Effect of Sweetgum (*Liquidambar orientalis*) Leaf Extract on Technological Properties of Pine (*Pinus brutia*)

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The main objective of this research was to determine the retention properties of extracts obtained from the leaves of *Liquidambar orientalis* Mill., (belonging to the class of medicinal aromatic plants) to organic (ecological) wood structures, thereby creating an ecological wood preservative that could be preferred in a wide variety of applications. Wood samples were taken from red pine trees in the Köyceğiz Agla region. Then, 1%, 3%, and 5% solutions of the extract were prepared. Vacuum method was used as the impregnation method. After impregnation and conditioning, the experimental and control samples were tested for mechanical properties such as bending strength, modulus of elasticity, compressive strength, and dynamic bending strength, while physical properties such as air-dry and specific gravity tests were conducted. The highest retention value was found at a 5% concentration (1.13%), the highest air-dry specific gravity value at a 1% concentration (0.56 g/cm³), and the highest air-dry specific gravity at a 1% concentration (0.53 g/cm³). Among the mechanical properties, the highest bending strength value was determined at a 5% concentration (1.13%), the highest modulus of elasticity at 1% (9145 N/mm²), and the dynamic bending strength at a 3% concentration (0.27 kgm/cm²).

DOI: 10.15376/biores.21.2.3272-3283

Keywords: Wood preservation; Ecological material; Impregnation; Extract; Technological properties; Wood industry

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INTRODUCTION

Wood, one of the primary building materials in traditional architecture, stands out as an option for sustainable architecture in the face of global environmental challenges. Wood has renewable resources, high carbon storage capacity, low embodied energy, is non-polluting, recyclable, and poses no threat to human or environmental health (Perker and Öztürk 2024). Despite its superior properties, wood is known to deteriorate due to various factors. Extending its lifespan is possible through impregnation, a common preventative protection practice. This is important as a means to ensuring resource efficiency and sustainability.

Biomaterials derived from renewable resources play a critical role in improving human life by offering an environmentally friendly and sustainable solution for future technologies (Ramage *et al.* 2017). Traditionally used building materials, such as metals, concrete, and plastics, create energy-intensive and non-recyclable waste, causing environmental problems (Omer and Noguchi 2020). Over the last decade, the use of wood in single- and multi-story structures has increased, spurring interest in bio-based products and providing a promising alternative for future technologies (Hepburn *et al.* 2019; Amiri *et al.* 2020).

Some materials used in the construction and furniture industries can contain hazardous substances, such as asbestos, formaldehyde, and lead, which can harm human health. Therefore, the demand for environmentally friendly, renewable, and green building materials has increased, and the use of biomaterials has become critical to achieving sustainable development goals (Toppinen *et al.* 2018; Wen *et al.* 2020). Extending the service life of wood is important for environmental sustainability, considering the principle of efficient resource use. However, simply extending the service life of wood is not sufficient for environmentally friendly architecture. While the use of chemicals provides wood with a long service life, research into the discovery of new environmentally friendly alternatives to these substances is important for environmental sustainability (Teaca *et al.* 2019; Hülagü 2021).

Various experimental studies have described the impregnation of wood with natural materials. Experimental research is being conducted on the impregnation effectiveness of plant materials, such as tree bark and fruits, leaves of trees, and other plants, tannins, plant-based oils, *etc.* It has been reported that the plant extracts adhered to the wood and would act as a natural preservative (Baysal 2003; Ulusoy *et al.* 2020). Wood is a preferred component in buildings due to its high physical and mechanical properties, ease of processing, cost-effectiveness, and low thermal conductivity. However, wood materials must be protected against biotic and abiotic damage. Furthermore, they are actively used as impregnations for floor materials, especially in countries with a high termite risk (Kartal and Imamura 2004).

The increasing prevalence of environmental pollution and diseases in recent years demonstrates the importance of environmental and human health. People are increasingly drawn to natural products. Therefore, products used in homes, such as furniture, the paper industry, park/garden furniture, the wooden toy industry, and others, are of great importance for a healthy life. Children grow up surrounded by toys from the first months of their lives, and it has been reported that impregnation of wooden toys and the use of herbal extracts creates a high level of hygiene (Kızılca 2025).

