

Extraction of Tea Plant Waste Extracts Using Various Solvents in the Eastern Black Sea Ecology and its Effect on Some Technological Properties of Wood

Doğu Karadeniz Ekolojisinde Çay Bitki Atıklarından Çeşitli Çözücülerle Ekstrakt Elde Edilmesi ve Ahşabın Bazı Teknolojik Özellikleri Üzerine Etkisi

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Abstract

Drought, climate change, water scarcity, and rapid population growth are putting forest resources at risk in this ecological century. Optimal and economical use of wood, preservation with natural materials, and reuse of used wood have become essential. Wood is currently being preserved with chemically based solutions, which threatens human and environmental health. In addition, animal, agricultural, and plant waste is not being utilized effectively. In this study, factory tea waste was obtained, and extracts were prepared using various solvents (water, ethanol, methanol) from maple (*Acer sp.*) and brutia (*Pinus brutia*) wood. These samples were then impregnated according to ASTM D 1413-76 (1976) standard, and some of their technological properties were determined. The highest retention level was observed in samples impregnated with a water-based (Maple wood/4.79%) solution.

Öz

Kuraklık, iklim değişiklikleri, su kaynakları azlığı ve hızlı nüfus artışı ekolojik yüzyılda orman kaynaklarını da riske atmaktadır. Ahşap malzemenin optimum, ekonomik kullanımı, doğal gereçlerle korunması ve kullanılan ahşabın tekrar kullanımı zorunlu hale gelmiştir. Ahşap materyal kimyasal kökenli yapılarla korunmakta bu da insan/çevre sağlığını tehdit etmektedir. Buna ek olarak hayvansal, tarım, bitki atık/atıkları değerlendirilememektedir. Bu çalışma kapsamında fabrika çay atıkları temin edilerek çeşitli çözücülerle (su, etanol, metanol) ekstraktlar hazırlanmış, akçaağaç (*Acer sp.*) ve kızılçam (*Pinus brutia*) odunları ASTM D 1413-76 (1976) standardına göre empenye işlemleri yapılarak bazı teknolojik özellikleri tespit edilmiştir. En yüksek tutunma düzeyi su bazlı çözelti (Akçaağaç odunu/%4.79) ile empenyesi yapılmış örneklerde belirlenmiştir.

INTRODUCTION

In Türkiye, approximately 75.000 to 120.000 tons of tea waste (tea stalks) are generated annually. This waste is a significant source of organic waste, particularly in the Black Sea region, arising from the processing of fresh tea (TEMA, 2019). Wood material has become an industrial product whose usage area has become quite widespread with the technological advances in recent years. In the woodworking industry, the desire for durable wood material, the growing value and the ecology consciousness caused by the shrinking forest stand have become a necessity to expand the usage area in the industry by increasing the strength properties of loose-textured wood types (Pelit, 2014).

The seeds, flowers, branches, leaves, fruits, fruit kernels, or peels of many plants have been consumed as tea in various societies for centuries. Among these, tea obtained from the shoots and fresh leaves of the tea plant (*Camellia sinensis*) has spread to five continents and has become the most consumed non-alcoholic beverage after water worldwide due to its unique taste, aroma, and health benefits (Yılmaz et al., 2020).

By processing tea leaves in different ways, teas with different appearances, tastes, and flavors such as black, green, and oolong tea can be obtained. The most important substances that make these teas different and special from other herbal teas are the catechins and caffeine found in their composition (Balci & Özdemir, 2016).

In recent years, research on determining the antioxidant properties of food components and food-health relationships has increased, and the results of this research have shown that catechins, which are important components of tea, and their oxidation products, theaflavin (TF) and thearubigins (TR), have positive effects on health (Pou et al., 2019; Sen et al., 2020).

Tea cultivation in Türkiye is carried out in the Eastern Black Sea Region, starting from the Georgian border and extending to the Fatsa district of Ordu province. Within this region, tea cultivation is mainly carried out in Rize, Ordu, Giresun, Trabzon and Artvin provinces. This region is among the top regions in the world for tea cultivation. (Akova, 2008). Herbal dye is a dye obtained from parts of the plant such as leaves, flowers, cones, stem bark and roots, without or with minimal chemical processing (Mert et al., 1992).

