

Effect of Using Oak (*Quercus pontica*) Leaves on Particleboard Quality

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Physical (thickness swelling) and mechanical (modulus of rupture, modulus of elasticity, and internal bond) properties of the particleboard samples produced by mixing spruce (*Picea orientalis*) particles and oak (*Quercus pontica*) leaves at various ratios were investigated. Chemical composition of oak leaves and spruce wood (holocellulose, cellulose, lignin, ash content, alcohol-benzene solubility, 1% NaOH solubility, hot and cold-water solubility) were determined. Single-layer test panels were produced using urea-formaldehyde adhesive. Increasing the oak leaf content in the furnish negatively affected the mechanical strength properties, while improving the thickness swelling resistance. However, the particleboard samples produced with 10% oak leaves addition met the minimum mechanical requirements for general uses. Overall, it was found that oak leaves could be used as an alternative supplementary raw material source in the particleboard industry when blended with wood particles.

DOI: 10.15376/biores.21.2.3792-3801

Keywords: Particleboard; Oak leaves; Mechanical strength properties; Thickness swelling; Chemical properties

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INTRODUCTION

Global population growth and technological development have increased product diversity and production volume. However, raw material shortages have become a critical limitation to production. In recent years, shortages have been reported in the particleboard industry, because the main raw material is wood derived from forest resources. Forests are limited resources (Çöpür *et al.* 2007; Guuntekin *et al.* 2009). The increasing demand for wood raw materials in the composite industry has a detrimental effect on existing forests (Çöpür *et al.* 2007). To meet this demand, researchers have been searching for under-utilized non-wood materials to reduce pressure on forest resources (Rachtanapun *et al.* 2012).

Forest and forestry wastes are potential raw materials for the composite panel industry. Examples of such wastes include branches, twigs, bark, needles, wood shavings, and sawdust (Sahin and Yalçın 2017). Forest and agricultural wastes are typically incinerated, and fumes from this process cause air pollution. Leaves from forest wastes are either used as bedding material to provide insulation on the floors of cattle barns or are used in bio-compost production. (Aghakhani *et al.* 2014; Akinyemi *et al.* 2016). In addition, some animals consume fresh oak leaves as a nutrient (Kamalak *et al.* 2015). Agricultural and forest wastes occupy large volumes because of their low density, thus increasing the transportation and storage costs. During storage, fungi and bacteria cause

decay and mass loss. Another major limitation is that such wastes cannot be supplied continuously. Nevertheless, the utilization of forest and agricultural wastes contributes to forest and environmental cleanliness while alleviating raw material shortages and production bottlenecks in the wood-based composite panel industry, including particleboard manufacturing. Moreover, the collection and sale of forest residues, such as oak leaves, can provide supplementary income for rural populations living near forested areas (Çöpür *et al.* 2007; Flores *et al.* 2011; H. Sahin and Yalcin 2017). Leaves are metabolically active organs of trees and are strongly influenced by habitat and environment conditions (Castro-Díez *et al.* 1997). Soil properties represent another factor affecting the structure of leaves, particularly the chemical composition (Sariyildiz and Anderson 2005).

The use of low-quality logs, alternative lignocellulosic materials, and various industrial, agricultural, and forestry wastes has increased the industrial relevance in particleboard production. Particleboard is also favored due to its homogeneous structure, large surface area, and low cost. Particleboard is used as a covering material (wall, floor, roof), furniture production, door core, stairs tread, case goods, sporting goods, and insulation materials (Dukarska *et al.* 2017).