The long-term use of chemical, synthetic, and VOC-based wood preservatives (paints, varnishes, lacquers, and various cleaning and degreasing products) on wood materials poses a serious threat to human and environmental health. Therefore, there is an ongoing goal to produce natural wood preservatives from plant-based (medicinal aromatics, *etc*.) and animal-based (seashells, mussel waste, lichens, algae, *etc.*) waste and residues. This study aimed to determine the adhesion level and some technological properties of wood preservatives by obtaining an extract from sweetgum tree leaves using distilled water. The wood was impregnated with solutions obtained at various concentrations (1, 3, 5%). The goal was to partially determine the scale of wood preservative use as a natural and healthy material in all spaces where wood is used.

EXPERIMENTAL

Materials

Wood and plant

In this study, wood from the Turkish coniferous tree, the red pine (*Pinus brutia* Ten.), was used. This species is widely used in the woodworking industry and native to

Turkey. The impregnation extract used was from the leaves of the sweetgum (*Liquidambar orientalis* Mill.). This is an endemic species found in the Köyceğiz region of Turkey that is known to have antibacterial/antioxidant properties.

Sample preparation

The samples (12%) were air-dried, then placed in a drying oven for 24 h at a temperature of 103+2 °C until completely dry, and subsequently impregnation treatments were performed. The TS 2472 (1976) standard was used for determining specific gravity. The TS 2477 (1976) standard was used for dynamic bending strength (shock), and the TS 2478 (1976) standard was used for determining modulus of elasticity in bending. Bending strength, modulus of elasticity, and compressive strength tests were performed on wooden specimens using a universal testing machine. Loading was done at a constant and controlled rate on the surface. The loading rate was set so that fracture would occur within 1.5 ± 0.5 min from the start of the experiment.

Methods

Impregnation

Impregnation was performed using a 30-min vacuum and 30-min diffusion process (Fig 1). Impregnation was carried out in a laboratory environment using the appropriate conditions, in accordance with the ASTM D1413-76 (1976) standard. Accordingly, completely dry test samples were impregnated in a natural preservative derived from plant extracts for short, medium, and long periods. For each test, all test group samples, except the control group samples, were individually impregnated with a solution prepared from frankincense plant extract using a 30-min vacuum and 30-min diffusion process. Afterwards, these samples were brought to air-dry moisture at 20 ± 20 °C temperature and 65 ± 3% relative humidity and then dried at 103 ± 2 °C until they reached full dry weight. After drying, they were cooled to room temperature (TS 2471 1976) and their wet weight, air-dry weight, and full dry weight and dimensions were measured with 0.01 precision after impregnation, except for the control group.

Fig. 1. Impregnation machine

Plant extract preparation

Liquidambar tree leaves (Muğla/Turkey) were collected in August (from 8 to 10 trees). All leaves were cleaned and dried in a shaded/airy environment in the laboratory for 6-7 days. After grinding into large pieces using a Willey mill, 10 grams of plant particles were mixed in 10 mL of distilled water for 24 h using a magnetic shaker. The mixture was then filtered using ordinary filter paper, and solutions were prepared in specific volumes (1, 3, and 5 grams respectively, at concentrations of 1%, 3%, and 5%) (Ceylan 2020).

Fig. 2. Plant extract preparation

Determination of retention (%) and Physical Properties

The amount of material remaining in impregnated wood samples compared to completely dry wood (tkoao-% retention) was calculated using the Eq. 1 (Baysal 1994),

$$\text{Retention (\%)} = \frac{M_{oes} - M_{oeo} \times C}{100} \quad (1)$$

where M_{oes} is the total dry weight of the test piece after impregnation (g), M_{oeo} is the total dry weight of the test piece before impregnation (g), and C is the concentration.

Air-dry specific gravity test samples were allowed to reach dimensional equilibrium at a temperature of 20 ± 2 °C and 65 ± 5% relative humidity until no change in weight or size was observed. Samples dried under these conditions were weighed using an analytical balance with ±0.01 g accuracy, and their dimensions were measured using a caliper with ±0.01 mm accuracy to determine their volumes, after which calculations were performed. Samples with completely dry specific gravity were placed in an oven, and the temperature was gradually increased to 103 ± 2 °C. They were kept at this temperature until no change in mass was observed, ensuring complete drying. After drying, the samples were removed from the oven, cooled, weighed (M_o) using an analytical balance with ±0.01 g accuracy, and their dimensions were measured using a digital caliper with ±0.01 mm accuracy to determine their volumes, after which the completely dry specific gravity value was calculated (TS 2471, TS 2472).