While there are studies and applications aimed at utilizing black tea production waste, the production of concentrated tea extract from this waste has recently attracted attention as a value-added production method. Thus, the remaining organic matter can still be used as fertilizer, fuel, etc. Currently, the concentrated tea production line generally consists of extraction, filtration, separation for coarse particles, pre-concentration, cooling, and final concentration stages (Özdemir, 1992; Özdemir et al., 2018). Due to the effects of chemical substances used to protect wood material against biotic and abiotic effects on human health and the environment, it is necessary to develop alternative impregnation agents that will only harm the target organism and to carry out impregnation methods in a way that does not create environmental risk (Kartal et al., 2005). Dye obtained from walnut shells was used on wood material and its protection in the environment of decay fungi and its color change values under UV were investigated (Söğütü & Sönmez, 2006). Increased environmental pressures and bans against wood preservatives, which are widely used due to their toxic components, have made the use and development of environmentally friendly impregnation agents necessary (Tomak & Yıldız, 2011).

In Roman civilization, olive oil and cedar oil were used in particular. The Egyptians, on the other hand, tried to take precautions by keeping the wood material dry. In the following years, various impregnation solutions were used in the protection of wood materials. These substances were applied by brushing or by dipping into the impregnation substance (Bozkurt et al., 1993). As awareness of human and environmental health came to the forefront, governments introduced new protective standards, and therefore, natural dyes are demanded by society as important alternative materials to synthetic and harmful dyes (Tsatsaroni et al., 1998; Kamel et al., 2005; Calogero & Marco, 2008). Especially in the food and textile sectors, a "green wave" movement has begun with the increasing interest in environmentally friendly, non-toxic, antioxidant, anticarcinogenic, antibacterial and antiallergic natural dyes obtained from plants (Kızıl, 2005).

Within the scope of the study, the importance of developing suitable and harmless alternative products by utilizing natural and renewable energy (bioindustry) resources, with an awareness of the environment and human health, is increasing day by day worldwide. In this study, by obtaining an extract from tea waste (factory), a natural product, we aimed to obtain a natural preservative that is harmless to the environment and human health, and subsequently, to determine its wood retention properties as well as some technological properties. It could be used in the indoor/outdoor furniture industry and in children's toys.

MATERIAL AND METHOD

Wood /Plant Material

Maple (*Acer sp.*) and red pine (*Pinus brutia*) wood were preferred for this study, and care was taken to ensure that the samples were free of knots, ridges, and cracks. All procedures were carried out according to the TS 2470 standard. The tea samples were sourced from tea factories (Arhavi Tea Factory) for processing in silos. Particular attention was paid to ensuring that the tea samples did not undergo any chemical processing according to ISO 1573/TS 1562, ISO 1574/TS 1563, ISO 1839/TS 1568-2948 and that the samples taken were free from harmful agents (biotic-abiotic-moisture) such as mold and fungi.

Method

Preparation of Experimental Samples

The TS ISO 3129 standards were taken into consideration when preparing the test specimens, and particular attention was paid to ensuring that the test/control specimens were free from defects such as fungus, knots, cracks, splinters, mold, insects, etc. The specimens were cut (from live wood) to the following specifications: dynamic bending strength (TS ISO 13061-10), bending strength (TS ISO 13061-3), modulus of elasticity in bending strength (TS ISO 13061-4), and specific gravity (TS ISO 13061-2) and compressive strength (TS ISO 13061-17) with specimen dimensions of 20x20x30 mm. Ten (10) samples were prepared in each experimental period.

Preparation of Plant Extract from Waste Tea

In Waste products obtained from factories during production were extracted using ethanol, methanol, and water-based materials. For the extraction process, 10 g tea waste (Figure 1) samples were placed in cartridges inside a Soxhlet apparatus. 150 ml of water/ethanol/methanol was used as a solvent. The extraction process was carried out for 4 hours. At the end of the extraction process, the extracts collected in the flasks were evaporated in an evaporator device until 15 ml remained. The remaining 15 ml of extracts were combined and prepared in sufficient quantities for application to the wood material (Ceylan, 2020).



