Hossein Rajabloo, Vahid Vaziri*, Loya Jamalirad, Majid Mokaber-Esfahani[1]

The Effect of Citric Acid Treatment on Particleboard Properties Obtained from a Combination of Garden Tree Branches with Bagasse and Palm Leaves

Utjecaj tretmana limunskom kiselinom na svojstva iverice proizvedene od grana vrtnog drveća pomiješanih s ostatkom od prerade šećerne trske i palminim lišćem

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ABSTRACT • *The aim of this research was to determine the effect of citric acid treatment on the particleboard properties obtained by mixing three types of lignocellulosic sources. The board was produced by mixing garden tree branches, bagasse and palm leaves in different mass portions (90:5:5, 70:15:15, 50:25:25). Urea-formaldehyde (UF) resin was used at two levels as 10 % surface layer and 8 % middle layer, and 8 % surface layer and 6 % middle layer based on the raw materials. Citric acid was used at three levels of 0, 10, and 20 % by weight. The physical and mechanical properties of particleboards are measured according to the European Standard EN. Fourier transform infrared spectroscopy was used to distinguish the effect of citric acid treatment on the particles. The results showed that, when the amount of citric acid increased, the water absorption of panels decreased, and the mechanical properties improved. As garden tree branch content in the particleboard increased, so did the total resistance. According to the results of this study, the particleboards containing 70 % garden tree branches, 0 % citric acid, and 8 % UF resin, as well as those of 50 % garden tree branches, 0 % citric acid, and 10 % UF resin can be used for type P1 boards (bending strength of 10 MPa and 0.24 MPa internal bonding). In comparison, the boards containing 90 % garden tree branches, 10 % citric acid and 10 % UF resin were proposed for type P2 boards (bending strength of 11 MPa, modulus of elasticity of 1600 MPa and internal bonding of 0.35 MPa).*

KEYWORDS: *citric acid treatment; bagasse; palm leaves; garden tree branches; particleboard*

SAŽETAK • *Cilj ovog istraživanja bio je utvrditi utjecaj tretmana limunskom kiselinom na svojstva iverice proizvedene miješanjem triju vrsta lignoceluloznog materijala. Ploča je proizvedena miješanjem grana vrtnog drveća,*

* Corresponding author
[1] Authors are M.Sc. graduated student, assistant professor, associate professor and assistant professor at Gonbad Kavous University, Gonbad Kavous, Iran. https://orcid.org/0009-0009-4606-8805; https://orcid.org/0000-0003-3119-5157; https://orcid.org/0000-0002-7767-4172; https://orcid.org/0000-0002-2128-719X

ostataka od prerade šećerne trske i palmina lišća u različitim masenim udjelima (90 : 5 : 5; 70 : 15 : 15; 50 : 25 : 25). Urea-formaldehidna (UF) smola dodavana je u različitim udjelima s obzirom na lignoceluloznu sirovinu: 10 % u površinski sloj i 8 % u srednji sloj te 8 % u površinski sloj i 6 % u srednji sloj. Primijenjena su tri težinska udjela limunske kiseline: 0, 10 i 20 %. Fizička i mehanička svojstva ploča iverica mjerena su na temelju europskog standarda. Za određivanje utjecaja tretmana limunskom kiselinom na čestice lignoceluloznog materijala primijenjena je Fourierova infracrvena spektroskopija. Rezultati su pokazali da se s povećanjem količine limunske kiseline smanjilo upijanje vode ploča i da su se poboljšala njezina mehanička svojstva. Kako se udio grana vrtnog drveća u iverici povećavao, tako se povećavala i ukupna otpornost ploče. Kao ploče tipa P1 (čvrstoća na savijanje od 10 MPa i čvrstoća na raslojavanje od 0,24 MPa) mogu se upotrebljavati iverice koje sadržavaju 70 % grana vrtnog drveća, 0 % limunske kiseline i 8 % UF smole te iverice koje imaju 50 % grana vrtnog drveća, 0 % limunske kiseline i 10 % UF smole. Za usporedbu, ploče koje sadržavaju 90 % grana vrtnog drveća, 10 % limunske kiseline i 10 % UF smole predlažu se kao ploče tipa P2 (čvrstoća na savijanje 11 MPa, modul elastičnosti 1600 MPa i čvrstoća na raslojavanje 0,35 MPa).

KLJUČNE RIJEČI: *tretman limunskom kiselinom; ostatak od prerade šećerne trske; palmino lišće; grane vrtnog drveća; iverica*

1 INTRODUCTION
1. UVOD

Demand for the utilization of wood products in the world and, subsequently in Iran, has increased significantly (Baharlouei *et al*., 2020). Due to the scarcity of forest resources in Iran and the ban on the import of bark logs, the use of other lignocellulosic sources, including agricultural and garden waste, is unavoidable (Vaziri *et al*., 2018; Avarand *et al*., 2018).