Data analysis

The SPSS statistical program (a product long distributed by SPSS Inc., which was acquired by IBM in 2009, version 26, Chicago, IL, USA) was used to analyze the data. The effects of wood type and the percentage change in plant extract concentration were analyzed to create homogeneity groups and apply simple analysis of variance. Analyses were performed at a significance level of 0.05.

RESULTS AND DISCUSSION

Solution Properties

The concentration properties (1%, 3%, and 5% solution) of the sweetgum plant used in the impregnation process are shown in Table 1.

Table 1. Solution Properties (%)

Plant Extract	Solvent Material	Temperature (ºC)	pH		Density (g/mL)	
			Bİ	Aİ	Bİ	Aİ
Sweetgum plant 1%	Water	22	4.6	4.6	0.875	0.875
Sweetgum plant 3%			4.7	4.7	0.877	0.877
Sweetgum plant 5%			4.8	4.8	0.878	0.878

Bİ: Before impregnation **Aİ:** After impregnation

When the solution properties were examined, no significant changes were observed in the pH and density values before and after impregnation.

Retention Value

The Retention values are shown in Table 2.

Table 2. Retention Values

Wood	Sweetgum Plant Extract (%)	Vacuum Time (min)	Diffusıon Time (min)	Retention (%)	HG
Red Pinus	1%	30	30	0,49	A
	3%	30	30	0,31	B
	5%	30	30	1,13	C

HG: Homogeneity groups

The highest retention was found for the 5% extract with 30 min of vacuum and 30 min of diffusion (1.13%), whereas the lowest was found for the 3% extract with 30 min of vacuum and 30 min of diffusion (0.31%). The Duncan test analysis showed that the three experimental conditions gave statistically different results.

Studies using asphodel and tea plant extracts showed high retention values in wood (beech, Oriental beech) (Ulusoy *et al.* 2020b). Similarly, a study using materials consisting of pomegranate and walnut peels and quince leaves showed that these substances have a positive effect on the retention value of wood (black poplar) (Var and Özkan 2018).

Alkan (2025) impregnated mahogany and larch woods with mussel shell solution and the highest retention in mahogany wood was determined as 10.9% at 6% concentration and 24 h of immersion time. The highest retention in larch wood was determined as 12.6% at 6% concentration and 24 h of immersion time. Bozkurt (2025) impregnated Scots pine and chestnut wood with moss + boric acid and determined the highest retention in Scots pine wood in the 24-h period (17.4%), and the highest retention in chestnut wood in the 24-h application (10.3%). Atılgan *et al.* (2013) reported that the retention percentage in various wood types impregnated with tea plant extract was highest in beech wood (6.75%) and lowest in iroko wood (1.58%); the highest total retention value was in beech wood (100.6 kg/m^3) and the lowest in iroko (31.3 kg/m^3).

Determination of Physical Properties (Air/Full Dry Density)

The simple variance analysis and Duncan's test results for air-dry and fully dry density values are shown in Table 3 and the related graph in Fig. 3.

Table 3. Air/Full Dry Density (g/cm^3)

Wood	Sweetgum Plant Extract (%)	Vacuum Time (min)	Diffusion Time (min)	Air Dry Density (g/cm^3)		Full Dry Density (g/cm^3)	
				Mean.	HG	Mean	HG
		Control		0.54	B	0.53	C
Red Pine	1%	30	30	0.56	A	0.53	C
	3%	30	30	0.52	D	0.49	E
	5%	30	30	0.53	C	0.52	D