Figure 1. Tea waste

Impregnation Method

Impregnation was performed according to the principles of ASTM D 1413-76 (1976). All test samples were treated with 30 cm Hg-1 (Hg-1: Vacuum) followed by 30 minutes of vacuum/30 minutes of diffusion treatment. The amount of solid matter retained relative to the total dry wood weight (retention) was calculated using the following formula:

$$\text{Retention (\%)} = \frac{\text{Moes} - \text{Moeö}}{\text{Moeö}} \times 100$$

Moes = Total dry weight after impregnation (g)

Moeö = Final dry weight before impregnation (g)

Determining Technological Characteristics (Physical/Mechanical)

Air-dry specific gravity determination was carried out based on the TS ISO 13061-2 standard. The samples were allowed to reach equilibrium moisture content until mass and dimensional changes ceased. At this stage, air-dry samples were measured using calipers. Full-dry density analysis was also performed based on the TS ISO 13061-2 standard. According to this standard, tests were applied to 20*20*30 mm specimens, placed in an oven, and the temperature was gradually increased to 103 ± 2 °C. After reaching a fully dry state with the stabilization of mass change, the samples were removed from the oven, cooled to room temperature, and calculations were performed after measurements/weighing. Bending strength measurement was based on the TS ISO 13061-3 standard, and a load was applied to the surface at a constant and controlled rate using a universal testing machine. The loading rate was adjusted so that fracture would occur within 1.5 ± 0.5 minutes from the start of the test. The $P_{\max}$ values recorded at the fracture point were used to calculate the bending strength (σ_e) using the equation given below. The dimensions defined in the TS ISO 13061-4 standard were used as a basis, and test specimens with dimensions of 20*20*300 mm were prepared for the bending strength tests. During the test, the force difference (ΔF) applied within the elastic limit and the corresponding observed deflection difference (Δf) were considered, and the modulus of elasticity (E) was calculated using this data. The TS ISO 13061-6 standard was used as the basis for determining compressive strength. Before the tests, the cross-sectional dimensions ($a*b$) to which the force would act were measured with an accuracy of ± 0.01 mm. Then, the highest force ($P_{\max}$) occurring at the fracture point of the specimen was determined, and compressive strength calculations were performed. For dynamic bending (shock) resistance, the TS ISO 13061-10 principles were followed, and tests were conducted on conditioned specimens.

Evaluation of Data

Test results were analyzed using a computerized MSTAT-C statistical program that included "analysis of variance" (ANOVA) and "DUNCAN" test at a 95% confidence level. Homogeneity groups (HG) were formed by performing statistical evaluations.

RESULTS

Solution Properties

The findings regarding the solution properties are given in Table 1.

Table 1. Solution properties

Plant Extract (Tea Waste)/Concentration	Solvent Material	Temperature (°C)	pH		Density (g/mL)	
			Bİ	Aİ	Bİ	Aİ
%1	Water	22	5.38	5.38	0.996	0.996
	Ethanol		5.66	5.66	0.808	0.808
	Methanol		5.75	5.75	0.790	0.790

Bİ: Before impregnation, Aİ: After impregnation

No changes in density or pH values were observed before or after impregnation processes. This may be due to the properties of the solution. The solution is acidic, which can cause hydrolysis in the wood.

Retention (%)

The percentage of solid matter adhering to the wood material is given in Table 2.

Table 2. Retention (%)

Wood Type	Tea waste Extract (%)	Vacuum Time (min)	Diffusion Time (min)	Solvent	Retention (%)	HG
Maple	1%	30 Minute	30 Minute	Water	4.79	A
				Ethanol	3.86	B
				Methanol	3.04	D
Pine	1%	30 Minute	30 Minute	Water	3.22	C
				Ethanol	2.95	E
				Methanol	2.11	F

The highest retention was observed in the water-based extract of maple wood (4.79%), while the lowest retention value was found in the methanol solution of red pine wood (2.11%). We can say that wood type, anatomical structure, and solvent type are of great importance, especially in these species. Var and Kaplan (2019) found the highest retention value in red pine wood treated with geothermal waters as 2.77% in the SJ-5 40.9 °C treatment, while the lowest value was 2.565% in the SJ-1 23.0 °C treatment.