The release of toxic gases and the high price of resin led to the use of alternative materials (Mostafalo *et al*., 2019). Due to environmental concerns, the use of synthetic adhesives containing harmful chemicals is decreasing (Umemura *et al*., 2012). Therefore, in the future, emphasis will be placed on the use of natural adhesives (Umemura *et al*., 2013). In the literature survey, natural polymers from plants and animals are used as a natural resin and chemical activator of wooden surfaces (Pizzi, 2006). In the activation method, compounds such as surface lignin and hemicellulose are activated (Umemura *et al*., 2012).

Citric acid can be easily obtained by the fermentation of compounds containing glucose and sucrose (Tsao *et al*., 1999). Citric acid has been researched as a crosslinking agent for wood (Vukusic *et al*., 2006; Šefc *et al*., 2009; Huaxu *et al.,* 2021), plant fiber (Ghosh and Samanta, 1995), pulp and paper (Yang *et al*., 1996).

Umemura *et al*. (2013) used a solution of sucrose and citric acid as a natural resin for producing particleboard with a 25:75 % mixture. Considering the relationship between adhesion and proper bonding of wood particles, they found that these two materials can be used as natural adhesives for the manufacture of particleboard. The internal bonding, bending strength, and thickness swelling values of such boards were comparable to or higher than the type 18 requirements of the Japanese industrial standard for particleboard, JIS A 5908 (2003).

Ksumah *et al.* (2016) investigated the use of sweet sorghum bagasse and citric acid for particleboard manufacturing. The citric acid content was varied in the range of 0-30 wt%. The physical properties of boards improved with increasing citric acid content up to 20 wt%. Infrared (IR) spectra analysis suggests the presence of ester linkages where the carboxyl groups of citric acid had reacted with the hydroxyl groups of the sorghum bagasse to give the boards good physical properties.

Zhao *et al*. (2016) investigated the effect of citric acid on the tannin-sucrose resin and physical properties of the particleboard. The results showed that the particleboards containing 20 and 33.3 % citric acid resin at 200 °C satisfies the requirements of the type 18 JIS A 5908.

Widyorini *et al.* (2016) investigated the physical and mechanical properties of particleboard from bamboo using citric acid. The results showed that the dimensional stability and mechanical properties of the particleboards could be significantly improved by adding citric acid. The particleboards containing citric acid could meet the requirements of the type 18 JIS A 5908.

Kusumah *et al.* (2017) investigated the effects of the weight ratio of citric acid to sucrose on the physical and mechanical properties of particleboard. The results showed that the mechanical properties of particleboards bonded with adhesives in citric acid/sucrose weight ratios of 15/85 and 10/90 were better than those of particleboards in other ratios. As the sucrose content increases, the thickness swelling of the particleboard increases. According to the results of thermal analysis and measurements of the infrared spectra, reactions leading to ester linkages occurred between the citric acid, sucrose and sweet sorghum bagasse.

Widyorini *et al.* (2018) used elephant dung fibers as material for composite board and citric acid as a bonding agent. The results showed that elephant dung fibers can be used as a potential material for composite board. By adding citric acid, the quality of the composite board could be significantly improved.

Mostafalo *et al*. (2019) investigated the effect of citric acid treatment on particleboard properties. The results showed that resin content could be reduced due to the good performance of citric acid in improving strength. It can be concluded that particleboard containing 20 % urea-formaldehyde resin can be used for type P1 boards. The suitability of urea-formaldehyde resin of 10 % and citric acid of 20 % for type P2 boards was given.

Widyorini *et al.* (2019) focused on the effect of an extractive treatment and the application of citric acid on the particleboard properties made from *salacca* frond. The hot water extractive treatment was carried out by boiling the particles for 2 hours. The results showed that the addition of citric acid led to an improvement in the physical and mechanical properties of the particleboard. When using citric acid as an adhesive, the hot water treatment of *salacca* frond is not necessary.

Syamani *et al*. (2020) analyzed the utilization of sugarcane bagasse and citric acid for particleboards production. The infrared (IR) spectra analysis showed the formation of an ester linkage between the carboxyl groups of citric acid and the hydroxyl groups of the sugarcane particles, providing the boards with good physical and mechanical properties.

Due to the shortage of wood resources in Iran, particleboard production companies will face a significant challenge in the future, so companies are focusing on recycling using agricultural and garden waste and other lignocellulosic waste. This research studied the effect of citric acid pretreatment on the particleboard properties obtained from garden tree branches, bagasse and palm leaves. Finally, based on the result, with the aim of increasing the use of palm waste and bagasse as required by particleboard standards, it can be proposed as a solution for the industry.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

2.1 Raw material
2.1. Sirovina

The lignocellulosic raw material for this research was obtained as follows: garden tree branches (mixture of plum and peach) from Momaz Golestan Particleboard Company, bagasse from Khuzestan province and palm leaves from Kerman**.** These particles were sieved to the size passed through and retained by 20-40 mesh (fine particles with a thickness of 0.41-0.84 mm) and 10-20 mesh (coarse particles with a thickness of 0.841-1 mm). After being prepared, these particles were dried in an oven at a temperature of 80 degrees Celsius until the moisture content of 4 %.