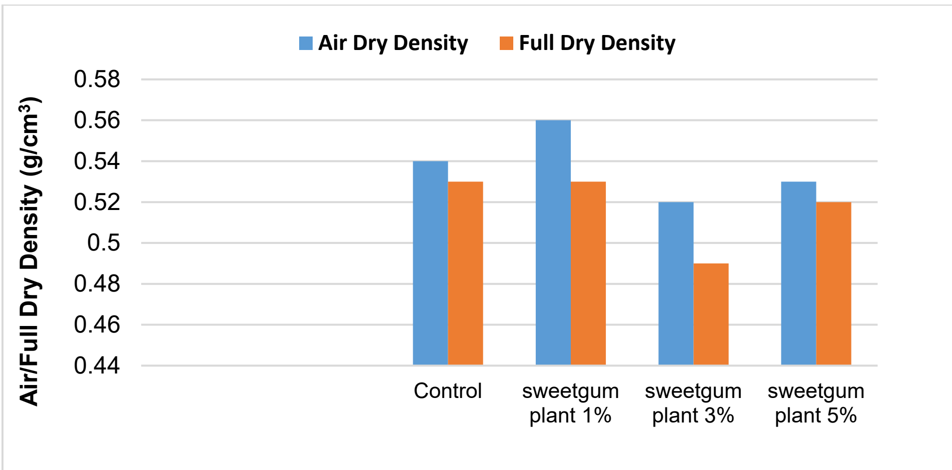

Fig. 3. Change of density (air/full dry)

The results (Fig 3, Table 3) were found to be of low significance when an error level of 0.05 was taken into account. Air-dry specific gravity was highest in 1% extract (0.56 g/cm^3) at 30 min of vacuum and 30 min of diffusion, lowest in 3% extract (0.52 g/cm^3) at 30 min of vacuum and 30 min of diffusion; full dry specific gravity was highest in 1% extract (0.53 g/cm^3) and lowest in 3% extract (0.49 g/cm^3) at 30 min of vacuum and 30 min of diffusion.

Esen (2009) investigated the full-dry and air-dry density values of beech, pine, and sapele woods treated with different impregnation agents (boric acid, borax, tanalith-E, and imersol aqua); the air-dry density of beech wood was measured as 0.72 g/cm^3, while the full-dry density was measured as 0.66 g/cm^3 at the highest level. Var and Kaplan (2019) reported in their study that the average density value for all three wells in red pine wood treated with geothermal waters ranged between 0.619 and 0.628 g/cm^3 in the treatment with normal room temperature, while it ranged between 0.62 and 0.64 g/cm^3 in the treatment at the well outlet temperature, and the density value of the control samples was obtained as 0.55 g/cm^3. Ölmez (2020) reported in his study that tree species and impregnation materials used showed different effects in terms of air-dry density values, and that in applications with plant extracts, the air-dry density of chestnut wood generally varied between 0.49 to 0.51 g/cm^3, while these values varied between 0.42 to 0.48 g/cm^3 in Scots pine wood. Yaşar *et al.* (2017) compared the effectiveness of plant-derived impregnation materials, such as acorn tannin and pine tannin, with chemical impregnation materials. It was determined that the air-dry density and fully dry density values of the wood material (cedar) after impregnation with plant-derived impregnation materials were very close to the values given by commonly used impregnation materials.

Mechanical Tests

Duncan test results regarding bending strength values are given in Table 4.

Table 4. Bending Strength Values (N/mm^2)

Wood	Sweetgum Plant Extract (%)	Vacuum Time (min)	Diffusıon Time (min)	Bending Strength	HG
Red Pine	Control	-	-	90.40	C
	1%	30	30	103.28	B
	3%	30	30	100.49	A
	5%	30	30	83.42	D

HG: Homogeneity groups

The highest bending strength was determined for the 1% extract at 30 min of vacuum and 30 min of diffusion (103.28 N/mm^2), while the lowest was determined for the 5% extract at 30 min of vacuum and 30 min of diffusion (83.42 N/mm^2). As the solution concentration was increased, the flexural strength increased, but it decreases for the 5% plant extract. This was observed positively when compared with the control samples.