Alkan (2025) impregnated mahogany and larex wood with mussel shell solution and the highest retention in mahogany wood was determined as 10.88% at 6% concentration and 24 h of immersion time; and the highest retention in larex wood was determined as 12.62% at 6% concentration and 24 h of immersion time.

Physical Features

Air/Dry Specific Density

The changes in air-dry and fully dry specific gravity and the corresponding Duncan test results are given in Table 3, the change graph is given in Figure 2.

Table 3. Air/Dry specific density (g/cm³)

Wood Type	Tea waste Extract (%)	Solvent	Air-dry Density (g/cm ³)	HG	Full-dry Density (g/cm ³)	HG
Maple	1%	Control	0.63	B	0.59	B
		Water	0.65	A	0.61	A
		Ethanol	0.63	B	0.59	B
		Methanol	0.62	C	0.59	B
Pine	1%	Control	0.51	G	0.48	F
		Water	0.53	F	0.50	E
		Ethanol	0.57	D	0.54	C
		Methanol	0.56	E	0.53	D

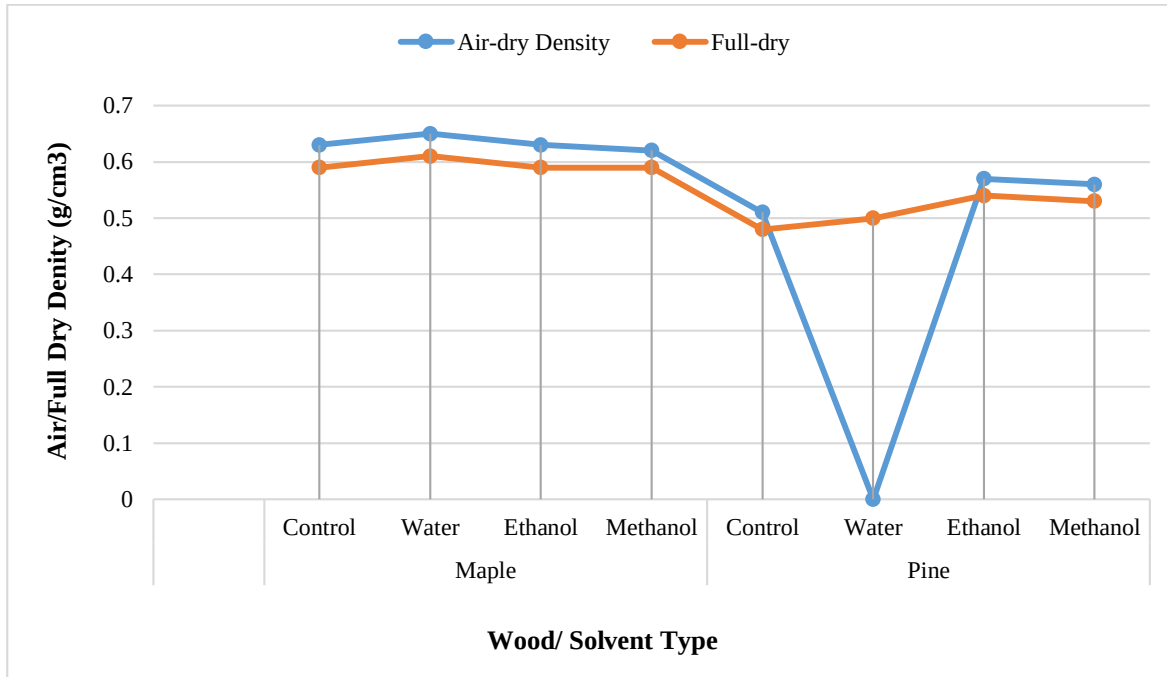


Figure 2. Air/dry specific density variation graph

The highest air-dry specific gravity was found in the maple wood solution prepared with water (0.65 g/cm^3), while the lowest air-dry specific gravity was found in the Scots pine wood control sample (0.51 g/cm^3). The highest air-dry specific gravity was also found in the maple wood solution prepared with water (0.51 g/cm^3), and the lowest air-dry specific gravity was again found in the Scots pine wood control sample (0.48 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.