2.2 Adhesive
2.2. Ljepilo

Citric acid**)** Anhydrous**(** was dissolved in distilled water to the concentration of 50 wt%. Prepared citric acid was then added during the production of particleboard at three levels of 0, 10, and 20 % by weight. The characteristics of citric acid are given in Table 1.

Urea-formaldehyde (UF) resin was used at two levels as a 10 % surface layer and 8 % middle layer, and 8 % surface layer and 6 % middle layer based on the dry weight of the particles. The characteristics of urea-formaldehyde resin are given in Table 2. Ammonium chloride as a hardener was also used at 2 % of the dry weight of the resin.

2.3 Manufacture of particleboard
2.3. Proizvodnja ploča iverica

The mixed proportion of garden tree branches, bagasse and palm leave was selected at three levels: (90 % : 5 % : 5 %), (70 % : 15 % : 15 %), and (50 %: 25 %: 25 %), respectively.

A citric acid solution was sprayed onto dried particles to achieve various citric acid contents, i.e., 10, 20 wt%. These particles were dried at 80 ˚C to a final moisture content of 4 % by weight. In order to produce three-layer particleboard, the ratio of coarse particles to fine particles was 60:40.

Table 1 Characteristics of citric acid
Tablica 1. Svojstva limunske kiseline

Density, g/cm³ *Gustoća*, g/cm³	**Melting point, °C** *Talište*, °C	**Molar mass, g/mol** *Molna masa*, g/mol	**pH**	**Purity, %** *Čistoća*, %
1.665	153	192.13	1.7	99

Table 2 Characteristics of urea-formaldehyde resin
Tablica 2. Svojstva urea-formaldehidne smole

Density, g/cm³ *Gustoća*, g/cm³	**Viscosity, cP** *Viskoznost*, cP	**Gel time, s** *Vrijeme želiranja*, s	**pH**	**Solids, %** *Sadržaj suhe tvari*, %
1.27	320	56	7	61

The particleboard was hot-pressed at 170 °C for 7 min at a pressing pressure of 30 kg/cm^2. Other factors, including board density of 0.7 g/cm^3 and board thickness of 16 mm, were considered constant for all treatments. After each mixture was prepared, the resin in a blender was sprayed onto the particles. These particles were formed into mats using a forming box with the size of 450 mm × 450 mm (Figure 1 and 2). In total, 18 variants of boards were manufactured (Table 3).

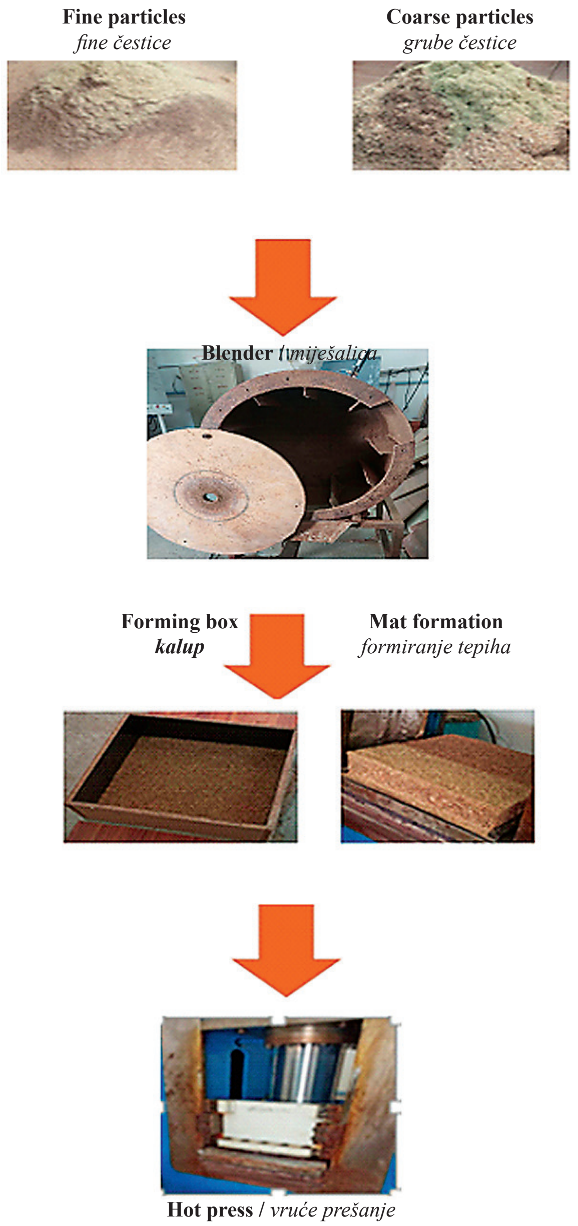

Figure 1 Production stages of particleboard
Slika 1. Faze proizvodnje ploče iverice

2.4 Evaluation of board properties
2.4. Ocjena svojstava ploča

The number of three specimens of every particleboard were tested to obtain a reliable average. After two weeks of conditioning at 20 °C and a relative humidity of approx. 65 %, the panels were cut according to the standard EN 326-1. After immersion in water for 24 hours, water absorption and thickness swelling were measured according to standard EN 317, bending strength and modulus of elasticity according to standard EN 310, and internal bonding according to standard EN 319. The results of this study were compared with those for type P1 board (bending strength of 10 MPa and internal bonding of 0.24 MPa) and type P2 board (bending strength of 11 MPa, modulus of elasticity of 1600 MPa and internal bonding of 0.35 MPa) according to EN 312 standards.

