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Research paper

A comprehensive study of Iranian wild jujube (*Ziziphus jujuba* Mill.) by morphological and biochemical traits

Goshtasb Jalaie-Esfandabadi[1], Hossein Ali Asadi-Gharneh[1*], and Elmira Ziya Motalebipour[2,3,4]

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[1]Department of Horticulture, Isfahan (Khorasgan) Branch, Islamic Azad University, Isfahan, Iran
[2]Agronomy and Plant Breeding Department, Isfahan (Khorasgan) Branch, Islamic Azad University, Isfahan, Iran
[3]Medicinal Plants Research Center, Isfahan (Khorasgan) Branch, Islamic Azad University, Isfahan, Iran
[4]Transgenesis Center of Excellence, Isfahan (Khorasgan) Branch, Islamic Azad University, Isfahan, Iran
*Corresponding author; Email: h.asadi@khuisf.ac.ir

Abstract
Jujube (*Ziziphus jujuba* Mill.), with high nutritional value, is an important medicinal plant and is consumed worldwide as fresh and dry fruit. Iran is one of the most important germplasm centers for jujube. Jujube fruits are rich in mineral nutrients, protein, carbohydrates, and vitamin C. In this study, 12 different wild accessions of jujube were collected from different regions of Isfahan province. A total of thirty-four morphological and biochemical traits were evaluated. Significant differences were detected among accessions. The highest values of fruit length, fruit width, fruit weight, moisture percent, fruit flesh weight, flesh/stone ratio, stone weight, stone length, and stone width were 32.36 mm, 21.68 mm, 7.00 g, 87.11%, 6.61 g, 19.15, 0.39 g, 18.46 mm, and 7.45 mm, respectively. The highest level of total acidity content was observed in the Mahabad accession (1.38%) and the highest level of total soluble solids content was observed in the Poodeh accession (39.6% °Brix). The highest level of ascorbic acid and flavonoid content was measured in the Zavvareh (403.62 mg/kg DW) and Ganje-Ghobad accessions (250.12 mg/kg DW), respectively. The range of total phenolic compounds and mucilage content was from 8.8 to 37.97 (mg/kg DW) and 18.85 to 37.97 (mg/kg DW), respectively. The Anarak accession had the highest Zn (0.82 mg/100 g), Mn (58.37 mg/100 g), and K (698.72 mg/100 g) content, while the highest Fe (11.28 mg/100 g) and Ca (120.09 mg/100 g) content was observed in the Poodeh accession. In addition, the richest source of P (119.94 mg/100 g) was identified in the Kachoomesghal accession. Ganje-Ghobad, Poodeh, Koohpayeh, Anarak, and Zavvareh accessions showed higher values for morphological, and biochemical traits, which can be used for selecting specific genotypes for special purposes in the breeding programs of jujube and for drug industries.

Keywords: cluster analysis; genotype; nutrients and biochemical traits; *Ziziphus jujuba* Mill.

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Introduction
The Jujube is species of the genus *Ziziphus* which belongs to Rhamnaceae family. The genus *Ziziphus* includes two major domesticated species; Indian jujube or ber (*Z. mauritiana* Lam), and common jujube (*Z. jujuba* Mill) (Tripathi and Tripathi 2014). Jujube was cultivated 4000 years ago and is a native plant in China. It was through the famous 'Silk Road' that jujubes were introduced to Europe at the beginning of the Christian era (Lyrene 1979; Liu 2006). It is widely distributed in Iran, Armenia, Syria, Spain, and France (Lyrene 1979). Iran is the most important source of germplasm of jujube and the main cultivation area is in Southern Khorasan,

Isfahan, Golestan, Mazandaran, and Fars provinces. Moreover, wild shrubs of *Ziziphus* species are distributed in almost all parts of Iran, especially the Isfahan province. Also, shrubs more than 400 years old are grown in Southern Khorasan, Khonik village (Ghous 2017). Jujube trees are well known for their resistance to biotic and abiotic stresses such as water deficit, chilling, salinity, high temperature, and pest and diseases (Jalaie-Esfandabadi and Asadi-Gharneh 2016).

Jujube has an essential effect on human health in many ways (San *et al*. 2009). Jujube is used in traditional medicine for the curing of various diseases (Li *et al*. 2007). Jujube fruit is known as both a delicious fruit and an effective herbal remedy (Zhang *et al*. 2015). It has an important role in Iranian traditional medicine and is selected for its anti-inflammatory and antimicrobial effects (Mahajan *et al*. 2009). *et al*. 2009). Jujube causes a reduction in the blood levels of glucose and lipids, and it has been described as causing a significant decline in triglyceride, LDL, and cholesterol levels (Zhao *et al*. 2006).