Yaşar *et al.* (2017) determined that the bending strength and modulus of elasticity values of cedar wood test samples impregnated with natural impregnation materials were lower than the chemically impregnated wood samples, and that the highest bending strength was 88.71 N/mm^2 in the control sample, 80.61 N/mm^2 in pine tannin, one of the natural impregnation materials, and 94.7 N/mm^2 in imersol aqua, one of the chemical impregnation materials. A study by Efe and Çağatay (2011) on the determination of the bending strength of solid wood materials found that the highest bending strength of Scots pine wood was 104 N/mm^2 and the lowest was 75 N/mm^2. When the bending strength values of wood materials were examined by Ulusoy *et al.* (2020a), they determined that larex wood impregnated with 1% stone water solution gave the highest bending strength value (135.39 N/mm^2).

The modulus of elasticity values and their related Duncan test results are shown in Table 5.

Table 5. Modulus of Elasticity Values (N/mm^2)

Wood	Sweetgum Plant Extract	Vacuum Time (min)	Diffusıon Time (min)	Modulus of Elasticity	HG
Red Pine	Control	-	-	7375	D
	1%	30	30	9145	A
	3%	30	30	9096	B
	5%	30	30	7849	C

HG: Homogeneity groups

As shown in the Table 5, the highest elastic modulus was determined in 1% sweetgum plant extract (9145 N/mm^2) and the lowest value was determined in 5% extract (7849 N/mm^2). As the solution concentration increased, the elastic modulus increased, but it decreased in the case of the 5% plant extract. The highest elastic modulus value was determined in the impregnated groups compared to the control sample. It can be stated that this situation may be due to the anatomical structure of the wood, the impregnation method and the solution concentration.

Dynamic Bending Strength

Duncan test results regarding dynamic bending strength values are given in Table 6.

Table 6. Dynamic Bending Strength Values (Kgm/cm^2)

Wood	Sweetgum Plant Extract (%)	Vacuum Time (min)	Diffusıon Time (min)	Dynamic Bending Strength (kgm/cm^2)	HG
Red Pine	Control	-	-	0.18	D
	1%	30	30	0.22	B
	3%	30	30	0.27	A
	5%	30	30	0.20	C

HG: Homogeneity groups

As shown in Table 6, the highest dynamic bending strength was determined in the 3% sweetgum plant extract (0.27 kgm/cm^2), while the lowest dynamic bending strength (shock) was determined in the 5% extract (0.20 kgm/cm^2). This may be due to wood anatomy, wood type, and impregnation method.

Bektaş *et al.* (2008) reported that the dynamic bending strength of eucalyptus (*E. grandis*) wood was 0.544 kgm/cm^2, its full dry density value was 0.482 gr/cm^3, and that it was in the "good quality" class wood group in terms of dynamic quality value. Yıldırım (2020) reported that the change in dynamic bending strength was positive compared to the control sample. The highest shock resistance was observed in spruce wood (0.63 N/mm^2), and the lowest in 1% spruce + borax (0.24 N/mm^2). Aydın (2015) investigated the changes in some physical-mechanical properties of wenge (*Millettia laurentii*) wood after impregnation with three different solution concentrations (1%, 3%, 5%) prepared from barite and boron compounds. According to the findings obtained from the experiment, the highest dynamic bending strength was determined as 5% Bx (1.26 kpm/cm^2).

CONCLUSIONS

1. No change was detected in solution properties, pH, and density. In terms of retention, the highest retention (1.13%) was found for the 5% extract in 30 min of vacuum and 30 min of diffusion, and the lowest (0.31%) was found for the 3% extract in 30 min of vacuum and 30 min of diffusion. The Duncan test analysis found a high level of significance. Impregnation was performed, and its usability in wood was determined. The results were found to be of low-significance, considering the 0.05 error level. Air-dry specific gravity was determined to be the highest in 1% extract (0.56 g/cm^3) at 30 min of vacuum and 30 min of diffusion, the lowest in 3% extract (0.52 g/cm^3)

at 30 min of vacuum and 30 min of diffusion, and fully dry specific gravity was determined to be the highest in 1% extract (0.53 g/cm^3), and the lowest in 3% extract (0.49 g/cm^3) at 30 min of vacuum and 30 min of diffusion. When compared with the control samples, the average values for both air and fully dry specific gravity changes were slightly lower.