Numerous studies have examined the feasibility of incorporating waste materials into particleboard production. These materials include infused black tea leaves (Avcı *et al.* 2025), pine braches (Wronka and Kowaluk 2022), areca leaf sheath (Anggini *et al.* 2023), teak leaves waste (Masturi *et al.* 2020), corn straw waste (Yan *et al.* 2024), sugarcane bagasse and eucalyptus residues of the pulp industry (Sugahara *et al.* 20019), tomato stalks (Guuntekin *et al.* 2009), hazelnut husks (Çöpür *et al.* 2007), conifer cones (Sahin and Yalcin 2017), corn cobs and sawdust (Akinyemi *et al.* 2016), vine prunings (Yeniocak *et al.* 2016), almond shells (Pirayesh and Khazaeian 2012), waste tea leaves (Yalinkilic *et al.* 1998; Batiancela *et al.* 2014), grass clippings (Nemli *et al.* 2009), oceanic posidonia waste (Saval *et al.* 2014), coffee waste (Rachtanapun *et al.* 2012), coffee parchment (Scatolino *et al.* 2017), canola straw (Kord *et al.* 2016), waste peach nut shells (Sahin *et al.* 2017), rapeseed straw (Dukarska *et al.* 2017), sago waste (Tay *et al.* 2016), wheat straw (Azizi *et al.* 2011), sugarcane bagasse (Battistelle *et al.* 2016), and waste tobacco stalk (Acda and Cabangon 2013).

The aim of this study is to investigate the use of oak leaves as a supporting raw material source to solve the wood raw material bottleneck caused by the increasing demand for wood-based panel products. Furthermore, it aims to reduce the use of wood in this industry, thereby reducing pressure on forests and contributing positively to the carbon cycle in nature and combating global warming. For this purpose, oak leaves were considered in this work as a supplementary raw material source in particleboard production. Effects were evaluated relative to physical (thickness swelling, 2 h and 24 h) and mechanical (modulus of elasticity (MOE), modulus of rupture (MOR), and internal bond (IB)) properties of particleboard.

EXPERIMENTAL

Materials and Methods

Oak (*Quercus pontica*) leaves were collected during the autumn season from the province of Trabzon, located in the Eastern Black Sea region of Turkey. The leaves were washed to remove dirt, such as soil or dust. Subsequently, the leaves were chopped using a laboratory-scale hammer mill (Robert Hildebrand, Germany). After size reduction, the

particles were oven-dried to a target 3% moisture content (MC) in a laboratory oven at (102 ± 3) °C. Wood particles were obtained from spruce (*Picea orientalis*) tree. The wood was first chipped with ring-type flaker and subsequently reduced to particles in a laboratory hammer mill. The particles were oven-dried to 3% MC at 102 ± 3 °C. Both wood and leaf particles were screened using a vibrating screening machine with 3.0 to 0.5 mm sieves, and oversized and undersized particles were removed. Particles were blended with urea formaldehyde (UF) resin, which was donated by Star wood, a commercial particleboard plant in Bursa, Turkey. The properties of the UF resin are presented in Table 1.

Table 1. Properties of the UF Adhesive

Properties	
Solids (%)	65
Density (g/cm ³)	1.3
Viscosity (cps)	51
pH	7.95

Based on the oven-dry weight of the particles, 10% UF resin (65% solid content) was applied using an atomized spray gun. As a hardener, 1% ammonium chloride solution (20% solid content) was added into the resin during blending. Wax or any other hydrophobic substances were not used to improve the dimensional stability of the test panels. The test panels were manufactured with dimensions of $50 \times 50 \times 1$ cm³. The panels were manually blended and formed into single-layer particleboards. A cold press was applied manually. The mats were hot-pressed for 5 min at 150 °C and 25 kg/cm² pressure. Six types of panels were prepared, as shown in Table 2.

Table 2. Experimental Design for Particleboard Production

Board Type	Raw Material	
	Oak leaves (%)	Wood (%)
Control	0	100
BT1	10	90
BT2	20	80
BT3	30	70
BT4	40	60
BT5	100	0

Two replications of each panel type were produced, resulting in a total of 12 panels. Stop bars were used to control panel thickness. The target density was 0.650 g/cm³.

Chemical analyses of oak leaves and spruce wood were conducted according to the TAPPI Tm-45 (1992) standard. Alcohol-benzene solubility (TAPPI T 204 cm-97) (1997), solubility in dilute alkali (1% NaOH) TAPPI T204 om-98 (1992), hot/cold water solubility TAPPI T207 cm-99 (1992), holocellulose and cellulose as per Wise and Karz (1962), lignin TAPPI T222 om-98 (1992), and ash TAPPI T211 om-93 (1993) were determined.

