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PHYSICAL AND CHEMICAL PROPERTIES OF THREE WILD ALMOND WOOD SPECIES GROWN IN ZAGROS FORESTS

FIZIKALNE IN KEMIJSKE LASTNOSTI LESA TREH DIVJIH VRST MANDLJEVCA, KI RASTEJO V GOZDOVIH ZAGROSA

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Abstract / Izvleček

Abstract: In this study, the physical properties (oven-dry density, basic density, volumetric shrinkage, and swelling) and structural components (cellulose, lignin, and extractives content) of three wild almond wood species from southwestern Iran, namely *Amygdalus arabica*, *Amygdalus eburna*, and *Amygdalus scoparia*, were investigated. Wild almond is a valuable wood species in the Zagros forests of Iran, but there is a lack of data on their wood properties. Three adult trees of each species were chosen, and samples were prepared from the breast height diameter to measure the focal properties. Results of analysis of variance (ANOVA) showed that the wood species had a significant effect on the wood density and volumetric shrinkage. Maximum oven-dry density and volumetric shrinkage of wood were identified in *Amygdalus scoparia*. The highest and lowest content of structural components were found in *Amygdalus* scoparia and *Amygdalus arabica* wood species, respectively. A deep understanding of the almond wood characteristics will provide a fresh insight into the relationship between the properties and conservation of these special, as well as applications of their wood.

Keywords: *Amygdalus*, wood, density, volume shrinkage, cellulose, lignin, Zagros, Iran

Izvleček: V študiji so bile raziskane fizikalne lastnosti (gostota, osnovna gostota, prostorninsko krčenje in nabrekanje) in kemijska sestava (celuloza, lignin in ekstraktivne snovi) lesa treh divjih vrst mandljev, in sicer *Amygdalus arabica*, *Amygdalus eburna* in *Amygdalus scoparia* iz jugozahodnega Irana. Divji mandelj je dragocena drevesna vrsta v gozdovih Zagrosa v Iranu, podatki o lastnostih lesa pa so pomanjkljivi. Izbrana so bila tri sestojna drevesa vsake vrste, za merjenje omenjenih lastnosti pa so bili pripravljeni vzorci iz nivoja v prsni višini. Rezultati analize variance (ANOVA) so pokazali, da vrsta pomembno vpliva na gostoto lesa in prostorninsko krčenje. Največje vrednosti gostote absolutno suhega lesa in prostorninskega skrčka so bile ugotovljene pri vrsti *Amygdalus scoparia*. Najvišje in najnižje vsebnosti kemijskih komponent pa so bile ugotovljene pri lesnih vrstah *Amygdalus scoparia* in *Amygdalus arabica*. Poglobljeno razumevanje značilnosti mandljevega lesa bo omogočilo nov vpogled v povezavo med lastnostmi in ohranjanjem ter uporabo lesa raziskanih vrst.

Ključne besede: *Amygdalus,* les, gostota, prostorninsko krčenje, celuloza, lignin, Zagros, Iran

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1 INTRODUCTION
1 UVOD

Almond species grow with a large geographical distribution from the southwest to the centre of Asia (Gradziel, 2011). Iran is thought to be the centre of the origin and growth of almonds (Zohary & Hopf, 2000). As such, Iran is an important region for the world almond gene pool and the distribution of wild almond species due to its suitable climate (Balvardi et al., 2015; Nikoumanesh et al., 2011). Twen-

ty-one wild species and seven inter-specific hybrids have been identified and reported in Iran, of which ten are supposed to be endemic (Khatamsaz, 1998). Zagros forests represent about 40% of Iranian forests and are the most extensive forest area (Sagheb-Talebi et al., 2004). Almonds are deciduous shrubs and small trees adapted to arid or semi-arid environments. They exist as a relatively pure and dominant stand or scattered between 600 to 2200 meters above sea level. This plant is a shrub with a height of 2 m that sometimes reaches a height of 6 m and a stem diameter of 5-20 cm.