In the past few years, there has been a growing interest in jujubes as a table fruit, chiefly due to their nutritive and health-promoting values (Jalaie-Esfandabadi and Asadi-Gharneh 2016). Jujube contains about 5% protein, 4% carbohydrate, and a considerable amount of A, C, and B vitamins and mineral nutrients (Shirdel Moreover, Jujube is rich in different flavonoids, sterols, tannins, saponin, and fatty acids (Zhao *et al*. 2006). Some research has been conducted about the morphological and biochemical features of jujube such as fruit weight (Reich 1991), nutritional composition (Li *et al*. 2007), seed weight (Ecevit *et al*. 2008), mineral composition of leaf and fruit (San *et al*. 2009), physicochemical properties and antioxidant capacity (Gao *et al*. 2011), juice content (Collado-Gonzalez *et al*. 2013), and fruit quality (Amin *et al*. 2018). Furthermore, variations of vegetative and fruit physicochemical characteristics (Ghazaeian 2015; Jalaie-Esfandabadi and Asadi-Gharneh 2016), morphological and pomological traits (Tatari *et al*. 2016) of jujube have been assessed through cluster analysis.

To our knowledge, there is not adequate information about jujube wild genotypes in Iran. This study is a comprehensive report revealing the morphological and biochemical traits in the Iranian wild jujube. Therefore, we aimed to investigate variations in 12 jujube wild genotypes of Iran (Isfahan province).

Materials and Methods

Sampling description

Twelve wild jujube accessions from different locations in the Isfahan province, Iran were collected from June to August 2015 (Table 1, Figure 1). Isfahan province is located between 49˚38´ E to 55˚32´ E longitude and 30˚42´ N to 34˚27´ N latitude. The Isfahan province has a good potential for cultivating plants like *Ziziphus jujuba* Mill., which are grown in arid and semi-arid regions. All samples were collected from their native localities and no treatments have been on them. In each area, 10 plants were randomly selected. Ten fruits from different branches of each plant with 30 cm in trunk diameter were collected and labeled according to their collection places. For further analysis, 30 mature fruit samples from each accession was used.

Table 1. Geographical locations of 12 wild *Ziziphus jujuba* Mill. accessions

Genotype	Longitude (E)	Latitude (N)	Altitude (m)
Ardestan	52˚37′	33˚38′	1207
Isfahan	51˚39′	32˚38′	1570
Anarak	53˚41′	33˚18′	1475
Bayazieh	55˚60′	33˚20′	915
Poodeh	51˚66′	32˚12′	2150
Khoorobiabanak	55˚09′	33˚77′	796
Zavvareh	52˚29′	33˚26′	1217
Kachoomesghal	52˚43′	33˚29′	1465
Koohpayeh	52˚67′	32˚72′	2078
Ganje-Ghobad	51˚64′	32˚13′	1880
Mahabad	52˚21′	33˚53′	1380
Natanz	51˚91′	33˚51′	1666

Figure 1. Geographical locations of 12 *Ziziphus jujuba* Mill. genotypes used in this study

Morphological characters

Fruit morphological characteristics (fruit length, fruit width, fruit weight, fruit flesh weight, flesh/stone weight, stone length, stone width, stone weight) were measured according to the International Plant Genetic Resources Institute (IPGRI) descriptor (Asadi-Gharneh 2015; Ghazaeian 2015). Fruit length, fruit width, stone length, and stone width were measured by a digital caliper. Fruit weight, flesh weight, stone weight, and flesh/stone ratio were measured by a digital balance (0.001 g sensitivity). To calculate moisture percent, fruit flesh weight was measured and transferred to an oven at 105 ˚C for 48 h, and fruit dry weight was measured. Then moisture percent was calculated using the following formula:

moisture percent = (fruit fresh weight – fruit dry weight)/ fruit flesh weight ×100 (Ghazaeian 2015).

The shoot and leaf morphological characteristics, young shoot length, young thorn length, the longest thorn, number of thorns in a shoot, leaf length, leaf width, terminal leaflet length, terminal leaflet width, and petiole length were also measured based on the jujube descriptor (Asadi Gharneh 2015; Ghazaeian 2015) by a digital caliper.