The panels were conditioned in a climate-controlled room with a relative humidity of 65% and a temperature of 20 °C until they reached equilibrium MC. The test samples

were prepared in accordance with European (EN) standards. Physical properties, including thickness swelling (TS) after 2 h and 24 h water immersion, were determined according to EN 317 (1993). Mechanical properties, including modulus of rupture (MOR) and modulus of elasticity (MOE), were evaluated according to EN 310 (1993), while internal bond strength (IB) was measured according to EN 319 (1993). Twenty samples were tested for each property and panel.

Statistical analyses were performed using SPSS software (version 26; IBM Corp., Armonk, NY, USA). One-way analysis of variance (ANOVA) was conducted at a significance level of $p \leq 0.05$ to evaluate the effect of oak leaf content on panel properties. Significant differences among the mean values were determined using Newman–Keuls *post-hoc* tests.

RESULTS AND DISCUSSION

The chemical compositions of spruce wood and the oak leaves are presented in Table 3, along with selected literature values for other bio-wastes, softwoods, and hardwoods for comparison.

Table 3. Chemical Compositions of Bio-Wastes, Softwoods, Hardwoods, Oak Leaves and Spruce Wood

Raw Material	Holo-cellulose (%)	Cellulose (%)	Lignin (%)	Ash (%)	Alcohol-benzene (%)	1 % NaOH (%)	Hot Water (%)	Cold Water (%)
Spruce	73.21	46.87	27.69	0.41	1.52	11.25	2.26	1.72
Oak leaves	34.32	21.65	16.72	9.95	8.97	28.63	25.41	21.63
Almond shell ^a	64.3	29.1	32.7	3.4	2.8	30.2	9.1	6.3
Hazelnut husk ^a	55.1	34.6	41.4	8.23	2.0	50.4	20.9	18.2
Sycamore leaves ^a	57.3	27.4	23	7.9	14.8	35.7	21.8	19.1
Softwoods ^a	63 to 70	45-50	25-35	0.35	2 to 8	9 -16	3 to 6	2 to 3
Hardwoods ^a	70 to 78	45-50	30-35	0.35	2 to 6	14 - 20	2 to 7	4 to 6

^a According to Nemli *et al.* 2009; Pirayesh and Khazaeian 2012; Aghakhani *et al.* 2014

According to the results of the chemical analysis of oak leaves and the literature findings, holocellulose content (34.3%) was lower than those of almond shell, hazelnut husk, sycamore leaves, softwoods, and hardwoods (Pirayesh and Khazaeian 2012; Aghakhani *et al.* 2014). Cellulose (21.6%) and lignin (16.7%) content of oak leaves were detected as the lowest among the materials listed in Table 3. Regarding the ash content (9.95%), the oak leaves had the highest values. Alcohol-benzene solubility value (8.97%) was found higher than spruce wood and almond shell, comparable to wood species, but lower than sycamore leaves. One percent sodium hydroxide solubility was found higher than spruce wood and wood species, comparable to almond shell, but lower than hazelnut husk and sycamore leaves. Hot and cold-water solubility were found substantially higher than those of wood species and other bio-wastes listed in Table 3.

The MOE and MOR mean values presented in Table 4 ranged from 1040 to 1860 N/mm² and from 6.08 to 13.4 N/mm², respectively. The highest MOE and MOR values were obtained from particleboard samples produced using 100% wood particles (control), while the lowest MOE and MOR values were obtained from samples including 100% oak leaves (BT5). No statistically significant differences were found between control group and BT1. Significant differences were determined between the other groups at a 95% confidence level ($p \leq 0.05$) statistically and shown by different letters in Table 4. The effect of 10% oak leaves on the MOE and MOR values was negligible relative to the control group. However, the addition of higher amounts of oak leaves affected these values negatively. Based on the EN 312 (2005) standard, 12.5 and 13.0 N/mm² are the minimum requirements for MOR of particleboards for general uses and interior fitments (including furniture), respectively, while the minimum requirement for MOE of particleboards for interior fitments was 1800 N/mm². The control group satisfied the minimum MOR requirements for general purpose use and interior fitments including furniture manufacture, while BT1 satisfied the minimum MOR requirements for general use required in the EN 312 (2005) standard. Only the Control group met the EN 312 (2005) requirements for interior fitments including furniture manufacture.