Most studies regarding almond tree species are related to their distribution, ecological requirements, and morphological properties, while wood properties such as the physical and chemical properties have not been reported yet. Fundamental studies in these cases can reveal the possibility of the wood's use in various applications or lead to creating a database of different wood species (Bahmani et al., 2020; Dong et al., 2021). Kiaei and Samariha (2011) investigated the physical properties of five important hardwood plants from the forests of north Iran and found that the highest wood density was determined for hornbeam, beech, ash, and oak. Most studies regarding Zagros forest wood species are related to their distribution and ecological factors, and few have examined the wood properties. For example, Bahmani et al. (2018) investigated oak wood's physical and chemical properties in Zagros forests. They found that the density of the Persian oak (*Quercus brantii* Lindl.) is between 0.85 g·cm^{-3} and 1.01 g·cm^{-3}, and volumetric shrinkage ranges from 11.32% to 14.15%. Moreover, their results indicated that the cellulose content increased with increasing diameter, and the lignin content decreased. Nazari et al. (2020) studied the geographic variations of wood density and fibre dimensions of Persian oak wood, and reported a significant statistical effect of altitude and slope on the volumetric swelling of this material. In another study by Nazari et al. (2021), the influence of site conditions on the physical and morphological properties of hawthorn (*Crataegus azarolus*) wood grown in the Zagros forests of Iran was investigated. They reported that there were statistically significant differences in the oven-dry density of hawthorn wood at various altitudes, while no significant differences were found between the values of volumetric shrinkage. Understanding the properties of almond wood is important for utilizing wood resources. To the best of our knowledge, there are no published studies relevant to the properties of wild almond wood. Considering the valuable position of these wood species in the Zagros forests of Iran, this study aims to investigate the physical properties, including dry-density, basic density, volumetric shrinkage and swelling, and chemical components (cellulose, lignin, extractives, and ash) of three wild almond wood species.

2 MATERIALS AND METHODS
2 MATERIALI IN METODE

2.1 MATERIALS
2.1 MATERIALI

This research was done on three wild almond wood species – desert almond (*Amygdalus arabica*; H=2.58 m, DBH=6 cm), grey almond (*Amygdalus eburna*; H=2.45 m, DBH=7.5 cm), and mountain almond (*Amygdalus scoparia*; H=2.00m, DBH=4.7cm), which were all cut from natural forests in Karebass and choliche-Charmahal and Bakhtiari province in the southwest of Iran. The research area is located between 31°31'36" N and 31°33'55" N and between 51°1920" E and 51°12'15". Disks from each sampled tree were cut at breast height. The annual rainfall and annual average temperatures were 555 mm and 16.7 °C, respectively. December and November are high-rain months and June and July are low-rain months. The temperature reaches its maximum level in June, July and August. The altitude of this site was 1580 m.

2.2 PHYSICAL PROPERTIES
2.2 FIZIKALNE LASTNOSTI

Discs, 5 cm in thickness, were taken from logs to determine physical properties such as oven-dry density, basic density, volumetric shrinkage, and volumetric swelling. Determination of wood density was carried out based on the ISO-3131 (2016) standard. For determining the physical properties, testing samples were obtained following ASTM-D143 (2000) and used for measuring the oven-dry and basic density, volumetric swelling and volumetric shrinkage. For this propose, thirty samples were prepared from different parts of the disks (10 samples from each disk) with the dimensions of

30 × 20 × 20 mm³ (tangential × radial × longitudinal). The samples were oven dried at 103 °C to reach a constant weight. Dimensions and dry weight were then measured, with the former Measured in all three principal directions with a digital caliper to the nearest 0.001 mm. The digital balance used for the measurement had an accuracy of 0.01 g. Afterwards the samples were immersed in water (one week) and the weight and dimensions of the samples were re-measured.

