Fermentation Pretreatment and Extraction's Effect on the Acoustic Properties of Walnut Wood *(Juglans regia)*

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Despite the progress in synthetic polymer industries, wood is one of the main materials in making musical instruments because of its unique characteristics. Many instrument makers try to improve the acoustic properties of wood by traditional treatments. In this study, the changes in the acoustic properties of walnut wood during the processes of fermentation pretreatment, water washing, and organic solvent washings were evaluated. For this, the samples were divided into two groups of 20. For the first group, de-extraction was started with fermentation pretreatment, while the second group samples directly underwent stepwise extraction, using hot water and ethanol-acetone solvents. The results showed a decrease in density, dynamic modulus of elasticity, and damping factor due to the soaking process. But the elastic stiffness did not change. The values of the acoustic coefficient and the acoustic conversion efficiency increased due to the soaking process. The values of density, dynamic modulus of elasticity, elastic stiffness, and damping factor decreased due to ethanol-acetone washing, while the acoustic coefficient and acoustic conversion efficiency showed a significant increase. In general, soaking process and ethanol-acetone washing with fermentation pretreatment improved the acoustic properties of walnut wood.

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INTRODUCTION

The use of wood in special applications, such as covering walls in movie theaters, auditoriums, movie studios, music halls, and as the main material in making musical instruments, has attracted the attention of researchers to recognize new mechanical and physical properties of this material (Brémaud 2012; Xu *et al*. 2014). Despite the progress in the synthetic polymer industry, the unique acoustic properties of wood have made it possible to use this material in a contrasting manner, and this material is used in sound insulation applications and as a sound resonator in musical instruments (Matsunaga *et al*. 1999; Wegst 2006; Roohnia 2019). It is obvious that the choice of wood in each of the uses of sound insulation or sound reflector is made according to its physical and mechanical characteristics. In general, woods with low porosity are used for applications requiring sound reflection, and wood with high porosity are used for sound insulation applications

(Gan *et al*. 2019a,b). Wood extractives have a significant effect in mass of wood, damping factor, and modulus of elasticity.

Many traditional musical instrument makers improve the acoustic properties of wood by washing the wooden plates used in the instruments and thereby removing extractives from the wood (Roohnia *et al*. 2011). In recent years, in addition to the effect of soaking as a polar solvent, the effect of removing extractives by non-polar solvents, such as ethanol-acetone combination and other non-polar solvents, has attracted the attention of many researchers. Obataya *et al*. (1999) investigated the effect of extracting water-soluble substances on the acoustic properties of a species of reed called giant cane or elephant grass (*Arundo donax* L.), which is effective in the vibrating plate of a clarinet, at different percentages of moisture content. The results indicated that at low humidity, the presence of extractives increases the modulus of elasticity, and this effect decreased with the increase in moisture content due to the release of water-soluble extractives. Minato *et al*. (2010), through investigating the effect of extractive on the vibrational properties of Muirapiranga species (*Brosimun* sp.), stated that this species has a rather small damping factor value and its use in making violin bows is not a good idea. The reason for the low tan δ in this wood is the presence of extractives, such as xanthyletin and luvangetin. Roohnia *et al*. (2011) studied the acoustic properties of white mulberry wood before and after a traditional soaking process. The reduction of extractive values improved the acoustic properties of white mulberry wood. Segolpayegani *et al*. (2012) extracted white mulberry wood extracts separately and step-by-step in polar and non-polar solvents and investigated their effects on its dynamic properties. The removal of extractives by their dissolution in organic solvents with less polarity caused the damping factor to increase, while the specific elastic modulus elasticity of this wood and its anisotropy factor did not change significantly. Roohnia *et al*. (2015) investigated the effect of extracting substances from maple wood species (*Acer velutinum*) on acoustic properties. The finding revealed the improvement of the acoustic properties of this species due to the removal of extractive. Mollaeikandelousi *et al.* (2016) investigated the effect of removing extractives from maple wood (*Acer pseudoplatanus*) and found that removing extractive materials from this species also improves its acoustic properties. Miao *et al.* (2021) investigated the effect of extraction of extractives from *Picea jezoensis* var. *microsperma* using deionized water and non-polar organic solvents. The results indicated that after the extraction process, the factors of acoustic coefficient and vibration damping were improved. Because the main acoustic quality of wood used in musical instruments depends on the density and damping factor of the wood, therefore, a method that reduces the density and damping factor can be a suitable modification.