Biochemical analysis

Total soluble solids were measured by a digital refractometer (Erma, Tokyo, Japan; calibrated using distilled water). After homogenizing, the electrical conductivity (EC: dS/m) of the juice was measured using a conductometer (Metrohm Herisau, Type 712, Switzerland). Total acidity was measured by following the AOAC (1984) method. Fruit juice was titrated with 0.1 M NaOH at pH 8.1 and the malic acid percent was calculated. The ascorbic acid content was determined according to the method described by Ruck (1963). Also, the total flavonoid content was estimated according to Park *et al*. (2008). The concentration of phenolic compounds was determined by the spectrophotometry method (Singleton and Rossi 1965). The mucilage was extracted by the hot extraction method of Nazif (2002).

Mineral elements including Ca, Mg, Mn, Cu, Fe, and Zn were determined by an atomic absorption spectrophotometer (model 3400, Perkin Elmer, Wellesley, Mass) according to Chapman *et al*. (1996). Potassium was measured in the emission mode of the spectrometer. Phosphorus content was determined by b a spectrophotometer (Jeffery *et al*., 1989).

Data analysis

All data were expressed as the mean three replications. The means were compared by Duncan's multiple range test. Differences were considered significant at $p \leq 0.05$.

The 34 morphological and biochemical traits were used to evaluate the variability of 12 wild jujube accessions. The UPGMA cluster analysis was performed to construct a dendrogram from the distance matrix. The dendrogram was drawn using NTSYSpc v2.10e (Rohlf 2000) software. Other statistical analyses were carried out by MSTATC (Michael 1997, version 1.2) and Excel 2010 software.

Results

Morphological and biochemical characteristics

Geographical locations of 12 wild *Ziziphus jujuba* Mill. accessions are shown in Table 1. The Poodeh accession was collected from the highest altitude (2150 m) while Khoorobiabanak was gathered from the lowest one (796 m). The highest longitude and latitude belonged to Bayazieh (55˚60´E) and Khoorobiabanak (33˚77 N) accessions, respectively. Isfahan (51˚39´E) and Poodeh (32˚12´ N) accessions were from the lowest longitude and latitude, respectively.

Several descriptive statistics were summarized in Table 2. The analysis of variance demonstrated that there was a significant difference among the jujube accessions for all of the measured traits (data were not included). The values of the measured traits for each accession are shown in Table 2.

The highest fruit length was found in Ganje-Ghobad (32.36 mm) and the lowest was in the Natanz (14.09 mm) accession (Table 3). The highest flesh/stone ratio was observed in the Zavvareh accession (19.15) and the Isfahan accession (5.82) had the lowest value. For the stone weight and stone width, Ganje- Ghobad (0.39 g and 7.45 mm) and Mahabad (0.11 g and 4.77 mm) accessions had the highest and lowest values, respectively. Also, the longest and the shortest stone length were found in the Ganje-Ghobad

Table 2. Some descriptive statistics of the morphological and biochemical traits of 12 wild *Ziziphus jujuba* Mill. accessions.

Trait	Abbreviation	Max	Min	Mean	SD*
Potassium	K	698.72	162.52	314.93	141.20
Phosphorus	P	119.94	35.09	67.82	25.65
Calcium	Ca	120.90	44.26	79.52	28.05
Magnesium	Mg	32.94	13.52	21.61	6.57
Iron	Fe	11.28	0.99	3.86	3.14
Manganese	Mn	58.37	16.79	31.06	11.23
Zinc	Zn	0.82	0.30	0.48	0.14
Copper	Cu	1.19	0.10	0.24	0.30
Titratable acidity	TA	1.38	0.70	0.98	0.20
Total soluble solids % (Brix)	TSS	39.60	20.40	29.09	5.69
Ascorbic acid (mg $100g^{-1}$ FW)	AA	403.62	183.04	276.23	75.31
Total flavonoids (mg 100 g^{-1} FW)	TFC	250.12	153.41	200.90	33.52
Moisture percent (%)	MP	87.11	65.27	77.37	7.26
Total phenolic compound (GAE*)	TPC	8.80	4.05	6.10	1.59
Mucilage (%)	MP	18.58	37.97	27.07	7.00
Young shoot length	YSL	30.40	14.96	21.11	4.99
Young thorn length	YTL	1.36	0.30	0.56	0.33
The longest thorn	LT	2.30	1.43	1.85	0.29
Number of thorns in a shoot	NTS	65.33	22.00	33.91	12.85
Fruit weight (g)	FWT	7.00	1.61	3.12	1.66
Hundred fruit weight (g)	HFW	701.00	160.33	312.61	166.21
Fruit flesh weight (g)	FFW	6.61	1.39	2.89	1.61
Stone weight (g)	SWT	0.39	0.11	0.23	0.08
Flesh/stone ratio	F/S	19.15	5.82	12.42	5.09
Fruit length (mm)	FL	32.36	14.09	19.86	5.73
Fruit width (mm)	FWD	21.68	15.03	17.28	2.18
Stone length (mm)	SL	18.46	8.98	11.94	3.18
Stone width (mm)	SWD	7.45	4.77	6.28	0.84
Fruit length/width ratio	FL/FW	1.49	0.93	1.13	0.20
Leaf length (cm)	LL	6.63	3.80	5.22	0.89
Leaf width (cm)	LW	2.63	1.56	2.19	0.33
Terminal leaflet length (cm)	TLL	3.73	1.83	2.48	0.60
Terminal leaflet width (cm)	TLW	1.76	0.60	1.12	0.34
Petiole length (cm)	PL	0.50	0.23	0.38	0.08