2.5 Fourier transform infrared spectroscopy (FT-IR)
2.5. Fourierova infracrvena spektroskopija (FT-IR)

A Fourier transform infrared spectrometer (model PUYCOM SP1100) was used to determine the effect of citric acid treatment on particles. The edge of the particleboard was scratched to obtain particles. These particles were ground into powder. An FT-IR spectrometer (PUYCOM, SP 1100) was used with the KBr disc method and was recorded by an average of 16 scans at a resolution of 4 cm^{-1} in the range 400 - 4000 cm^{-1}.

2.6 Data analysis
2.6. Analiza podataka

The results were analyzed by a factorial test in a completely randomized design. To compare the means, Duncan's test with a 95 % confidence level was used.

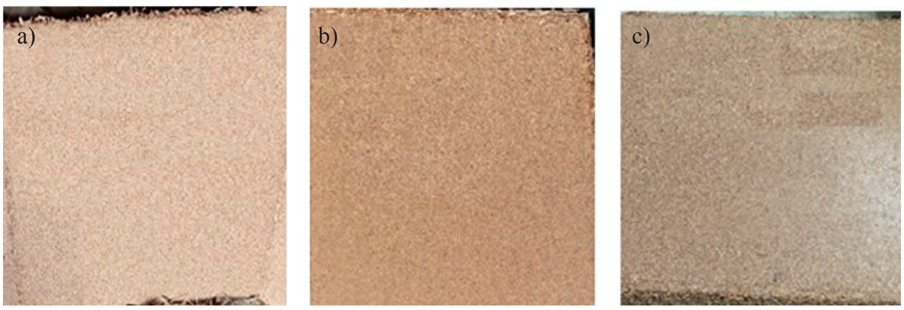

Figure 2 Pictures of particleboards: a) treatment G90A0R10, b) treatment G70A0R10, c) treatment G50A0R10
Slika 2. Slike ploča iverica: a) tretman G90A0R10, b) tretman G70A0R10, c) tretman G50A0R10

Table 3 Combination of test samples
Tablica 3. Kombinacije ispitnih uzoraka

Treatment code *Oznaka tretmana*	**Particles for producing particleboard, %** *Sirovina za proizvodnju ploče iverice, %*			**Adhesive, %** *Ljepilo, %*	
	Garden tree branches (G) *Grane vrtnog drveća* (G)	**Bagasse** *Ostatak od prerade šećerne trske*	**Palm leaves** *Palmino lišće*	**Citric acid (A)** *Limunska kiselina* (A)	**UF resin in surface layer (R)** *UF smola u površinskom sloju* (R)
G50A0R8	50	25	25	0	8
G70A0R8	70	15	15	0	8
G90A0R8	90	5	5	0	8
G50A0R10	50	25	25	0	10
G70A0R10	70	15	15	0	10
G90A0R10	90	5	5	0	10
G50A10R8	50	25	25	10	8
G70A10R8	70	15	15	10	8
G90A10R8	90	5	5	10	8
G50A10R10	50	25	25	10	10
G70A10R10	70	15	15	10	10
G90A10R10	90	5	5	10	10
G50A20R8	50	25	25	20	8
G70A20R8	70	15	15	20	8
G90A20R8	90	5	5	20	8
G50A20R10	50	25	25	20	10
G70A20R10	70	15	15	20	10
G90A20R10	90	5	5	20	10

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

3.1 FT-IR analysis
3.1. FT-IR analiza

The FT-IR spectra of citric acid, particleboard without citric acid used a control sample, particleboard with 10 % and particleboard with 20 % citric acid treatment were merged in S1, S2, S3, and S4 in Figure 3, respectively.

In FT-IR spectra of citric acid (S1), the stretching vibration of the acidic carbonyl group in citric acid can be seen in the absorption peaks of around 1740 cm^{-1} and 1640 cm^{-1}. In the spectrum of particleboards (S2, S3, and S4), the peak in the region of 3433 cm^{-1} corresponds to the stretching vibration of the abundant hydroxyl groups in the structure of lignocellulosic materials (garden tree branches, bagasse and palm leaves) derived from cellulose, hemicellulose and lignin.