Most of the extractives do not have a structural role in wood, and their removal as much as possible – provided that it does not affect the elastic stiffness – can further improve the acoustic properties of wood used in soundboard. Therefore, pre-treatments such as fermentation (before the processes of extracting substances with organic and inorganic solvents) can cause more extractive substances to be removed from wood. Bread yeast is found on plants, grains, and fruits, which is sometimes used for baking. In general, it is not found in pure form, but comes from being propagated in a sourdough starter. One of the most famous bread yeasts belongs to the *Saccharomyces* genus, which is also known as *S. minor* (Ali *et al.* 2012). A living organism fungus requires warmth, water, albumen or nitrogenous material, and sugars to remain alive. Consequently, fermentation can convert the free sugar compounds in the extractive into alcohol in the depth of the wood. The resulting alcohol dissolves a number of other organic substances in itself, and finally, in the processes of soaking and washing with ethanol-acetone mixture, the extractives from the wood are emptied as best as possible. Therefore, the purpose of this study was to investigate the effect of the soaking process (removal of extractives soluble in polar solvent) and the process of removing extractives with ethanol-acetone (removal of extractives soluble in non-polar solvent) on the acoustic properties of the walnut wood (*Juglans regia*), which is one of the popular species in making traditional Iranian musical instruments, is fermented (with bread yeast) before and after pretreatment.

EXPERIMENTAL

Materials

Walnut wood species (*Juglans regia*) were collected from heartwood of a commercial log harvesting place in Karaj Gardens. It was visually graded as suitable for Iranian musical instrument making. Forty clear specimens with the dimensions of 150 × 12 × 2 mm^3 (L × R × T) were cut and kept in a climatic chamber (20 ± 1 °C and 65 ± 5% RH) for three weeks. After the mentioned period, the samples were removed from the climatic chamber to measure the initial physical and acoustic properties. After weighing and measuring the dimensions, the forced vibration in free-free beams test was performed on them by the NDT-lab$^{@}$ system (Karaj, Iran) (Roohnia 2007).