SD: standard deviation

Table 3. Means of the morphological traits of fruits for *Ziziphus jujuba* Mill. accessions.

Accession	Fruit weight (g)	Hundred fruit weight (g)	Flesh fruit weight (g)	Stone weight (g)	Flesh/ stone ratio	Fruit length (mm)	Fruit width (mm)	Stone length (mm)	Stone width (mm)	Length/ width ratio
Ardestan	2.31^{f}	231.33^{f}	2.13^{f}	0.18^{fg}	11.85^{d}	17.71^{fg}	16.36^{e}	10.41^{ef}	5.28^{e}	1.08^{c}
Isfahan	1.86^{hi}	186.80^{h}	1.59^{g}	0.27^{c}	5.82^{g}	17.15^{gh}	15.64^{f}	11.67^{d}	6.92^{b}	1.09^{c}
Anarak	3.40^{d}	344.10^{d}	3.09^{d}	0.30^{c}	10.33^{e}	24.01^{c}	17.03^{d}	15.31^{c}	6.80^{b}	1.40^{b}
Bayazieh	1.68^{hi}	168.53^{i}	1.43^{g}	0.24^{d}	6.03^{g}	15.00^{i}	15.20^{f}	9.81^{fg}	6.94^{b}	0.98^{ef}
Poodeh	5.27^{b}	528.53^{b}	4.93^{b}	0.33^{b}	14.93^{c}	28.91^{b}	19.85^{b}	16.85^{b}	6.95^{b}	1.45^{a}
Khoorobiabanak	1.89^{gh}	189.60^{h}	1.68^{g}	0.20^{ef}	8.31^{f}	15.22^{i}	15.60^{f}	9.17^{gh}	6.42^{c}	0.97^{fg}
Zavvareh	3.41^{d}	342.06^{d}	3.23^{d}	0.17^{g}	19.15^{a}	18.75^{e}	18.58^{c}	10.35^{ef}	5.59^{de}	1.00^{ef}
Kachoomesghal	2.68^{e}	268.46^{e}	2.48^{e}	0.19^{efg}	12.95^{d}	18.23^{ef}	17.13^{d}	11.05^{de}	5.48^{e}	1.06^{cd}
Koohpayeh	4.17^{c}	417.93^{c}	4.08^{c}	0.21^{df}	18.82^{a}	20.29^{d}	19.69^{b}	11.73^{d}	5.89^{d}	1.02^{de}
Ganje-ghobad	7.00^{a}	701.00^{a}	6.61^{a}	0.39^{a}	16.95^{b}	32.36^{a}	21.68^{a}	18.46^{a}	7.45^{a}	1.49^{a}
Mahabad	2.12^{fg}	212.66^{g}	2.00^{f}	0.11^{h}	17.69^{ab}	16.56^{h}	15.57^{f}	9.43^{gh}	4.77^{f}	1.06^{cd}
Natanz	1.61^{i}	160.33^{i}	1.39^{g}	0.22^{de}	6.25^{g}	14.09^{j}	15.03^{f}	8.98^{h}	6.87^{b}	0.93^{g}

Values in each column followed by the same letter are not significantly different at $p \leq 0.05$ based on Duncan's multiple range test.

(18.46 mm) and Natanz (8.98 mm) accessions, respectively (Table 3). The data for shoot, thorn, and leaf characteristics are shown in Tables 4 and 5. The Kachoomesghal jujube accession had the longest shoot and leaf and the longest thorn belonged to the Bayazieh accession.