In S2, S3, and S4, the peak in the region around 2930 cm^{-1} corresponds to stretching vibrations of aliphatic CH bonds in the lignocellulosic structures. The strong peaks at about 1045 cm^{-1} to 1050 cm^{-1} are related to the stretching vibrations of the aliphatic ether C-O-C bond. Also, the peak observed in the region of 1729 cm^{-1} indicates the stretching vibration associated with the ester carbonyl group, and its increase intensity in the S4 compared to S3 indicates an increase in the number of ester groups resulting from the esterification reaction between the carboxyl group of citric acid and the hydroxyl groups of lignocellulosic materials (Mostafalo *et al*., 2019; Widyorini *et al*., 2019). The absorption peak of the acid carbonyl group in S1 was shifted from 1740 cm^{-1} to 1729 cm^{-1} in S3 and S4. The ester bonds increase the adhesion in the particleboard structure.

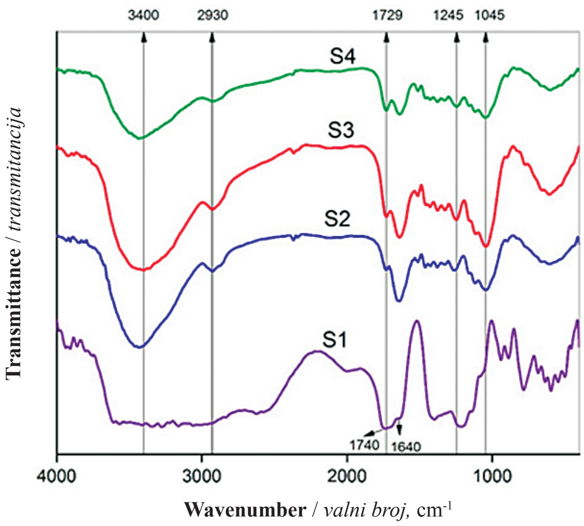

Figure 3 FT-IR spectra of citric acid (S1), particleboard without citric acid used a control sample (S2), particleboard with 10 % citric acid (S3), and particleboard with 20 % citric acid (S4)
Slika 3. FT-IR spektri limunske kiseline (S1), iverice bez limunske kiseline – kontrolni uzorak (S2), iverice s 10 % limunske kiseline (S3) i iverice s 20 % limunske kiseline (S4)

Table 4 Results of variance analysis
Tablica 4. Rezultati analize varijance

Parameter	Source of variance* *Izvor varijance**	Degrees of freedom *Stupnjevi slobode*	Mean square *Srednji kvadrat*	*F* value *F-vrijednost*	*P* Sig.
Bending strength *čvrstoća na savijanje*	Factor A	1	4.576	80.607	0.000
	Factor B	2	4.785	84.282	0.000
	Factor C	2	2.850	50.201	0.000
	B×C	4	0.282	4.967	0.003
	A×B	2	0.233	4.101	0.025
	A×C	2	0.174	3.071	0.049
	A×B×C	4	0.110	1.939	0.035
	Error	36	0.057		
	Corrected Total	53			
Modulus of elasticity *modul elastičnosti*	Factor A	1	43067.130	164.996	0.000
	Factor B	2	49040.796	187.882	0.000
	Factor C	2	75804.019	290.416	0.000
	B×C	4	1293.963	4.957	0.003
	A×B	2	1688.685	6.470	0.004
	A×C	2	192.463	0.737	0.035
	A×B×C	4	2018.519	7.733	0.000
	Error	36	261.019		
	Corrected Total	53			

*Factor A – resin; Factor B – mixture garden tree branches; Factor C – citric acid / *faktor A – smola; faktor B – smjesa grana vrtnog drveća; faktor C – limunska kiselina*

3.2 Bending strength and modulus of elasticity
3.2. Čvrstoća na savijanje i modul elastičnosti

The results of variance analysis showed that the independent and dependent effects of the variable factors had a significant effect on the bending strength and modulus of elasticity of the boards at a 95 % confidence level (Table 4).

The bending strength and modulus of elasticity improved with increasing UF resin and citric acid content (Figure 4 and 5). Since citric acid has a melting point of 153 °C, it melts during the pressing, improving fiber bonding and acting like a resin (Umemura *et al.*, 2013). As the proportion of garden tree branches increases, both the bending strength and modulus of elasticity of the particleboards increase, so they have the highest resistance in a mixture of 90 % garden tree branches. The highest values of modulus of elasticity and bending strength were obtained from the mixture of 90 % garden tree branches, 20 % citric acid and 10 % UF resin (treatment G90A20R10). The lowest values of bending strength and modulus of elasticity were found in a mixture containing 50 % garden tree branches, 0 % citric acid and 8 % UF resin (treatment G50A0R8). For a better insight into the obtained results of bending strength and modulus of elasticity of particleboards made by mixing three types of lignocellulosic sources, it is important to highlight that, accord-