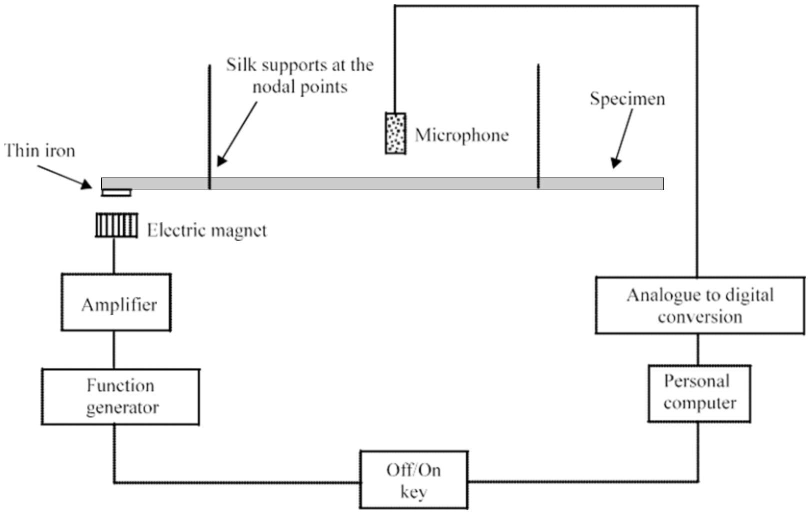

Fig. 1. A schematic view for the contactless forced vibration system

Method

First, samples were divided into two groups of 20 samples. The first group was placed in the process of removing extractives using pure water without fermentation pretreatment, and then by ethanol-acetone mixture for 12 h and inside a Soxhlet tube (Farvardin *et al*. 2015; Roohnia *et al*. 2015). After each step of soaking and ethanol-acetone mixture extraction, the forced vibration in free-free bar test was performed on the specimens. After each of the extraction processes, the specimens were subjected to an air-dried stabilization, beginning from a wet condition, in a climatic chamber (21 ± 1 °C temperature and 65 ± 5% RH) until the dimension shrinkages were stopped. The stabilized moisture contents were measured, and the extracted specimens were subjected to the vibration and acoustic characterization. The second group of samples was subjected to fermentation pretreatment by bread yeast-water solution (*Saccharomyces*, *S. minor*) in the process of removing extractives using water and ethanol-acetone mixture. After the completion of each process of removing extractives, a forced vibration test was performed to measure the acoustic properties of the samples. Therefore, the first group was washed with water without pretreatment and then washed with ethanol-acetone mixture, and the second group was washed with pretreatment of water and then the ethanol-acetone mixture. Bread or baker's yeast was used for the purpose of pretreating fermentation of the specimens. Some ice cream sticks, which had been already prepared, were submerged into the fermenting solvent and were kept until the fermentation stopped. When the boiling fermentation ceases, it is indicated that there is no food available for the yeasts anymore, and the yeasts have consumed the food that had been served to them from the additional sugar or wood extractives, while, converting them into ethanol and carbon dioxide. Thus, the pretreatment operation of the samples was completed according to the experience of traditional luthiers and the samples became ready to continue with the extraction operation.

According to Euler-Bernoulli's theory, the Young's modulus is evaluated as,

$$E_{\mathrm{L}} = \frac{48\pi^2 f^2 \rho L^4}{m_n^4 h^2} \tag{1}$$

where h is the height of the flexural beam and m_{n} is a scalar depending on the end support conditions and mode number, n. For a both ends free beam it is equal to 4.73 for the 1st mode. For higher modes of vibration, the result is calculated from the following Eq. 2 (Bodig and Jayne 1993):

$$m_{\mathrm{n}} = \frac{2_n+1}{2}\pi \tag{2}$$

Elastic stiffness is the most common indicator of the elastic property of a material, *i.e.*, wood, which means that wood is in the normal or shear stress-strain domain. Therefore, this factor of dividing the modulus of elasticity by the density is introduced as specific stiffness

$$(\mathrm{S}){:}S_{\mathrm{L}} = \frac{E_{\mathrm{L}}}{d} \tag{3}$$

Damping of vibration was introduced as shown in Fig. 2 and calculated using Eqs. 2 and 3 (Roohnia 2019),

$$\lambda = \frac{1}{n} ln \left|\frac{X_1}{X_{\mathrm{n}+1}}\right| \tag{4}$$

$$tan\ \delta = \frac{\lambda}{\pi} \tag{5}$$

where λ is the logarithmic decrement, and tan δ corresponds to the damping of vibration.

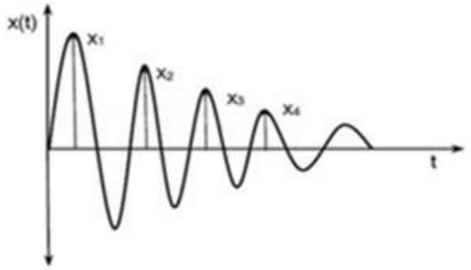

Fig. 2. Expressions of damping capacity in the temporal field through logarithmic decrement λ