Table 4. Means of the morphological traits of leaves in the *Ziziphus jujuba* Mill. accessions.

Genotype	Leaf length (cm)	Leaf width (cm)	Terminal leaflet length (cm)	Terminal leaflet width (cm)	Petiole length (cm)
Ardestan	6.36^{a}	2.50^{ab}	3.73^{a}	1.76^{a}	0.50^{a}
Isfahan	4.26^{fg}	2.13^{bc}	2.73^{bc}	1.10^{cd}	0.36^{abc}
Anarak	4.76^{ef}	2.26^{abc}	3.13^{b}	1.50^{ab}	0.23^{c}
Bayazieh	5.40^{bcde}	1.66^{de}	2.20^{de}	0.66^{e}	0.46^{ab}
Poodeh	6.03^{ab}	2.63^{a}	2.10^{de}	0.96^{d}	0.33^{bc}
Khoorobiabanak	4.23^{fg}	2.16^{bc}	1.86^{e}	0.96^{d}	0.36^{abc}
Zavvareh	3.80^{g}	1.56^{e}	2.43^{cd}	1.16^{cd}	0.33^{bc}
Kachoomesghal	6.63^{abcd}	2.30^{abc}	2.93^{b}	1.46^{b}	0.43^{ab}
Koohpayeh	5.73^{abc}	2.40^{abc}	1.86^{e}	0.60^{e}	0.43^{ab}
Ganje-ghobad	5.66^{abc}	2.56^{a}	2.80^{bc}	1.10^{cd}	0.46^{ab}
Mahabad	$4.83d^{ef}$	2.06^{c}	2.10^{de}	0.96^{d}	0.26^{c}
Natanz	4.96^{cdef}	2.03^{cd}	1.83^{e}	1.26^{bc}	0.36^{abc}

Values in each column followed by the same letter are not significantly different at $p \leq 0.05$ based on Duncan's multiple range test.

The values of the biochemical characteristics are shown in Table 6. The amount of total soluble solids varied from 20.4 (Zavvareh) to 39.6 (Poodeh) and the range of total flavonoids content TFC was from 153.41 (Zavvareh) to 250.12 (Ganje-Ghobad).

The results of the mineral elements in different accessions of wild jujube are presented in Table 7. K, P, Ca, and Mn had the highest level in the wild jujube accessions and K was the predominant mineral. The amount of K was approximately 5 and 15 fold higher than Ca and Mg, respectively. In many plants, K is higher than Ca or Mg in the xylem and phloem due to water movement, nutrient and metabolite transport, and stress responses. The highest value of P content was identified in the Kachoomesghal accession (119.94 mg/100 g), followed by Ganje-Ghobade (92.09 mg/100 g). In this study, the observed Ca content was remarkable and ranged from 44.26 to 120.09 mg/100 g (Tables 2 and 7). The highest source of Mg content was the Zavvareh accession (32.94 mg/100 g) while Khoorobiabanak (13.52 mg/100 g) had the lowest value. The Fe content ranged from 0.99 to 11.28 mg/100 g (Tables 2 and 7). Poodeh showed the highest value of Fe among 12 jujube accessions. Anarak contained the highest level of Mn and Zn (58.37 mg/100 g and 0.82 mg/100 g, respectively).

Cluster analysis

The cluster analysis of 12 different accessions of jujube was grouped into two clusters. The first cluster contained accessions with the higher mean value of biochemical traits and also the highest mean value of longitude and altitude, whereas the second cluster showed lower mean values (Figure 2, Tables 8 and 9). The first cluster which contained six jujube wild accessions, was divided into two sub-clusters. The Ardestan accession was located in a separate cluster alone. Poodeh, Mahabad, Kohpayeh, Kachoomesghal, and Khoorobiabanak were gathered in the same sub-cluster. The second cluster was divided into two sub-clusters. Isfahan, Anarak, and Ganje-Ghobad were placed in the same sub-cluster, and Bayazieh, Natanz, and Zavvareh were grouped together. Zavvareh and Ardestan were placed in two different clusters and were the most distant accessions.

Table 5. Means of the shoot and thorn traits in the *Ziziphus jujuba* Mill. accessions.

