothermal waters and reported that there was no significant change in density and tangential swelling. Var and Kaplan (2019), in contrast, determined that the density increased 16.6% when impregnating red pine wood with various geothermal waters. Bak *et al.* (2023) impregnated beech and Scots pine wood with fluorinated silica nanoparticles and reported that this process provided significant positive effects on swelling, water uptake, and equilibrium moisture content. Three types of wooden materials (fir, beech, and spruce) used in park and garden construction were subjected to three types of impregnation processes (immersion, hot oil immersion, brushing) with waste oil. The highest weight increase (%) was determined with immersion technique while the lowest weight increase (%) was determined with the brushing technique. While the lowest water uptake was observed with the immersion technique, it was determined that waste oil improved the physical properties of wood (Özkan *et al.* 2020).

Air-Dry and Oven-Dry Specific Gravity: The air-dry specific gravity of the wood samples showed significant variation among species. Oriental beech exhibited the highest air-dry specific gravity (0.67 g/cm³), followed by walnut (0.66 g/cm³), and red pine (0.43 g/cm³). The oven-dry specific gravity followed a similar trend, with walnut showing the highest value (0.66 g/cm³), indicating its denser structure compared to the other species.

The observed differences in specific gravity align with the natural density variations among wood species. Oriental beech and walnut, being hardwoods, inherently have a denser structure compared to red pine, a softwood. The specific gravity measurements are crucial for understanding how impregnation treatments influence wood properties, as denser woods tend to retain impregnation materials differently, potentially affecting the treatment's efficiency.

Retention of Yarrow Extract and Hydrosol: The highest retention was observed in red pine treated with 10% hydrosol for 30 minutes (2.29%), while the lowest retention occurred in walnut treated for 24 hours with the same concentration (1.17%). Longer immersion times generally resulted in lower retention, indicating that prolonged exposure may dilute the impregnating effect.

Retention values indicate the ability of wood to absorb and hold the impregnation material. The higher retention in red pine suggests its porous structure facilitates deeper penetration of the yarrow extract and hydrosol. In contrast, walnut's denser structure and tighter cell arrangement may limit penetration. These findings are important for optimizing impregnation conditions based on wood type and treatment objectives.

Dimensional Stability and Water Uptake: Dimensional stability tests showed that yarrow-based treatments improved resistance to swelling and shrinkage in all wood species, particularly in red pine, due to its higher retention capacity. Water uptake tests revealed that untreated control samples absorbed significantly more water compared to impregnated samples. The lowest water uptake was observed in walnut impregnated with 10% hydrosol + mordant for 3 hours.

The water-repellent properties of yarrow hydrosol contribute to enhanced dimensional stability and reduced water absorption. This effect is critical for applications where wood is exposed to fluctuating moisture conditions, as it minimizes the risk of structural deformation and decay.

Resistance to Environmental Degradation: Impregnated samples showed reduced susceptibility to fungal decay and environmental wear compared to untreated controls. Yarrow extract and hydrosol treatments maintained the wood's color and surface properties, even under prolonged environmental exposure. The antimicrobial and decay-resistant properties of yarrow's bioactive compounds, such as quercetin and salicylic acid, play a significant role in preserving the wood's structural and aesthetic qualities. These findings highlight the potential of yarrow as a sustainable alternative to traditional chemical preservatives.

RECOMMENDATIONS

The extracts obtained from plants will further contribute to improving human comfort and protecting future generations, as they are protective against microorganisms. Considering in general the economic aspect of the issue and its effects on human and environmental health in the long term, it is possible to argue that the cost of natural preservative dyes is lower compared to synthetic-based and toxic chemical dyes and thereby will provide widespread economic benefits.

Economically recycling the yarrow plant, which has a significantly high production potential and opening a new purpose of use in the woodworking industry using it as a surface preservative for wood materials, will yield substantial results. The reactions of wooden materials treated with natural preservatives against burning are among the authors' suggestions as they can be the subject of further research as a guide to other studies.

The observed differences in specific gravity align with the natural density variations among wood species. Oriental beech and walnut, being hardwoods, inherently have a denser structure compared to red pine, a softwood. The specific gravity measurements are crucial for understanding how impregnation treatments influence wood properties, as denser woods tend to retain impregnation materials differently, potentially affecting the treatment's efficiency.

CONCLUSIONS

1. The use of herbal extracts as wood preservatives is of economic importance for the producers of these substances. Natural dyeing began to decline when synthetic dyes arrived in 1882 and it reached consumers easily. As the trade of natural dyes/paints has almost ground to a standstill, one of Turkey's most important sources of economic income is about to disappear. There are approximately more than 150 plants used in paint production in the country. Chemicals have an accelerating effect on combustion due to the high flammability, and this effect can be reduced by using natural preservatives. If natural preservatives are developed as an alternative to synthetic dyes, the agricultural fields where dye plants are grown may become widespread and a new

raw material source may emerge. Outdoor furniture and interior decoration products applied with plant-based natural preservatives may also constitute an important source of economic income for the domestic and foreign markets.

2. This study aimed to examine the effects of the extract and hydrosol obtained from the yarrow plant as a wood preservative (impregnation) on different wood types. While the highest retention (2.3%) was observed on red pine after 30 min of impregnation with 10% hydrosol concentration, the lowest retention (1.2%) was observed on walnut in 24 h after being impregnated at the same concentration. While the highest air-dry specific gravity (0.71 g/cm³) was obtained when walnut was treated with 10% hydrosol + mordant for 3 h, the lowest value (0.41 g/cm³) was observed when red pine was treated with 10% hydrosol for 30 min. While the highest water uptake capacity was detected in the red pine control sample (84.3%), the lowest water uptake (16.8%) was observed with the walnut material impregnated with 10% hydrosol + mordant for 3 h.
3. When comparing all retention studies on wood preservatives, somewhat parallel results have been obtained; however, some studies may show different results. This study may yield more meaningful results when tested with different tree species and extract concentrations. In this sense, it can serve as a reference for further studies.
4. This study investigated the potential of yarrow (*Achillea millefolium*) extract and hydrosol as environmentally friendly wood preservatives, focusing on their effects on the physical properties and dimensional stability of red pine (*Pinus brutia*), oriental beech (*Fagus orientalis* l.), and walnut (*Juglans regia* l.). The findings demonstrated that yarrow hydrosol and extract, particularly when combined with a mordant, enhanced the water-repellent properties of the treated wood, contributing to improved dimensional stability. Specifically, the highest retention was observed in red pine samples treated with 10% hydrosol for 30 minutes, while walnut exhibited the lowest retention due to its denser structure.
5. Despite variability in retention and swelling values across wood types, the yarrow-based treatments effectively reduced water uptake and swelling in all tested samples. These results highlight the suitability of yarrow hydrosol as a sustainable alternative to chemical preservatives, particularly for applications requiring eco-friendly solutions that minimize environmental impact.
6. The study's results align with its primary aim of developing a human- and environment-friendly impregnation material that offers comparable or superior performance to traditional chemical preservatives. Future research should explore the long-term performance of yarrow-based treatments under diverse environmental conditions, as well as their compatibility with other wood protection methods, to further validate their practical applicability in industrial settings.

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