The acoustical coefficient (K) and acoustical conversion efficiency (ACE), based on modulus of elasticity, density, and damping factor, are applied in the musical instrument industry as criteria in selecting the proper wood (Ono and Norimoto 1984; Tsoumis 1991; Roohnia 2019). These parameters are calculated through Eqs. 6 and 7,

$$K = \sqrt{\frac{E}{\rho^3}} \tag{6}$$

$$ACE = \frac{K}{Tan\delta} \tag{7}$$

where K is the acoustic coefficient ($m^4.s^{-1}.kg^{-1}$), E is the modulus of elasticity (Pa), ρ is the density of the wood specimens ($kg.m^{-3}$), and ACE is the acoustical converting efficiency ($m^4.s^{-1}.kg^{-1}$).

A comparison of each one of the mechanical properties obtained from each one of the test stages was also made by a statistical T-test at 95% confidence level. The SPSS v.17.5 software (IBM Corp., Armonk, NY, USA) was applied in the statistical tests and Microsoft Excel 2013 (Microsoft Corporation, Redmond, WA, USA) was applied to draw the diagram.

RESULTS AND DISCUSSION

Figure 3 shows the changes in density due to the two steps of the removal of extractives soluble in water and the removal of extractives soluble in an ethanol-acetone mixture without pretreatment and with pretreatment using bread yeast. As is evident from Fig. 3, the consecutive removal of the extractives by pure water and ethanol-acetone mixture in walnut wood reduced the density values (both without and with pre-treatment).

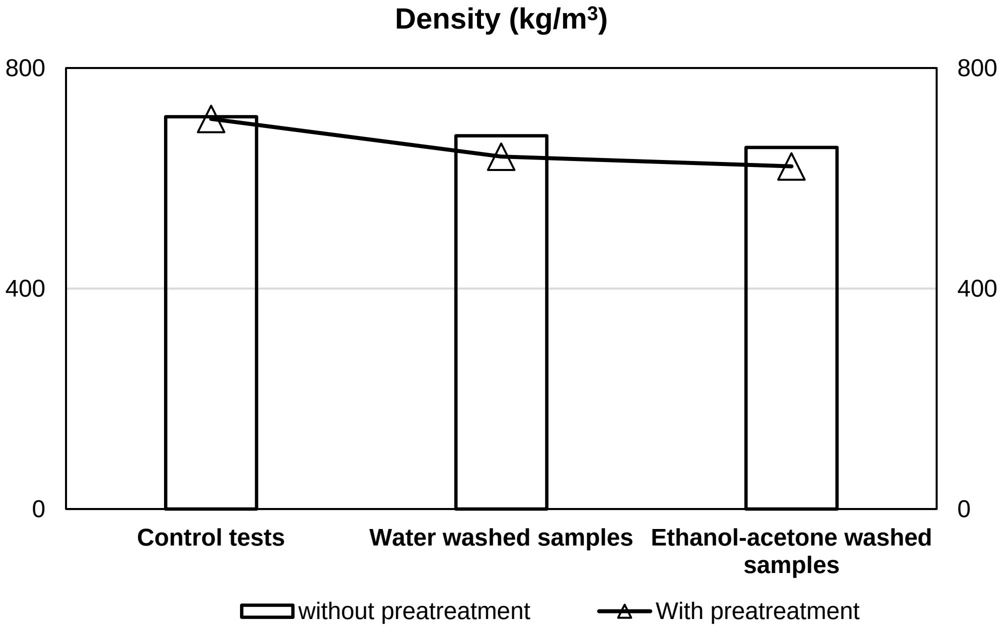

Fig. 3. Density: Comparing the data before and after consecutive extractions

In accordance with the results obtained from the values of modulus of elasticity, the process of soaking and washing by ethanol-acetone mixture both reduced the values of this factor (Fig. 4). The rate of decrease in the modulus of elasticity values in ethanol-acetone mixture washing was more than from the soaking process. Moreover, the pre-treatment in both processes of extraction caused the decrease in the values of the modulus of elasticity.