Genotype	Young shoot length (cm)	Young thorn length (cm)	The longest thorn (cm)	Number of thorns in a shoot
Ardestan	24.46^{b}	0.60^{cd}	1.43^{d}	23.00^{f}
Isfahan	17.13^{d}	0.36^{de}	1.46^{d}	26.66^{ef}
Anarak	16.33^{de}	0.53^{cde}	1.8b^{cd}	46.00^{b}
Bayazieh	14.96^{e}	0.80^{bc}	2.30^{a}	38.00^{bcd}
Poodeh	18.06^{de}	0.30^{e}	1.93^{abc}	43.33^{bc}
Khoorobiabanak	26.00^{b}	0.30^{e}	1.53^{cd}	22.66^{f}
Zavvareh	21.56^{c}	0.36^{de}	2.10^{ab}	22.00^{f}
Kachoomesghal	30.40^{a}	0.30^{e}	1.53^{cd}	28.33^{def}
Koohpayeh	21.46^{c}	1.36^{a}	2.10^{ab}	24.66^{f}
Ganje-ghobad	26.43^{b}	0.96^{b}	2.06^{ab}	65.33^{a}
Mahabad	21.60^{c}	0.33^{de}	2.00^{ab}	30.33^{def}
Natanz	14.96^{c}	0.50^{de}	1.96a^{bc}	36.66^{cde}

Values in each column followed by the same letter are not significantly different at $p \leq 0.05$ based on Duncan's multiple range test.

Table 6. Means of the biochemical traits in *Ziziphus jujuba* Mill. accessions.

Accession	TA	TSS% (Brix)	Ascorbic acid (mg in 100 g FW)	TFC (mg in 100 g FW)	Moisture (%)	Total phenolic compound GAE*	Mucilage
Ardestan	1.15^{bc}	23.46^{ef}	228.80^{e}	206.32^{e}	80.12^{ab}	7.02^{d}	24.15^{ef}
Isfahan	0.90^{e}	33.46^{b}	258.13^{d}	242.12^{b}	76.18^{bc}	8.80^{a}	18.58^{h}
Anarak	0.79^{fg}	37.93^{a}	220.72^{e}	224.24^{c}	71.23^{cde}	8.18^{b}	23.74^{f}
Bayazieh	0.81^{ef}	30.40^{bcd}	300.37^{c}	175.85^{g}	81.49^{a}	7.70^{c}	37.73^{a}
Poodeh	0.81^{ef}	39.60^{a}	219.41^{e}	193.49^{f}	65.27^{e}	6.87^{d}	31.88^{c}
Khoorobiabanak	1.07^{cd}	26.53^{de}	212.37^{e}	189.39^{f}	86.49^{a}	6.02^{e}	35.45^{b}
Zavvareh	1.18^{b}	20.40^{f}	403.62^{a}	153.41^{i}	77.21^{bc}	5.81^{e}	23.26^{f}
Kachoomesghal	1.00^{d}	25.73^{e}	183.04^{f}	238.56^{b}	74.03^{bcd}	4.52^{f}	18.70^{h}
Koohpayeh	1.13^{bc}	26.53^{de}	388.37^{ab}	160.63^{h}	75.02^{bcd}	4.05^{g}	37.97^{a}
Ganje-ghobad	0.70^{g}	31.20^{bc}	256.96^{d}	250.12^{a}	67.78^{de}	4.84^{f}	25.49^{de}
Mahabad	1.38^{a}	26.26^{de}	380.16^{b}	213.20^{d}	86.47^{a}	4.57^{f}	21.25^{g}
Natanz	0.89^{e}	27.60^{cde}	262.82^{d}	163.49^{h}	87.11^{a}	4.86^{f}	26.65^{d}

TA: Titratable acidity; TSS: Total soluble solids; TFC: Total flavonoids content; GAE: Gallic acid equivalent; Values in each column followed by the same letter are not significantly different at $p \leq 0.05$ based on Duncan's multiple range test.

Table 7. Means of the mineral substances in the studied *Ziziphus jujuba* Mill. accessions (mg/100g).