The physical properties of the samples were calculated using the following equations:

$\rho_0 = m_0 / V_0$

$R = m_0 / V_s$

$\alpha_v = (V_g - V_0)/V_0$

$\beta_v = (V_g - V_0)/V_s$

where: ρ_0 is oven dry density (g·cm^{-3}),
R is basic density (g·cm^{-3}),
β- volumetric shrinkage (%),
α is volumetric swelling (%),
V_g- volume in green state (g·cm^{-3}),
V_0 - volume in oven-dry state (g·cm^{-3}),
m_0 - weight in oven-dry state (g),
m_g - weight in green state.

2.3 CHEMICAL PROPERTIES
2.3 KEMIJSKE LASTNOSTI

The chemical components were determined according to the TAPPI Tests Methods: Cellulose (T 257 om-85), lignin (T 222 om-98), extractives (T 204 om-88) (Table 1). The cellulose content of almond wood was determined according to the nitric acid method (Rowell et al., 1997). All measurements were repeated three times, and the mean value was used.

2.4 STATISTICAL ANALYSIS
2.4 STATISTIČNE ANALIZE

To determine the physical properties (dry-density, basic density, volumetric shrinkage, and swelling) and chemical components (cellulose, lignin, extractives, and ash), statistical analysis was conducted using the SPPS 23 (IBM, Armonk, NY, USA) program in conjunction with the analysis of variance (ANOVA). Duncan's multiple range test (DMRT was used to test the statistical significance at the α = 0.05 level. All data were checked for normality with a Shapiro–Wilk's test.

3 RESULTS AND DISCUSSION
3 REZULTATI IN DISKUSIJA

3.1 MACROSCOPIC CHARACTERISTICS OF WOOD
3.1 MAKROSKOPSKA ZGRADBA LESA

The wood has a yellow to light brown colour with dark heartwood. Cross-sections indicate a semi-ring-porous distribution of vessels (Figure 1a, b, c). The presence of the vessels can be seen in all of the wood species investigated. As can be found from in literature (Allué et al., 2018), ray cells are uniseriate to 3- and 7-seriate depending on the species. Vessels show spiral thickenings with simple perforation plates. As seen on cross-sections, the wood is characterized by relatively wide annual rings, with clearly visible growth ring borders (Figure 1a, b, c). An attractive macroscopic appearance has made almond wood an excellent choice for furniture production in the past (Britannica Online Encyclopaedia, 2022). Due to the small dimensions of the trees, however, furniture applications are rare nowadays. The wood is now mainly used for high-quality end products such as knife handles, pencils, souvenirs and decorative boxes.

Table 1. Applied methods for measuring the structural components of wood
Preglednica 1. Metode, uporabljene za določitev kemijske zgradbe lesa

Chemical components	Standard	Description
Cellulose (%)	Pettersen (1984)	Concentrated nitric acid
Lignin (%)	T 222 om-98	Sulfuric acid 72%
Extractives (%)	T 222 om-88	Alcohol / acetone

a

Cross-section / Prečni prerez | Radial section / Radialni prerez | Tangential section / Tangencialni prerez

b

Cross-section / Prečni prerez | Radial section / Radialni prerez | Tangential section / Tangencialni prerez

c

Cross-section / Prečni prerez | Radial section / Radialni prerez | Tangential section / Tangencialni prerez

Figure 1. Macroscopic appearence of wild almond wood species: (a) Amygdalus arabica, (b) Amygdalus eburna, (c) Amygdalus scoparia

Slika 1. Prerezi lesa divjih mandljevcev (a) Amygdalus arabica, (b) Amygdalus eburna, (c) Amygdalus scoparia