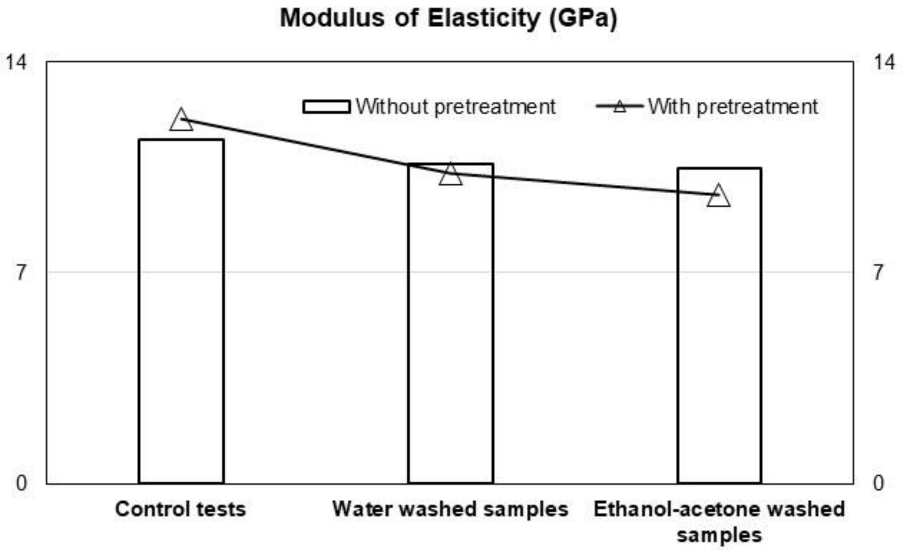

Fig. 4. Modulus of elasticity: Comparing the data before and after consecutive extractions

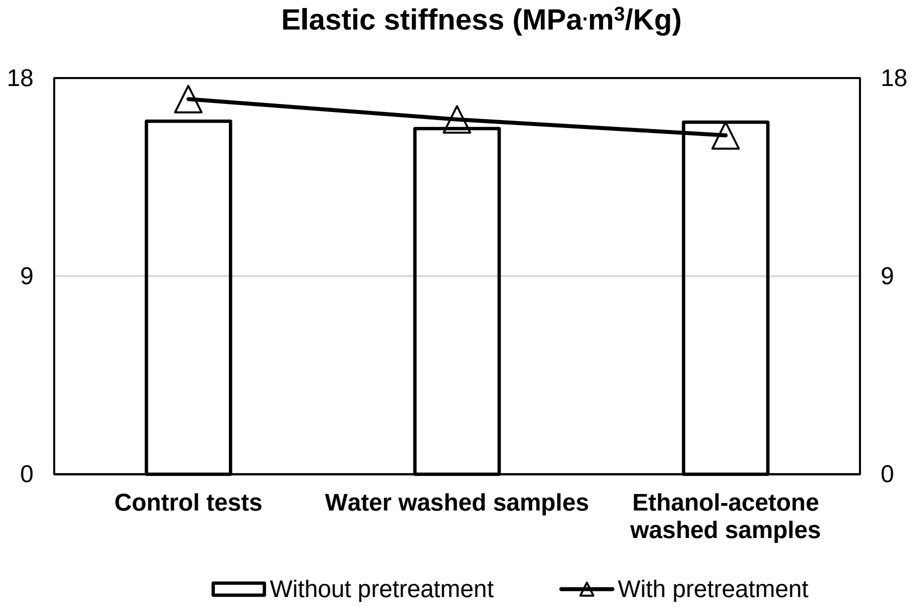

Fig. 5. Elastic stiffness: Comparing the data before and after consecutive extractions

Decreasing the modulus of elasticity is considered of high importance because of its direct effect on the elastic stiffness factor (Fig. 5). According to the results of elastic stiffness, it seems that some of the compounds extracted from the samples as a result of ethanol-acetone mixture washing play a structural role in the values of this factor, as opposed to the compounds extracted from the soaking process. The soaking process, both with and without pretreatment, did not have a significant effect on the values of elastic stiffness, while ethanol-acetone mixture washing of the samples caused a significant decrease in the values of this factor. Pretreatment aggravated the drop in stiffness modulus values due to the ethanol-acetone mixture washing.