2. The highest bending strength was determined for the 3% extract at 30 min of vacuum and 30 min of diffusion (103.28 N/mm^2), while the lowest was determined for the 5% extract at 30 min of vacuum and 30 min of diffusion (83.42 N/mm^2). As the solution concentration increased, flexural strength increased, but decreased for the 5% plant extract. This was observed positively when compared with the control samples. It can be said that wood type, anatomical structure, impregnation material, and impregnation type all have an impact on flexural strength.
3. In the future, plant extracts can be tested using methods other than immersion, such as brushing, roller application, pressure application, vacuum application, and both vacuum and pressure applications. This may result in variations in the amount of substance retained.

REFERENCES CITED

Alkan, E. (2025). *Ekolojik Restorasyonda Yeni Emprenye Maddeleri ve Kullanım Ölçeği [New Impregnants and Their Use Scale in Ecological Restoration]*, Master's Thesis, Artvin Çoruh Üniversitesi, Artvin, Turkey.

Alpay Ölmez, S. (2020). *Çeşitli Tıbbi Aromatik Bitki Ekstraktlarının Ahşap Endüstrisinde Değerlendirilme Olanakları [Evaluation Possibilities of Various Medicinal and Aromatic Plant Extracts in the Wood Industry]*, Master's Thesis, Artvin Çoruh Üniversitesi, Artvin, Turkey.

Amiri, A., Ottelin, J., Sorvari, J., and Junnila, S. (2020). "Cities as carbon sinks—Classification of wooden buildings," *Environmental Research Letters* 15(9), article 094076. https://doi.org/10.1088/1748-9326/aba134

ASTM D1413-76 (1976). "Standard test methods of testing wood preservatives by laboratory soil-block cultures," ASTM International, West Conshohocken, PA, USA.

Atılgan, A., Ersen, N., and Peker, H. (2013). "Çay bitki ekstraktı ile muamele edilen odun türlerinde retensiyon değerleri [Retention values in wood species treated with tea plant extract]," *Kastamonu University Journal of Forestry Faculty* 13(2), 278-286.

Aydın, Ö. (2015). *Çeşitli Emprenye Maddelerinin Wenge Odununun Bazı Teknolojik Özelliklerine Etkileri*, *[Effects of Various Impregnation Agents on Some Technological Properties of Wenge Wood]*, Master's Thesis, Artvin Çoruh Üniversitesi, Artvin, Turkey.

Baysal, E. (1994). *Çeşitli Borlu Ve WR Bileşiklerin Kızılçam Odununun Bazı Fiziksel Özelliklerine Etkisi [Effects of Various Boron and WR Compounds on Some Physical Properties of Red Pine Wood]*, Master's Thesis, Karadeniz Teknik Üniversitesi, Trabzon, Turkey.

Baysal, E. (2003). "Borlu bileşikler ve doğal sepi maddeleriyle emprenye edilen sarıçam odununun yanma özellikleri [Burning properties of Scots pine wood impregnated with boron compounds and natural tanning agents],” *Erciyes Üniversitesi Fen Bilimleri Enstitüsü Fen Bilimleri Dergisi* 19(1), 59–69.

Bektaş, İ., Alma, M. H., Bal, B. C., and Ayata, Ü. (2008). “Okaliptüs (*E. grandis*) odununun dinamik eğilme direncinin belirlenmesi ve bazı ağaç türleriyle karşılaştırılması [Determination of dynamic bending strength of eucalyptus (E. grandis) wood and comparison with some tree species],” in: *1. Ulusal Okaliptüs Sempozyumu [National Eucalyptus Symposium]*, Tarsus, Turkey, pp. 274–280.

Bozkurt, G. (2025). *Ekolojik Sistemde Bazı Kara Yosunu (Rhytidiadelphus triquetrus (Hedw.) Warnst.) Ekstraktlarının Bor Türevleriyle Ahşap Malzemede Kullanım Düzeyi [Usage Level of Some Moss (Rhytidiadelphus triquetrus (Hedw.) Warnst.) Extracts with Boron Derivatives in Wood Materials in Ecological Systems]*, Master’s Thesis, Artvin Çoruh Üniversitesi, Artvin, Turkey.