3.2 PHYSICAL PROPERTIES
3.2 FIZIKALNE LASTNOSTI

The oven-dry density and basic density values for the three wild almond species – *Amygdalus arabica* (0.92 g·cm^{-3}; 0.79 g·cm^{-3}), *Amygdalus eburna* (0.91 g·cm^{-3}; 0.78 g·cm^{-3}), and *Amygdalus scoparia* (0.96 g·cm^{-3}; 0.93 g·cm^{-3}) – are given in Table 2. The analysis of variance (ANOVA) showed a significant difference between species regarding oven-dry density and basic wood density. The highest and lowest oven-dry density and basic density were found in *Amygdalus scoparia* and *Amygdalus arabica* wood, respectively. It is reported that there are several factors affecting the density of the wood, such as anatomical properties, e.g. vessel and fibre morphology, provenance, moisture content, and chemical composition (Wagenführ & Scheiber, 1995; Pásztory et al., 2014; Zeidler & Borůvka, 2016; Bahmani et al., 2020). Wood density classification is grouped according to Wong (2002): light (<0.5 g·cm^{-3}), moderately dense (between 0.5–0.8 g·cm^{-3}), including the almond wood species examined in this study, heavy (between 0.8–1.0 g·cm^{-3}), very dense >1.0 g·cm^{-3}).

The values of oven-dry density and basic density obtained in this study for the three species of almond were lower than those of other hardwoods, such as Persian oak and hawthorn growing in the Zagros forests, as reported by Bahmani et al. (2018) and Nazari et al. (2021). From the ANOVA test, there is a significant difference between wood species and volumetric shrinkage and volumetric swelling. Maximum and minimum volumetric shrinkage and swelling were identified in *Amygdalus scoparia* and *Amygdalus arabica*, respectively. As is well known, the relationship between wood density and volumetric shrinkage is positive (Sousa et al., 2018). Wood density is generally variable and is related to many factors such as anatomical characteristics, e.g., vessel and fibre morphology, ecological site, moisture content and chemical constitutes. Fibres are the most important elements affecting wood density, followed by vessels, as (for instance) reported by Kiaei (2012) for *Carpinus betulus*.

3.3 CHEMICAL COMPOSITION
3.3 KEMIJSKA ZGRADBA

Table 3 illustrates the mean values of the chemical constituents of the three wood species of almond.

The analysis of variance (ANOVA) showed significant differences between the tested species and the chemical components they contain. The highest and lowest content of cellulose, lignin and extractives were found in *Amygdalus scoparia* and *Amygdalus arabica* wood, respectively Such differences could be related to site, growth conditions and forest management practices (Zobel & Buijtenen, 1989; Bahmani et al., 2018). On average, hardwood comprises 40-45% cellulose, 17-25% lignin, and less than 10% extractives. Overall, the cellulose lignin content of *Amygdalus scoparia* is higher than the average of most hardwoods, whereas the lignin content does not differ significantly.

Table 2. The average values of physical properties in the three studied species. Standard deviations are given in the parenthesis. The different letters indicate a different statistical group.
Preglednica 2. Povprečne vrednosti fizikalnih lastnosti preučevanih vrst lesa. V oklepajih so podani standardni odkloni. Različne črke označujejo različne statistične skupine.

Wood species / Lesna vrsta	Oven-dry density / Gostota lesa (g·cm^{-3})	Basic density / Osnovna gostota (g·cm^{-3})	Volumetric shrinkage / Prostorninski skrček (%)	Volumetric swelling / Prostorninski nabrek (%)
Amygdalus arabica	0.92a (0.07)	0.79a (0.09)	0.10a (0.05)	0.11a (0.06)
Amygdalus eburna	0.91a (0.06)	0.78a (0.06)	0.12a (0.08)	0.14a (0.01)
Amygdalus scoparia	0.96b (0.02)	0.93b (0.01)	0.14b (0.02)	0.16b (0.02)

Table 3. The average chemical composition in the three studied species. Standard deviations are given in parentheses. The different letters indicate different statistical groups.
Preglednica 3. Povprečna kemijska sestava preučevanih lesnih vrst. V oklepajih so podani standardni odkloni. Različne črke označujejo različne statistične skupine.