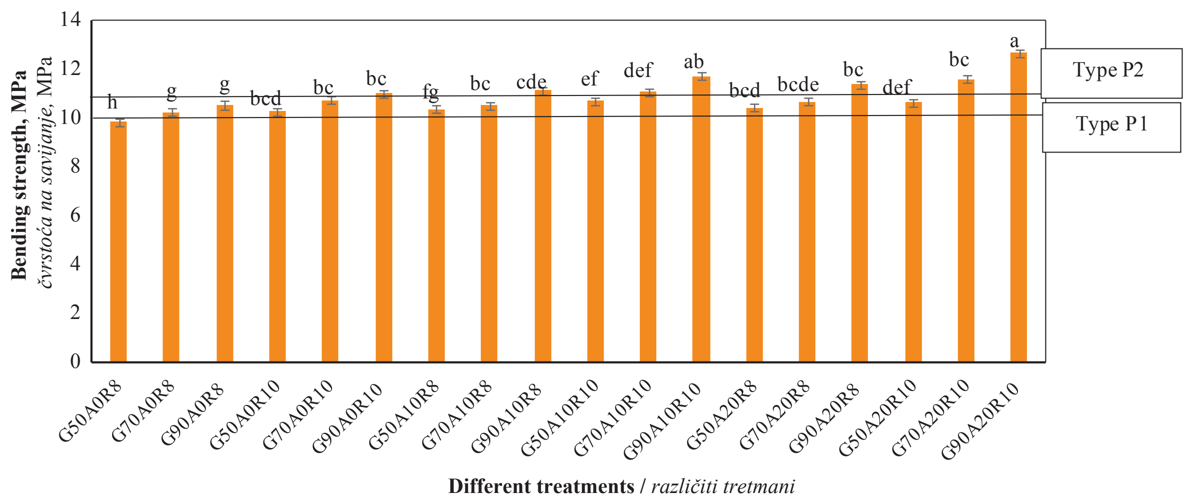

Figure 4 The effect of different treatments on bending strength of particleboards
Slika 4. Utjecaj različitih tretmana na čvrstoću na savijanje ploča iverica

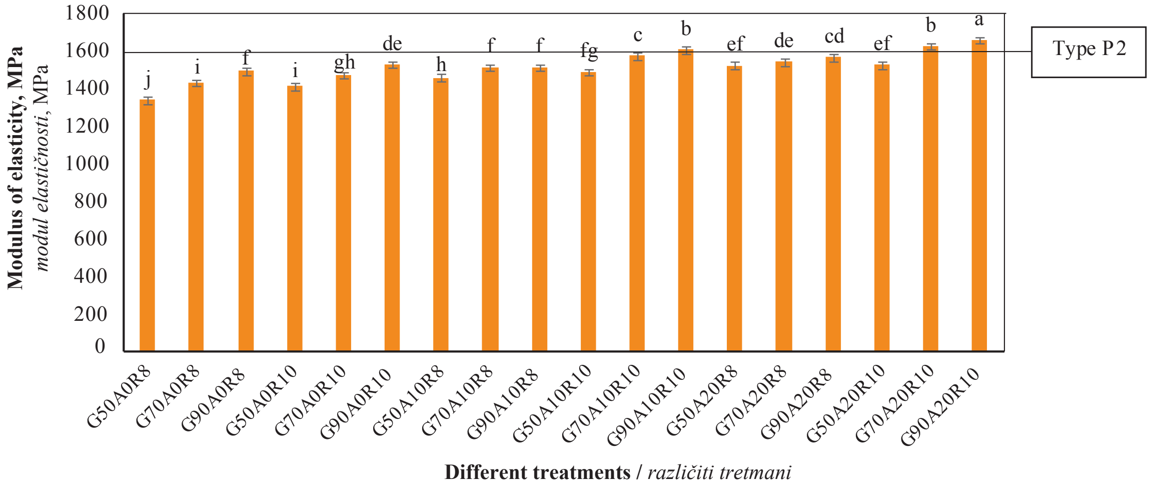

Figure 5 The effect of different treatments on modulus of elasticity of particleboards
Slika 5. Utjecaj različitih tretmana na modul elastičnosti ploča iverica

ing to EN 312 standards, the bending strength of boards with thickness ranging from 13 mm to 20 mm type P1 is 10 MPa, while that of type P2 is 11 MPa, and the modulus of elasticity is 1600 MPa. All particleboards, except the boards containing 50 % garden tree branches, 0 % citric acid and 8 % UF resin (treatment G50A0R8), met the requirements of EN 312 standards for type P1. The boards containing 90 % garden tree branches, 10 % citric acid and 10 % UF resin (treatment G90A10R10) and the boards containing 90 % garden tree branches, 20 % citric acid and 10 % UF resin (treatment G90A20R10) and the boards containing 70 % garden tree branches, 20 % citric acid and 10 % UF resin (treatment G70A20R10) met the requirements of EN 312 standards for type P2.

3.3 Internal bonding
3.3. Čvrstoća na raslojavanje

The results of variance analysis showed that the independent and dependent effects of the variable factors had a significant effect on internal bonding at the 95 % confidence level (Table 5).