Accession	K	P	Ca	Mg	Fe	Mn	Zn	Cu
Ardestan	337.05^{d}	60.81^{de}	74.01^{d}	29.46^{ab}	1.82^{ef}	22.24^{g}	0.46^{cde}	0.13^{b}
Isfahan	183.13^{h}	38.43^{f}	54.61^{e}	16.91^{cde}	2.34^{ef}	29.18^{de}	0.49^{cd}	0.10^{b}
Anarak	698.72^{a}	71.08^{c}	85.43^{c}	27.35^{b}	4.24^{cd}	58.37^{a}	0.82^{a}	0.17^{b}
Bayazieh	319.69^{e}	55.13^{e}	67.59^{d}	19.89^{c}	5.17^{c}	34.91^{c}	0.38^{ef}	0.16^{b}
Poodeh	398.06^{b}	88.03^{b}	120.9^{a}	30.08^{ab}	11.28^{a}	34.55^{c}	0.54^{c}	0.21^{b}
Khoorobiabanak	254.16^{g}	35.09^{f}	44.26^{f}	13.52^{e}	1.24^{f}	23.97^{fg}	0.30^{f}	0.13^{b}
Zavvareh	305.48^{f}	65.26^{cd}	116.28^{a}	32.94^{a}	2.04^{ef}	25.03^{efg}	0.48^{cd}	0.16^{b}
Kachoomesghal	360.77^{c}	119.94^{a}	82.61^{c}	18.15^{cd}	2.99^{de}	28.27^{def}	0.50^{cd}	0.14^{b}
Koohpayeh	259.09^{g}	87.63^{b}	107.78^{b}	19.81^{c}	3.97^{cd}	30.47^{cd}	0.45^{de}	0.19^{b}
Ganje-ghobad	307.82^{f}	92.09^{b}	105.36^{b}	20.04^{c}	8.47^{b}	44.73^{b}	0.63^{b}	0.17^{b}
Mahabad	162.52^{i}	63.33^{d}	50.80e^{f}	15.96c^{de}	0.99^{f}	16.79^{h}	0.31^{f}	0.17^{b}
Natanz	192.69^{h}	37.07^{f}	44.60^{f}	15.23d^{e}	1.72^{ef}	24.18^{fg}	0.38^{ef}	1.19^{a}

Values in each column followed by the same letter are not significantly different at $p \leq 0.05$ based on Duncan's multiple range test.

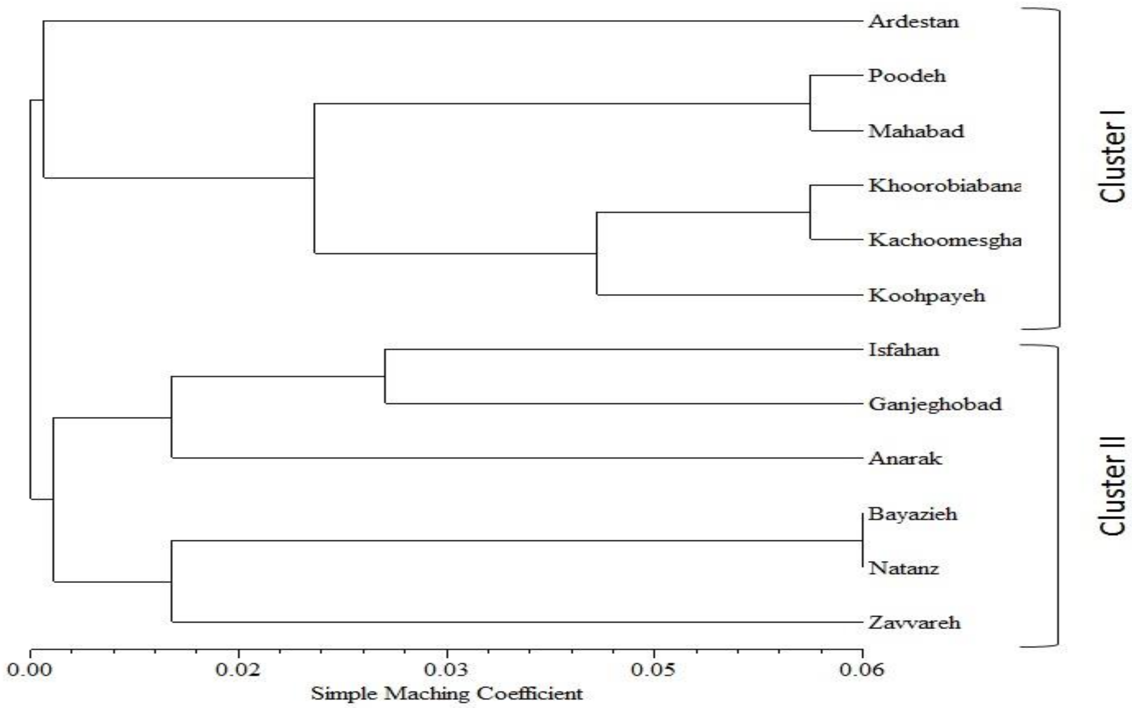

Figure 2. Dendrogram of the cluster analysis for 12 jujube accessions using 34 morphological and biochemical traits.