Wood species	Cellulose (%)	Lignin (%)	Extractives (%)
Amygdalus arabica	39.92a (2.86)	17.96a (1.6)	3.89a (0.6)
Amygdalus eburna	43.18a (3.13)	18.52a (1.8)	4.01a (0.7)
Amygdalus scoparia	49. 83b (4.18)	25.71b (2.10)	5.12b (0.9)

4 CONCLUSIONS
4 SKLEPI

Wild almonds are valuable tree species in Iranian Zagros forests, although there is limited data on their wood properties. As such, in this study the wood properties of three wild almond species were examined. The results indicated that the studied wood is moderately heavy with a density between 0.91 g·cm^{-3} to 96 g·cm^{-3} and can be classified into moderate-volumetric swelling species. In addition, the cellulose content (39.92-49.83 %), lignin content (17.96-25.71 %), and extractive content (3.89-5.12 %) were determined. Considering the valuable position of tree wood species in Zagros forests, the results obtained in this study can provide basic information about the conservation and rehabilitation of almond wood. Further studies will address other properties such as the fibre dimensions and natural durability of wild almond wood against fungi, moulds, insects, and termites.

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5 SUMMARY
5 POVZETEK

Divji mandelj je dragocena lesna vrsta v gozdovih Zagrosa v Iranu, podatki o lastnostih lesa pa so pomanjkljivi. Različne vrste mandljev so geografsko razširjene od jugozahoda do osrednje Azije (Gradziel, 2011). Iran naj bi bil središče izvora mandljev (Zohary & Hopf, 2000) in je zaradi primernega podnebja pomembna regija za svetovni genski sklad in razširjenost divjih vrst mandljev (Balvardi et al., 2015; Nikoumanesh et al., 2011). Mandlji so listopadni grmi in majhna drevesa, prilagojena na sušna ali polsušna okolja. Večina študij mandljev se nanaša na njihovo razširjenost, ekološke zahteve, morfološke lastnosti, o lastnostih lesa, kot so fizikalne in kemijske lastnosti, pa še niso poročali. Temeljne raziskave bi lahko ovrednotile možnost njihove uporabe in omogočile oblikovanje podatkovne zbirke različnih vrst lesa (Bahmani et al., 2020; Dong et al., 2021). Bahmani et al. (2018) so raziskovali fizikalne in kemijske lastnosti hrastovega lesa v gozdovih Zagrosa. V literaturi ni podatkov o lastnostih lesa divjega mandlja, zato je namen te študije raziskati fizikalne in kemijske lastnosti treh divjih vrst mandljev *Amygdalus arabica*, *Amygdalus eburna* in *Amygdalus scoparia*. Les je bil posekan v naravnih gozdovih v provincah Karebass, Choliche-Charmahal in Bakhtiari na jugozahodu Irana. Raziskovalno območje se nahaja med 31°31’36” S in 31°33’55” S ter med 51°1920” V in 51°12’15”.

Iz hlodov so bili odvzeti 5 cm debeli diski za določanje fizikalnih lastnosti, kot so gostota absolutno suhega lesa, osnovna gostota, ter prostorninsko krčenje in nabrekanje. Gostota lesa je bila določena na podlagi standarda ISO-3131 (2016). Za določanje fizikalnih lastnosti so bili po standardu ASTM-D143 (2000) pridobljeni preskusni vzorci z dimenzijami 2 × 2 × 2 cm³, ki so bili uporabljeni za merjenje gostote absolutno suhega lesa in osnovne gostote ter prostorninskega krčenja.

Kemične sestavine so bile določene v skladu s preskusnimi metodami TAPPI: Celuloza (T 257 cm-85), lignin (T 222 om-98), pepel (T 211 om-93) in

topnost v alkohol-acetonu (T 204 cm-88). Vsebnost celuloze v mandljevem lesu je bila določena po metodi z dušikovo kislino (Rowell et al., 1997). Vse meritve so bile ponovljene trikrat, uporabljena pa je bila povprečna vrednost.