Considering that the dimensions and thickness of the samples were small and therefore the drying conditions of the samples were done slowly and without applying external forces, it does not appear that the drop in the elastic stiffness values is related to the consecutive wetting and drying cycles of the samples. Furthermore, after each treatment and drying process, the dimensions of the samples were accurately measured. The findings of this research were similar to the results obtained from Farvardin *et al*. (2015) regarding *Albizia julibrissin* species, Segolpaygani *et al*. (2012) regarding white mulberry species, and Minato *et al*. (2010) about *Caesalpinia echinata* wood. Additionally, the results of previous research on the nature of extractives of walnut wood showed that the removal of extractives from this species has a negative effect on the resistance factors. The injection of extractives of the walnut species into the poplar species improved its strength factors (Hosseini Hashemi and Jahan Latibari 2011).

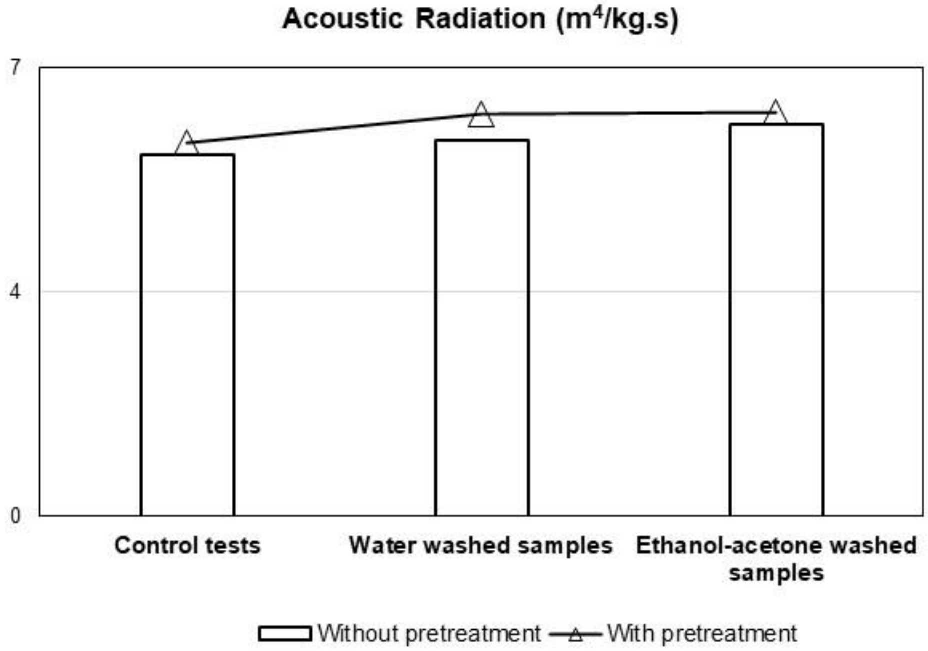

Fig. 6. Acoustic radiation: Comparing the data before and after consecutive extractions

As shown in Fig. 6, the acoustic coefficient of the samples increased due to the soaking process and the removal of extractive substances soluble in ethanol-acetone mixture. Pre-treatment in the soaking process increased the values of this factor, while pre-treatment in the removal of extractives soluble in ethanol-acetone mixture has not had an effect on the values of this factor compared to the process that did not involve pre-treatment. Therefore, pre-treatment in soaking process improved the process, while it did not affect the samples washed by ethanol-acetone mixture.