Ceylan, Ş. (2020). *Işgın Bitki (Antioksidan/Antibakteriyel) Özütünün Ahşap Endüstrisinde (Mobilya/Inşaat) Kullanılabilme Olanakları [Usage Possibilities of Rhubarb Plant (Antioxidant/Antibacterial) Extract in the Wood Industry (Furniture/Construction)]*, Bilimsel Araştırma Projesi, Artvin Çoruh Üniversitesi, Proje No: 2017.M82.02.02, Artvin, Turkey.

Efe, H., and Çağatay, K. (2011). “Çeşitli masif ağaç malzemelerin bazı fiziksel ve mekanik özelliklerinin belirlenmesi [Determination of some physical and mechanical properties of various solid wood materials],” *Politeknik Dergisi* 14, 55-61.

Esen, R. (2009). *Determination of the Effects of Surface Treatments Applied to Impregnated Wood Material on Fire Resistance*, Master’s Thesis, Karabük Üniversitesi, Karabük, Türkiye.

Hepburn, C., Adlen, E., Beddington, J., Carter, E. A., Fuss, S., MacDowell, N., Minx, J. C., Smith, P., and Williams, C. K. (2019). “The technological and economic prospects for CO_2 utilization and removal,” *Nature* 575(7781), 87-97. https://doi.org/10.1038/s41586-019-1681-6

Hülagü, B. (2021). *An Environmentally Friendly Approach to the Protection of Wooden Construction Materials: Usability of Vegetable Oils*, Master’s Thesis, Mimar Sinan Fine Arts University, İstanbul, Turkey.

Kartal, S. N., and Imamura, Y. (2004). “Borlu bileşiklerin emprenye maddesi olarak ağaç malzeme ve kompozitlerde kullanılması [Use of boron compounds as impregnation agents in wood materials and composites],” in: *Üçüncü Uluslararası Bor Sempozyumu Bildiriler Kitabı [Proceedings Book of the Third International Boron Symposium]*, Vol. II, Eskişehir, Turkey, pp. 333–338.

Kızılca, V. (2025). *Effect of Ecologically Based Wood Preservatives on Technological Properties and Human/Environmental Health*, Master’s Thesis, Muğla Sıtkı Koçman University, Muğla, Turkey.

Omer, M. A., and Noguchi, T. (2020). “A conceptual framework for understanding the contribution of building materials in the achievement of sustainable development goals (SDGs),” *Sustainable Cities and Society* 52, article 101869. https://doi.org/10.1016/j.scs.2019.101869

Perker, Z. S., and Öztürk, H. (2024). “Çevre dostu mimarlık için ahşap malzemede bitkisel emprenye çözümleri üzerine bir araştırma [A research on plant impregnation solutions for wood materials for environmentally friendly architecture],” *Sürdürülebilir Mühendislik Uygulamaları ve Teknolojik Gelişmeler Dergisi* 7(1), 60-69.

Ramage, M. H., Burridge, H., Busse-Wicher, M., Fereday, G., Reynolds, T., Shah, D. U., Wu, G., Yu, L., Fleming, P., Densley-Tingley, D., *et al.* (2017). "The wood from the trees: The use of timber in construction," *Renewable and Sustainable Energy Reviews* 68, 333-359. https://doi.org/10.1016/j.rser.2016.09.107

Teaca, C. A., Roşu, D., Mustaţă, F., Rusu, T., Roşu, L., Roşca, I., and Varganici, C. D. (2019). "Natural bio-based products for wood coating and protection against degradation: A review," *BioResources* 14(2), 4873-4901. https://doi.org/10.15376/biores.14.2.Teaca

Toppinen, A., Röhr, A., Pätäri, S., Lähtinen, K., and Toivonen, R. (2018). "The future of wooden multistory construction in the forest bioeconomy – A Delphi study from Finland and Sweden," *Journal of Forest Economics* 31, 3-10. https://doi.org/10.1016/j.jfe.2017.05.001

TS 2470 (1976). "Odunda fiziksel ve mekaniksel deneyler için numune alma metotları ve genel özellikler [Sampling methods and general properties for physical and mechanical tests on wood]," Türk Standartları Enstitüsü, Ankara, Turkey.

TS 2471 (1976). "Odunda fiziksel ve mekaniksel deneyler için rutubet miktarı tayini [Determination of moisture content in wood for physical and mechanical tests]," Türk Standartları Enstitüsü, Ankara, Turkey.