Za ugotavljanje razlik med vrstami mandljevca z vidika fizikalnih in kemijskih lastnosti je bila opravljena statistična analiza variance (ANOVA) s programom SPPS 23 (IBM, Armonk, NY, ZDA). Za preverjanje statistične značilnosti na ravni $\alpha = 0,05$ je bil uporabljen Duncanov test več razponov (DMRT).

Les je rumene do svetlo rjave barve s temno jedrovino. Prečni prerezi kažejo na (pol)venčasto porozno razporeditev trahej (slika 1a, b, c). Kot je mogoče razbrati iz literature (Allué et al., 2018), so trakovi 1-3 in 7-redni, odvisno od posamezne vrste. Traheje imajo spiralne odebelitve in enostavne perforirane ploščice. Kot je razvidno iz prečnih prerezov, so za les značilne razmeroma široke branike z jasno vidnimi mejami (slika 1a, b, c). Zaradi dekorativne teksture je bil mandljev les v preteklosti zaželen za izdelavo pohištva (Spletna enciklopedija Britannica, 2022). Zaradi manjših dimenzij dreves je danes uporaba za pohištvo redka. Les se večinoma uporablja za izdelke višjega cenovnega razreda, kot so ročaji nožev, svinčniki, spominki in okrasne škatle.

Vrednosti gostote absolutno suhega lesa in osnovne gostote so: *Amygdalus arabica* (0,92 $g \cdot cm^{-3}$; 0,79 $g \cdot cm^{-3}$), *Amygdalus eburna* (0,91 $g \cdot cm^{-3}$; 0,78 $g \cdot cm^{-3}$) in *Amygdalus scoparia* (0,96 $g \cdot cm^{-3}$; 0,93 $g \cdot cm^{-3}$) (Tabela 1). Analiza variance (ANOVA) je pokazala značilno razliko med vrstami za obe gostoti. Najvišja in najnižja gostota je bila ugotovljena pri lesu *Amygdalus scoparia* oziroma *Amygdalus arabica*.

Iz testa ANOVA je razvidna pomembna razlika med vrstami lesa v prostorninskem krčenju in nabrekanju. Največje in najmanjše prostorninsko krčenje in nabrekanje je bilo ugotovljeno pri vrstah *Amygdalus scoparia* in *Amygdalus arabica*.

Analiza variance (ANOVA) je pokazala pomembno razliko med vrstami in kemijskimi komponentami. Največja vsebnost celuloze, lignina in ekstraktivov je bila ugotovljena v lesu *Amygdalus scoparia* in najmanjša pri *Amygdalus arabica*. Razlike bi lahko bile povezane z rastiščem, pogoji rasti in praksami gospodarjenja z gozdom (Zobel & Buijtenen, 1989; Bahmani et al., 2018). V povprečju les listavcev vsebuje 40-45 % celuloze, 17-25 % lignina in manj kot 10 % ekstraktivnih snovi. Na splošno je vsebnost celuloze in lignina v drevesu *Amygdalus scoparia* višja od povprečja večine listavcev, medtem ko se vsebnost lignina bistveno ne razlikuje.

Rezultati so pokazali, da so preučevane vrste lesa srednje goste, z gostoto med 0,91 $g \cdot cm^{-3}$ in 96 $g \cdot cm^{-3}$, in jih uvrščamo med vrste z zmernim volumenskim nabrekanjem. Poleg tega je bila določena vsebnost celuloze (39,92-49,83 %), lignina (17,96-25,71 %) in pepela (3,89-5,12 %). Nadaljnje študije bodo obravnavale druge lastnosti, kot so dimenzije vlaken in naravno odpornost lesa divjega mandlja proti glivam, plesnim, žuželkam in termitom.

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