Mechanical Properties

Bending Strength/Elasticity Modulus Values

Bending strength/elastic modulus values are given in Table 4, and the variation graph is shown in Figure 3.

Table 4. Bending strength/elasticity modulus values (N/mm^2)

Wood Type	Tea waste Extract (%)	Solvent	Bending Strength	HG	Elasticity Modulus	HG
Maple	1%	Control	91.15	D	9950	C
		Water	104.01	A	10350	A
		Ethanol	94.21	C	9900	D
		Methanol	97.16	B	10150	B
Pine	1%	Control	79.23	H	8890	H
		Water	82.70	G	9100	F
		Ethanol	88.93	E	9850	E
		Methanol	81.44	F	9345	G

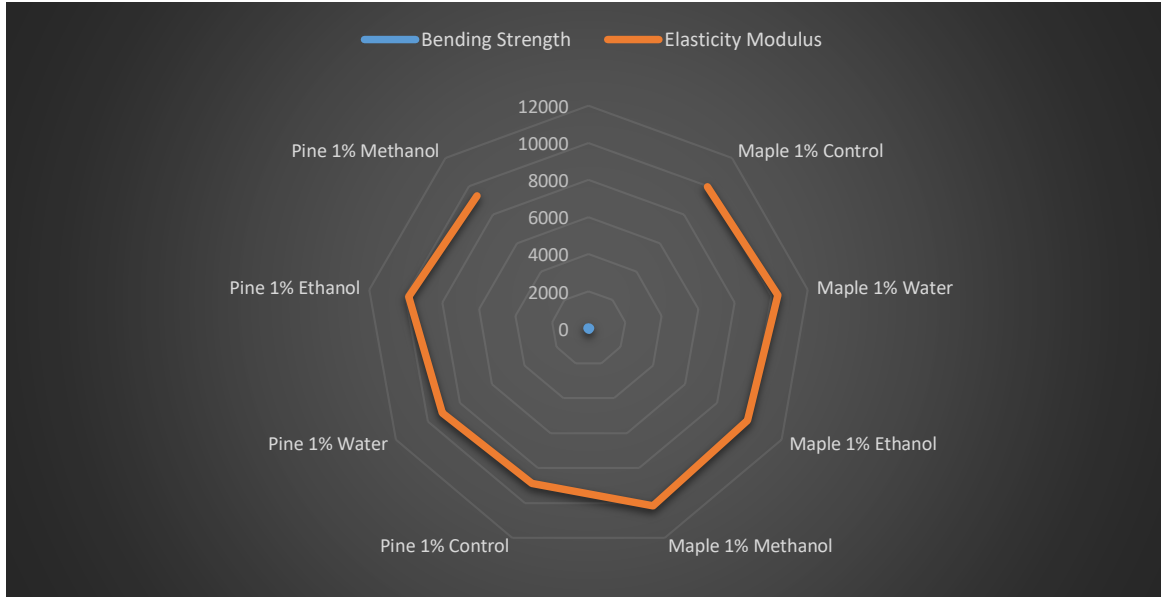


Figure 2. Change in bending strength and modulus of elasticity

The highest bending strength was determined in maple wood water-based solution (104.01 N/mm²), and the lowest bending strength was determined in the red pine wood control sample (79.23 N/mm²). The highest modulus of elasticity value was determined in maple wood water-based solution (10350 N/mm²), and the lowest modulus of elasticity value was determined in red pine wood (8850 N/mm²). A partial increase in bending strength/modulus of elasticity was observed compared to the control sample. Ulusoy and Peker (2020) determined that larex wood impregnated with 1% stone water solution gave the highest bending strength value (135.39 N/mm²). Efe and Çağatay (2011) studied the bending strength of solid wood materials and found that the highest bending strength of Scots pine wood was 104 N/mm² and the lowest was 75 N/mm².