TS 2472 (1976). "Odunda fiziksel ve mekaniksel deneyler için birim hacim ağırlığı tayini [Determination of unit volume weight for physical and mechanical tests on wood]," Türk Standartları Enstitüsü, Ankara, Turkey.

TS 2474 (1976). "Odunun statik eğilme dayanımının tayini [Determination of static bending strength of wood]," Türk Standartları Enstitüsü, Ankara, Turkey.

TS 2477 (1976). "Odunun çarpmada eğilme dayanımının tayini (şok testi) [Determination of bending strength of wood upon impact (shock test)]," Türk Standartları Enstitüsü, Ankara, Turkey.

TS 2478 (1976). "Odunun statik eğilmede elastiklik modülünün tayini [Determination of modulus of elasticity of wood in static bending]," Türk Standartları Enstitüsü, Ankara, Turkey.

Ulusoy, H., and Peker, H. (2020a). "Larex (*Larix decidua* Mill.) odununda modern/klasik yangın geciktiricilerin bazı teknolojik özellikler üzerine etkileri [Effects of modern/classical fire retardants on some technological properties of Larex (*Larix decidua* Mill.) wood]," *European Journal of Science and Technology* 19, 194-198. https://doi.org/10.31590/ejosat.779681

Ulusoy, H., and Peker, H. (2020b). "Tıbbi aromatik bitki çirişotu (*Asphodeline taurica*) özütünün kayın odununda emprenye edilebilme yeteneği ve bazı teknolojik özelliklere etkisi [Impregnation ability of medicinal aromatic plant asphodelus (*Asphodeline taurica*) extract on beech wood and its effect on some technological properties]," *Avrupa Bilim ve Teknoloji Dergisi* (19), 199-203. https://doi.org/10.31590/ejosat.779692

Var, A. A., and Kaplan, Ö. (2019). "Bazı jeotermal sularla muamele edilmiş kızılçam odununun yoğunluk, eğilme direnci ve elastikiyet modülü: Konya bölgesinden bir çalışma [Density, bending strength and modulus of elasticity of red pine wood treated with some geothermal waters: A study from Konya region]," *El-Cezerî Fen ve Mühendislik Dergisi* 6(1), 181-192.

Var, A. A., and Özkan, M. (2018). "Bitki boyası ve doğal mineralli su muamelesinin karakavak (*Populus nigra* L.) odununda absorpsiyon, retensiyon ve yoğunluk değerleri üzerine etkisi [Effect of plant dye and natural mineral water treatment on

absorption, retention and density values in black poplar (*Populus nigra* L.) wood]," *Turkish Journal of Forestry* 19(4), 435-441. https://doi.org/10.18182/tjf.449895
Wen, B., Musa, S. N., Onn, C. C., Ramesh, S., Liang, L., Wang, W., and Ma, K. (2020). "The role and contribution of green buildings on sustainable development goals," *Building and Environment* 185, article 107091. https://doi.org/10.1016/j.buildenv.2020.107091
Yaşar, M., Yaşar, Ş., Fidan, M. S., and Ertaş, M. (2017). "Doğal ve kimyasal emprenye maddeleri ile emprenye edilen sedir (*Cedrus libani* A. Rich.) odununun direnç özelliklerinin tespiti [Determination of resistance properties of cedar (*Cedrus libani* A. Rich.) wood impregnated with natural and chemical impregnation agents]," *İleri Teknoloji Bilimleri Dergisi* 6(3), 463–470.
Yıldırım, E. (2020). *Boraks ve Çeşitli Tıbbi Aromatik Bitki Özütlerinin Odunun Teknolojik Özelliklerine Etkisi [Effect of Borax and Various Medicinal Aromatic Plant Extracts on the Technological Properties of Wood]*, Master's Thesis, Artvin Çoruh Üniversitesi, Artvin, Turkey.

Article submitted: October 11, 2025; Peer review completed: December 27, 2025; Revised version received: January 4, 2026; Further revised version received: January 23, 2026; Accepted: January 30, 2026; Published: February 18, 2026.
DOI: 10.15376/biores.21.2.3272-3283