As the UF resin content increases from 8 to 10 %, the internal bonding increases from 0.36 MPa to 0.52 MPa. As the UF resin and citric acid content and the proportion of green tree branches increased, the internal bonding increased as well (Figure 6.). The highest internal bonding value was obtained with a mixture containing 90 % garden tree branches, 20 % citric acid and 10 % UF resin (treatment G90A20R10). According to the results of the FTIR spectrum, the intensity of the peak at approximately 1729 cm^{-1} increases with increasing citric acid content. This peak is attributed to C=O stretching by carboxyl groups and/or C=O ester groups, which improves the internal bonding of the boards (Ksumah *et al.*, 2016). The results showed that the internal bonding of all the boards is higher than that of type P1 boards according to EN 312 standards (0.24 MPa for a thickness ranging from 13 mm to 20 mm). Also, internal bonding of all the boards, except for the boards containing 50 % and 70 % garden tree branches, 0 % citric acid and 8 % UF resin (treatment G50A0R8 and treatment G70A0R8) and the boards containing 50 % garden tree branches, 10 % and 20 % citric acid and 8 % UF resin (treatment G50A10R8 and treatment G50A20R8), is higher than that of type P2 boards according to EN 312 standards (0.35 MPa for a thickness ranging from 13 mm to 20 mm).

Table 5 Results of variance analysis
Tablica 5. Rezultati analize varijance

Parameter	**Source of variance*** *Izvor varijance**	**Degrees of freedom** *Stupnjevi slobode*	**Mean square** *Srednji kvadrat*	***F* value** *F-vrijednost*	***P* Sig.**
Internal bonding *čvrstoća na raslojavanje*	Factor A	1	0.365	1021.43	0.000
	Factor B	2	0.065	181.352	0.000
	Factor C	2	0.034	94.306	0.000
	B×C	4	0.001	1.275	0.298
	A×B	2	0.001	2.005	0.149
	A×C	2	0.001	1.508	0.235
	A×B×C	4	0.001	3.093	0.027
	Error	36	0.0003		
	Corrected Total	53			

*Factor A – resin; Factor B – mixture garden tree branches; Factor C – citric acid / *faktor A – smola; faktor B – smjesa grana vrtnog drveća; faktor C – limunska kiselina*

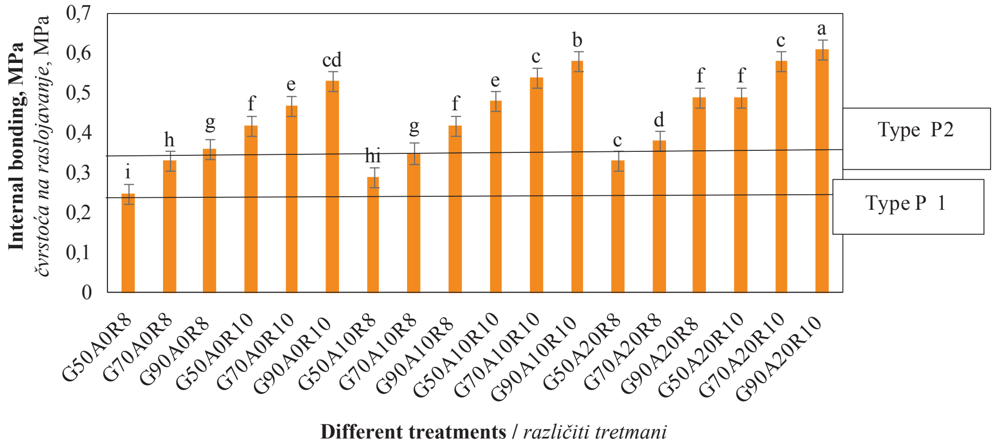

Figure 6 The effect of different treatments on internal bonding of particleboards
Slika 6. Utjecaj različitih tretmana na čvrstoću na raslojavanje ploča iverica

3.4 Water absorption and thickness swelling
3.4. Upijanje vode i debljinsko bubrenje

The results of variance analysis showed that the independent and dependent effects of the variable factors had a significant effect on water absorption and thickness swelling after 24 hours of immersion in water at a 95 % confidence level (Table 6).

With increasing UF resin and citric acid content and an increasing proportion of garden tree branches, water absorption and thickness swelling decreased. Boards containing 10 % UF resin and 20 % citric acid showed the lowest water absorption and thickness swelling (Figure 7.). As the content of citric acid and UF resin increases, the entanglement and bonding between the particles increase, and the number of voids decreases, resulting in less water absorption and less thickness swelling of the particleboards (Syamani *et al.*, 2020; Widyorini *et al.*, 2018).