Compression Strength

Compression strength values are given in Table 5 and the variation graph is shown in Figure 4.

Table 5. Compression strength (N/mm²)

Wood Type	Tea waste Extract (%)	Solvent	Compression Strength	HG
Maple	1%	Control	52	B
		Water	54	A
		Ethanol	51	C
		Methanol	52	B
Pine	1%	Control	45	F
		Water	47	D
		Ethanol	51	C
		Methanol	46	E



Figure 4. Change of compression strength (N/mm²)

The highest compression strength value was observed in the maple wood water-based solution (54 N/mm²), while the lowest compressive strength was observed in the Scots pine wood control sample (45 N/mm²). The partial increase compared to the control sample may be due to the anatomical structure of the wood, the type of wood, the impregnation method, and the impregnating agent. Çolak and Yıldız (2004) stated that when impregnation is applied at high temperatures and with high-content fluids, a decrease in compressive strength may occur, particularly perpendicular to the fibers, while slight increases may occur parallel to the fibers due to material accumulation. Kartal and Kakitani (2002) demonstrated that changes in compressive strength along the fiber direction in wood treated with natural and synthetic impregnates are related to the viscosity and diffusion depth of the impregnating fluid.

Dynamic Bending Strength (kgm/cm²)

Dynamic bending strength values are given in Table 6 and the variation graph is shown in Figure 5.

Table 6. Dynamic bending strength values (kgm/cm²)

Wood Type	Tea Waste Extract (%)	Solvent	Dynamic Bending Strength	HG
Maple	1%	Control	0.41	C
		Water	0.47	A
		Ethanol	0.42	B
		Methanol	0.40	D
Pine	1%	Control	0.22	F
		Water	0.27	E
		Ethanol	0.19	G
		Methanol	0.17	H

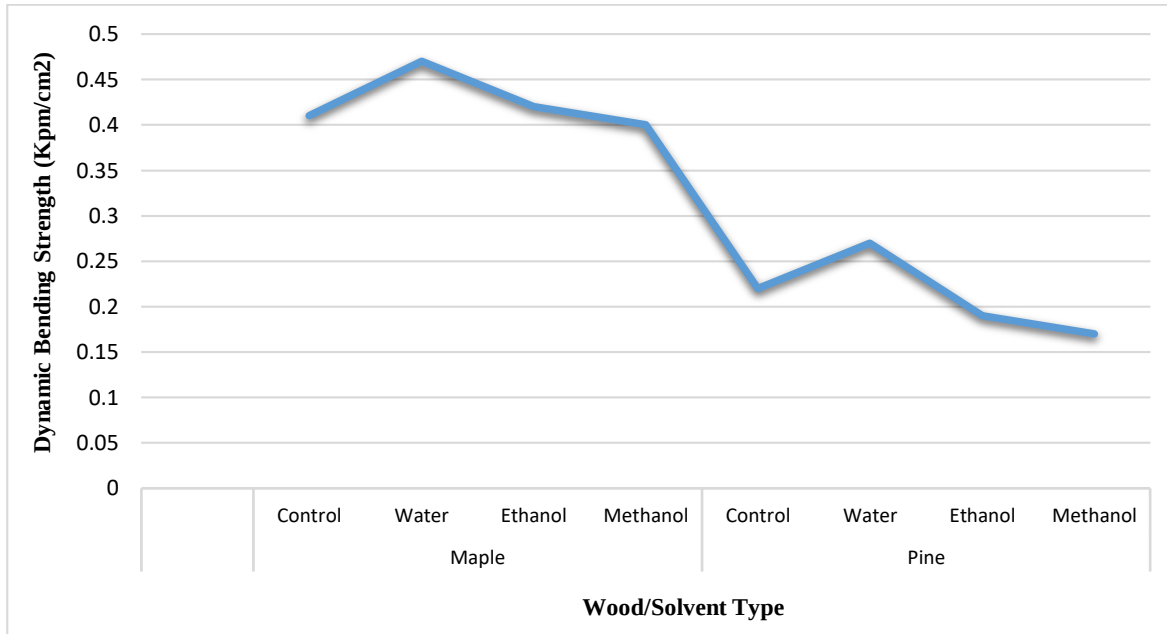


Figure 5. Change of dynamic bending strength (kgm/cm²)