Table 4. The Mechanical and Physical Properties of Panels

Board Type	MOE (N/mm ²)	MOR (N/mm ²)	IB (N/mm ²)	TS 2 h (%)	TS 24 h (%)
Control	1863.60 (72.65) a	13.39 (0.66) a	0.42 (0.048) a	18.20 (0.33) a	20.25 (0.86) a
BT1	1796.41 (65.34) a	12.91 (0.88) a	0.38 (0.026) a	17.92 (0.92) a	19.84 (1.08) a
BT2	1602.01 (69.43) b	11.04 (0.67) b	0.26 (0.031) b	14.60 (0.28) b	16.63 (0.65) b
BT3	1434.48 (84.34) c	9.82 (0.99) c	0.21 (0.056) c	13.42 (0.44) c	14.86 (0.43) c
BT4	1239.42 (67.61) d	8.47 (1.12) d	0.14 (0.042) d	11.01 (0.38) d	13.02 (0.56) d
BT5	1044.68 (73.56) e	6.08 (0.95) e	0.08 (0.048) e	9.25 (0.63) e	11.88 (0.34) e

Numbers in the parenthesis are standard deviations. The letters in the same column represent statistical differences at a 95% confidence level ($p \leq 0.05$).

Average IB values of test panels ranged from 0.08 to 0.42 N/mm². The highest IB values were obtained from Control group produced using 100% wood particles, while the lowest were obtained from BT5 produced using 100 % oak leaves. Increasing the ratio of oak leaf content in the test sample production reduced the IB value. The statistical analysis showed that, except for control group and BT1, there were differences ($p \leq 0.05$) in IB values among the others. The minimal requirements of IB strength for general purpose and furniture manufacturing (EN 312 2005) were 0.28 N/mm² and 0.40 N/mm², respectively. Control group satisfied the minimum IB requirements for both general purpose use and interior fitments, whereas BT1 met only the minimum requirements for general purpose use according to EN 312 (2005).

A decrease in mechanical properties was observed as the oak leaf content in the particle composition increased. Wood and non-wood plants involve the macromolecules cellulose, hemicellulose, and lignin, that strongly influence mechanical performance of composite panels (Cravo *et al.* 2015). Previous studies have reported that high cellulose

content decreases the brittleness of wood-based materials and improves the mechanical properties of particleboard, whereas low cellulose content adversely affects strength properties (Amirou *et al.* 2013). Another study reported that holocellulose and cellulose contain many polar hydroxyl groups, which are primarily responsible for hydrogen bonds with polar adhesives such as urea-formaldehyde used in this study (Pirayesh and Khazaeian 2012). Lignin caused the cellulose microfibrils to stiffen and appeared to limit perpendicular movement to the grain, thereby contributing to mechanical strength. High ash content caused poor mechanical properties because it masked reactive sites for adhesion with polar adhesives. However, extractives had a negative effect on the gel time of urea-formaldehyde adhesive, disrupting the interaction between wood and adhesive and hence adversely affecting the mechanical properties of particleboard (César *et al.* 2017). As shown in Table 3, oak leaves exhibited substantially lower holocellulose, cellulose, and lignin contents and higher extractive and ash contents than spruce wood.

For all these reasons mentioned above, the increase in the ratio of the oak leaves in the mat, which is used as a raw material in the production of test panels, may cause deterioration of the mechanical properties.