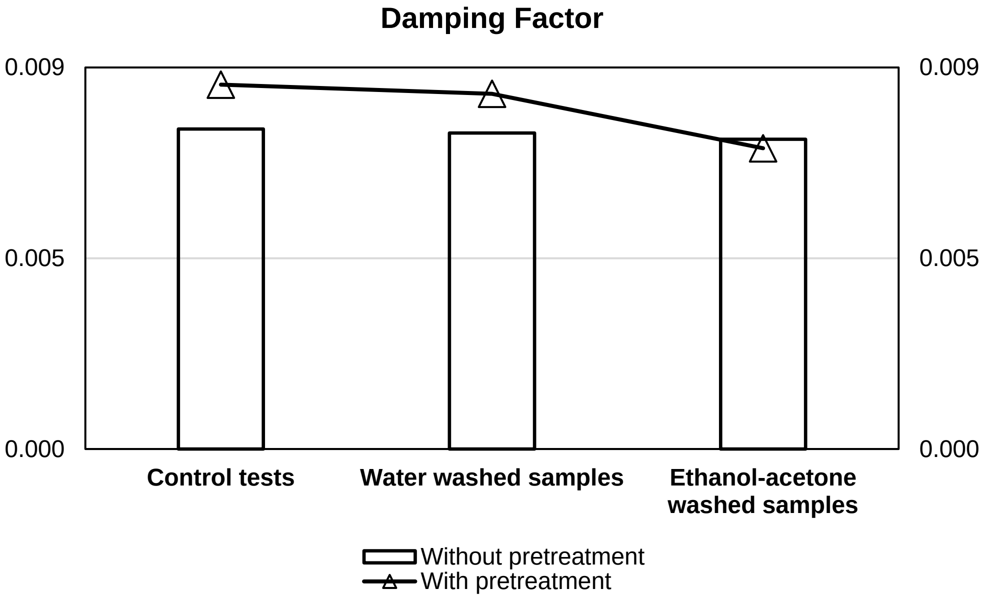

Fig. 7. Damping factor: Comparing the data before and after consecutive extractions

The soaking process and ethanol-acetone mixture washing without pretreatment of the samples had no significant effect on the damping factor values (2% and 3% drop due to soaking process and ethanol-acetone mixture washing, respectively). By contrast, pre-treatment caused a significant decrease in damping factors values of both treatments (Fig. 7). Therefore, the results demonstrate the favorable effect of pretreatment on the results of damping factor after soaking process and ethanol-acetone mixture washing. Pretreatment before ethanol-acetone mixture washing had the greatest effect in reducing damping factor values. In the previous studies by Miao *et al*. (2021), Mollaeikandelousi *et al*. (2016), and Roohnia *et al*. (2015), which investigated *Jezoensis* var. *microsperma*, *Acer velutinum*, and *Acer pseudoplatanus* species, respectively, revealed results that were similar to the present study.

The ACE is regarded as the most important indicator in the process of selecting the most proper type of wood for musical instruments. A higher value of this factor means the wood is more suitable for use in making musical instruments (Roohnia 2019). The values of this factor increased significantly due to soaking process and ethanol-acetone mixture washing (Fig. 8). Pretreatment caused a further improvement in ACE because of the soaking process and ethanol-acetone mixture washing, and the amount of increase in ethanol-acetone mixture washing reached 30%. In earlier research by Ghaznavi *et al.* (2013), Mollaeikandelousi *et al*. (2016), and Roohnia *et al*. (2015), results similar to the present research were obtained from *Pinus sylvestris*, *Acer pseudoplatanus*, and *Acer velutinum* species, respectively. Considering the involvement of modulus of elasticity, density, and vibration damping in the calculations related to the ACE, it seems that the improvement of this factor has compensated for the decrease in the values of the modulus of elasticity.