4 CONCLUSIONS
4. ZAKLJUČAK

In the spectroscopic results, the peak shown in the 1729 cm^{-1} region is attributed to C=O stretching due to carboxyl groups and/or C=O ester groups, and its intensity is increased in 20 % citric acid compared to 10 % citric acid due to the increase in the number of ester groups caused by the reaction between the carboxyl group of citric acid and the hydroxyl groups of

Table 6 Results of variance analysis
Tablica 6. Rezultati analize varijance

Parameter	Source of variance* *Izvor varijance**	Degrees of freedom *Stupnjevi slobode*	Mean square *Srednji kvadrat*	*F* value *F-vrijednost*	*P* Sig.
Water absorption after 24 h *upijanje vode nakon 24* h	Factor A	1	141.200	1126.89	0.000
	Factor B	2	36.866	28.431	0.000
	Factor C	2	162.156	125.056	0.000
	B×C	4	5.892	4.544	0.004
	A×B	2	27.837	21.468	0.000
	A×C	2	31.808	24.531	0.000
	A×B×C	4	4.984	3.844	0.011
	Error	36	1.297		
	Corrected Total	53			
Thickness swelling after 24 h *debljinsko bubrenje nakon 24* h	Factor A	1	134.111	295.472	0.000
	Factor B	2	56.925	125.417	0.000
	Factor C	2	47.607	104.887	0.000
	B×C	4	0.504	1.111	0.047
	A×B	2	4.334	9.549	0.000
	A×C	2	6.401	14.103	0.000
	A×B×C	4	0.767	1.691	0.024
	Error	36	0.454		
	Corrected Total	53			

*Factor A – resin; Factor B – mixture garden tree branches; Factor C – citric acid / *faktor A – smola; faktor B – smjesa grana vrtnog drveća; faktor C – limunska kiselina*

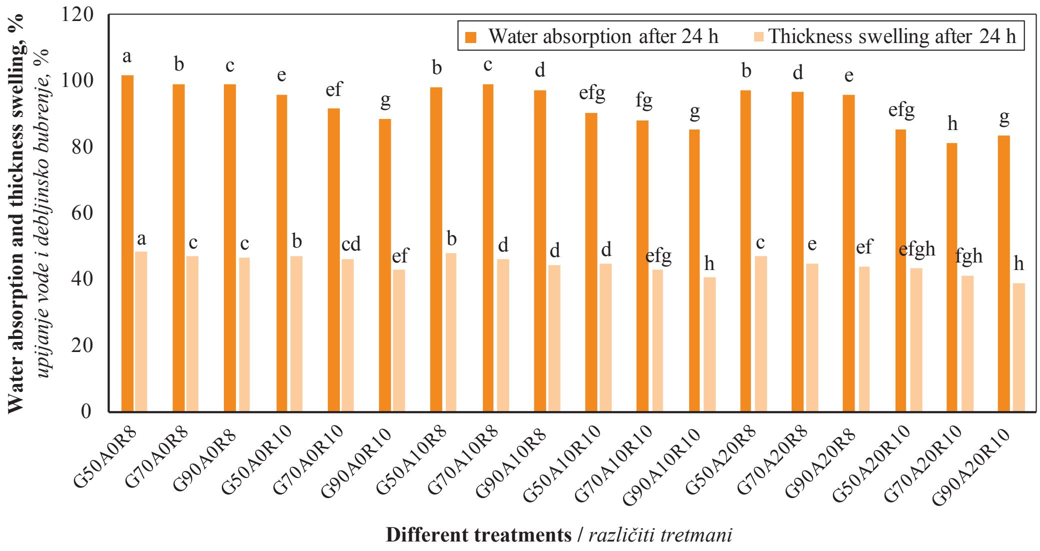

Figure 7 The effect of different treatments on water absorption and thickness swelling of particleboards after 24 hours of immersion in water
Slika 7. Utjecaj različitih tretmana na upijanje vode i debljinsko bubrenje ploča iverica nakon 24 sata potapanja u vodi

the particles. Thus, forming an ester linkage would provide good adhesion and impart excellent particleboard properties (Ksumah *et al*., 2017).

The results showed that all the boards, except for those containing 50 % garden tree branches, no citric acid, and UF 8 % resin (treatment G50A0R8), had a strength exceeding the EN˝312 standard for general use (Type P1). Considering the price of citric acid and the lack of wood resources, two types of boards for type P1 can be proposed to the factories, namely: 1) the boards containing 70 % garden tree branches, 0 % citric acid and 8 % UF resin (treatment G70A0R8) 2) the boards containing 50 % garden tree branches, 0 % citric acid and 10 % UF resin (treatment G50A0R10).

The boards containing 70 % and 90 % garden tree branches, 20 % citric acid and 10 % UF resin (treatment G70A20R10 and treatment G90A20R10), as well as the boards containing 90 % garden tree branches, 10 % citric acid and 10 % UF resin (treatment G90A10R10) have a higher resistance than specified by the EN312 standard for interior fittings (Type P2).

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Corresponding address:
VAHID VAZIRI
Gonbad Kavous University, Basirat Bolvar, Gonbad Kavous, Golestan, IRAN, e-mail: vahidvaziri@gmail.com