The mechanical (MOE, MOR, and IB) properties of the particleboards incorporating oak leaves were systematically compared with findings from earlier studies that investigated the use of forest and agricultural residues in particleboard production. Specifically, the observed decrease in mechanical properties with increasing oak leaf content has been considered in relation to similar trends reported for particleboards produced from waste tea leaves (Yalinkilic *et al.* 1998; Batiancela *et al.* 2014), grass clippings (Nemli *et al.* 2009), hazelnut husks (Çöpür *et al.* 2007), teak leaves waste (Masturi *et al.* 2020), and sycamore leaves (Aghakhani *et al.* 2014).

According to the results of statistical analysis of the test panels after 2 h and 24 h water immersions, the average TS values ranged from 9.25% to 18.20% (2 h) and from 11.9% to 20.2% (24 h), respectively. Although some test panel groups (BT3, BT4, BT5) had a thickness swelling values after 24 hours soaking lower than 16%, which is the maximum value required for panels used in load-bearing applications in dry conditions as specified in EN 312 (2005), they did not have any of the mechanical resistance values specified in the same standard. The physical (thickness swelling after 2 h and 24 h) properties of the particleboards incorporating oak leaves were compared with findings from earlier studies that investigated the use of forest and agricultural residues in particleboard production. The improvement in thickness swelling resistance observed with increasing oak leaf content was supported by previous studies reporting enhanced dimensional stability in particleboards produced from materials rich in extractives, such as almond shells (Pirayesh and Khazaeian 2012), waste tea leaves (Batiancela *et al.* 2014), and vine prunings (Yeniocak *et al.* 2016). Besides, some researchers stated that using paraffin and phenolic resins, coating of panel surfaces, or acetylation of particles may reduce the ratio of TS (Çöpür *et al.* 2007; Guuntekin *et al.* 2009; Nemli *et al.* 2009).

Increasing the concentration of oak leaves decreased the thickness swelling. Holocellulose and hemicelluloses attracted water due to their polar hydroxyl groups, which promote moisture uptake. Extractives have a positive effect on water resistance, as reported in previous studies (Pirayesh and Khazaeian 2012; Amirou *et al.* 2013; Batiancela *et al.* 2014; César *et al.* 2017). Table 3 shows that the oak leaves had lower holocellulose and hemicellulose contents, but higher extractive contents. Therefore, panels made from 100% oak leaves exhibited the lowest TS values. Additionally, particles obtained from oak leaves had a smaller particle size, which may improve mat packing and reduce water penetration.

The relatively smaller size of the particles obtained from oak leaves could be considered a possible factor contributing to tighter packing of the mat and limitation of water ingress pathways. However, since the particle size distribution was not quantitatively measured in this study, this effect should be considered as a hypothesis.

CONCLUSIONS

In this study, the possibility of using oak leaves, a forest waste in the particleboard production, was investigated as a potential alternative raw material for mitigating wood shortages. Sample test panels were successfully produced at a target density of 0.650 g/cm³ by adding oak leaves in the specified proportions.

1. According to the results obtained, the resistance to thickness swelling was improved by adding oak leaves to the test panels, while mechanical properties progressively deteriorated.
2. The test panels that were produced by adding 10% oak leaves (BT1) met the minimum mechanical strength requirements for general purpose use required in the EN 312 (2005) standard.
3. While oak leaves had lower holocellulose, cellulose, and lignin content compared to softwoods and hardwoods, their ash content, alcohol-benzene solubility, one percent sodium hydroxide solubility, and hot and cold water solubility were found to be higher.
4. As a result, oak leaves can be utilized as a supplementary raw material in particleboard manufacturing at low substitution ratios.
5. The use of oak leaves as a supporting raw material in the particleboard industry can reduce wood consumption, thus alleviating pressure on forests and making a positive contribution to the carbon cycle in nature. It can also help combat global warming.

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Article submitted: January 21, 2026; Peer review completed: February 21, 2026;

Revisions accepted: March 2, 2026; Published: March 6, 2026.

DOI: 10.15376/biores.21.2.3792-3801