The highest dynamic bending strength was observed in maple wood with a water-based solution (0.47 kgm/cm²), while the lowest dynamic bending strength was observed in Scots pine wood with an ethanol solution (0.19 kgm/cm²). Overall, the water-based solutions yielded positive results compared to the control sample. Yıldırım (2020) observed the change in dynamic bending strength to be positive compared to the control sample. The highest shock resistance was observed in spruce wood (0.63 N/mm²), and the lowest in 1% spruce + borax (0.24 N/mm²). Ölmez (2020) reported that the highest dynamic bending strength value was obtained in chestnut wood with 3% meadow onion extract (0.40 N/mm²), and the lowest value was obtained in Scots pine with 1% meadow onion extract (0.17 N/mm²).

CONCLUSIONS AND DISCUSSIONS

This study aimed to determine the potential for utilizing tea plant waste, which yields thousands of tons of waste annually in our country, in the wood industry. This natural (ecological) material has the potential for use in both beverages and a wide variety of other fields. Experiments were conducted with water-based solutions, as well as ethanol and methanol, and various technological properties were determined along with its impregnation, leading to evaluations of its potential application area.

The highest retention was observed in the water-based extract of maple wood (4.79%), while the lowest retention value was found in the methanol solution of red pine wood (2.11%). We can say that wood type, anatomical structure, and solvent type are of great importance, especially in these species. The highest air-dry specific gravity was found in the maple wood solution prepared with water (0.65 g/cm³), while the lowest air-dry specific gravity was found in the Scots pine wood control sample (0.51 g/cm³). The highest air-dry specific gravity was also found in the maple wood solution prepared with water (0.51 g/cm³), and the lowest air-dry specific gravity was again found in the Scots pine wood control sample (0.48 g/cm³). The highest bending strength was determined in maple wood water-based solution (104.01 N/mm²), and the lowest bending strength was determined in the red pine wood control sample (79.23 N/mm²). The highest modulus of elasticity value was determined in maple wood water-based solution (10350 N/mm²), and the lowest modulus of elasticity value was determined in red pine wood (8850 N/mm²).

A partial increase in bending strength/modulus of elasticity was observed compared to the control sample. The highest compression strength value was observed in the maple wood water-based solution (54 N/mm²), while the lowest compressive strength was observed in the Scots pine wood control sample (45 N/mm²). The partial increase compared to the control sample may be due to the anatomical structure of the wood, the type of wood, the impregnation method, and the impregnating agent. The highest dynamic bending strength was observed in maple wood with a water-based solution (0.47 kgm/cm²), while the lowest dynamic bending strength was observed in Scots pine wood with an ethanol solution (0.19 kgm/cm²). Overall, the water-based solutions yielded positive results compared to the control sample.

This study investigated the potential use of tea extract as an organic substance in the furniture and woodworking industry as a wood preservative (impregnating agent) for both indoor and outdoor applications. Its use in the indoor/outdoor wood furniture industry, wooden children's toys, and all areas requiring hygiene was explored. For outdoor use, it can be treated with various external (natural) preservatives. The impregnation method and solution concentration can be varied. There are benefits to using such waste and residual materials in the ecological cycle. When evaluated in terms of all general characteristics, sources report that acidic structures degrade retention, specific gravity, bending strength/elasticity, dynamic bending strength, and compressive strength, while basic structures do not have a negative effect.

The literature also indicates that the most significant factors affecting adhesion are wood moisture content, thickness, anatomical structure, and impregnation agent/impregnation method. Comparing this with other sources, we can say that the medicinal aromatic plant extract yielded positive results. While the same applies to all mechanical properties, the medicinal aromatic plant extract, being distinct from other materials (such as tea) mentioned in the literature, creates a unique situation.

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