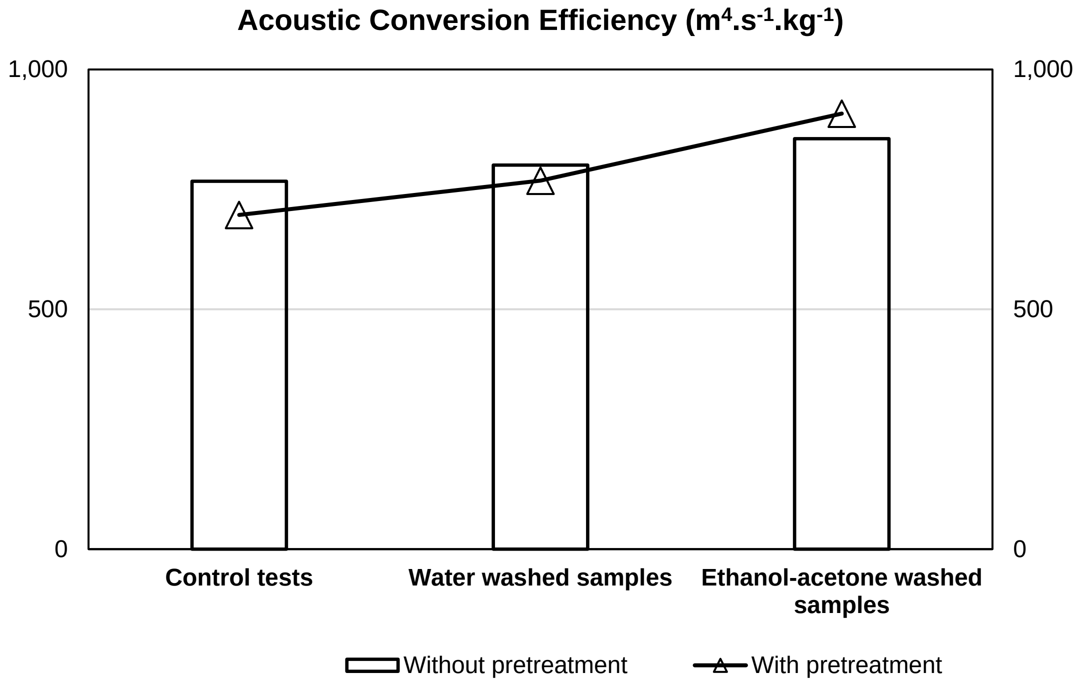

Fig. 8. Acoustic conversion efficiency: Comparing the data before and after consecutive extractions

CONCLUSIONS

1. A soaking process with water was effective in reducing the wood's density values, but it reduced the values of the modulus of elasticity and did not change the values of the elastic stiffness. This indicates that water-soluble extractives do not have a useful structural role in walnut wood.
2. Removal of extractives soluble in ethanol-acetone mixture was successful in reducing the density values, but it did not improve the values of the modulus of elasticity and elastic stiffness. This indicates that walnut extractives soluble in ethanol-acetone mixture are beneficial to dynamic elasticity modulus and elastic stiffness.
3. The soaking process with water and ethanol-acetone mixture washing improved the acoustic coefficient. Pretreatment in both methods caused further improvement of this factor.
4. The soaking process with water without pretreatment did not have much effect on improving damping factor values, while pretreatment before soaking process caused a significant decrease in damping factor values.
5. Ethanol-acetone mixture washing significantly improved the vibration damping values. Pretreatment before ethanol-acetone washing caused a further decrease in damping factor values. The presence of extractives soluble in ethanol-acetone mixture has a negative effect on damping factor values of walnut wood.
6. The soaking process with water and ethanol-acetone mixture washing improved the acoustic conversion efficiency as the main criterion in the selection of wood for musical

instruments. Pre-treatment in both methods had a very favorable effect in improving the ACE factor, so that in ethanol-acetone mixture washing it caused a 30% increase in its values.

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