Table 8. Means of the mineral elements (mg/100g) and biochemical characteristics in each cluster for the studied *Ziziphus jujuba* Mill. accessions.

Cluster	**Sub-cluster**	**Accession**	**K**	**P**	**Ca**	**Mg**	**Fe**	**Mn**	**Zn**	**Cu**
Cluster I	First sub-cluster	Ardestan	337.05	60.81	74.01	29.46	1.82	22.24	0.46	0.13
	Second sub-cluster	Poodeh	398.06	88.03	120.90	30.08	11.28	34.55	0.54	0.21
		Mahabad	162.52	63.33	50.80	15.96	0.99	16.79	0.31	0.17
		Khoorobiabanak	254.16	35.09	44.26	13.52	1.24	23.97	0.30	0.13
		Kachoomesghal	360.77	119.94	82.61	18.15	2.99	28.27	0.50	0.14
		Koohpayeh	259.09	87.63	107.78	19.81	3.97	30.47	0.45	0.19
Cluster II	First sub-cluster	Isfahan	183.13	38.43	54.61	16.91	2.34	29.18	0.49	0.10
		Anarak	698.72	71.08	85.43	27.35	4.24	58.37	0.82	0.17
		Ganje-Ghobad	307.82	92.09	105.36	20.04	8.47	44.73	0.63	0.17
	Second sub-cluster	Bayazieh	319.69	55.13	67.59	19.89	5.17	34.91	0.38	0.16
		Natanz	192.69	37.07	44.60	15.23	1.72	24.18	0.38	1.19
		Zavvareh	305.48	65.26	116.28	32.94	2.04	25.03	0.48	0.16

Table 8 continued

Cluster	**Sub-cluster**	**Accession**	TSS% (Brix)	Ascorbic acid (mg in 100 g FW)	TFC (mg in 100 g FW)	Humidity (%)	Total phenolic compound GAE	Mucilage
Cluster I	First sub-cluster	Ardestan	23.46	228.80	206.32	80.12	7.02	24.15
	Second sub-cluster	Poodeh	39.60	219.41	193.49	65.27	6.87	31.88
		Mahabad	26.26	380.16	213.20	86.47	4.57	21.25
		Khoorobiabanak	26.53	212.37	189.39	86.49	6.02	35.45
		Kachoomesghal	25.73	183.04	238.56	74.03	4.52	18.70
		Koohpayeh	26.53	388.37	160.63	75.02	4.05	37.97
Cluster II	First sub-cluster	Isfahan	33.46	258.13	242.12	76.18	8.80	18.58
		Anarak	37.93	220.72	224.24	71.23	8.18	23.74
		Ganje-Ghobad	31.20	256.96	250.12	67.78	4.84	25.49
	Second sub-cluster	Bayazieh	30.40	300.37	175.85	81.49	7.70	37.73
		Natanz	27.60	262.82	163.49	87.11	4.86	26.65
		Zavvareh	20.40	403.62	153.41	77.21	5.81	23.26

Table 9. Means of the morphological traits of shoots, thorns, leaves, and fruits in each cluster for the studied *Ziziphus jujuba* Mill. accessions.

Cluster	**Sub-cluster**	**Accession**	Young shoot length	Young thorn length	The longest thorn	Number of thorns in a shoot	Fruit weight (g)	Hundred fruit weight (g)	Flesh weight (g)	Stone weight (g)	Flesh/ stone ratio	Fruit length (mm)
Cluster I	First sub-cluster	Ardestan	24.46	0.60	1.43	23.00	2.31	231.33	2.13	0.18	11.85	17.71
	Second sub-cluster	Poodeh	18.06	0.30	1.93	43.33	5.27	528.53	4.93	0.33	14.93	28.91
		Mahabad	21.60	0.33	2.oo	30.33	2.12	212.66	2.00	0.11	17.69	16.56
		Khoorobiabanak	26.00	0.30	1.53	22.66	1.89	189.60	1.68	0.20	8.31	15.22
		Kachoomesghal	30.40	0.30	1.53	28.33	2.68	268.46	2.48	0.19	12.95	18.23
		Koohpayeh	21.46	1.36	2.10	24.66	4.17	417.93	4.08	0.21	18.82	20.29
Cluster II	First sub-cluster	Isfahan	17.13	0.36	1.46	26.66	1.86	186.80	1.59	0.27	5.82	17.15
		Anarak	16.33	0.53	1.80	46.00	3.40	344.10	3.09	0.30	10.33	24.01
		Ganje-Ghobad	26.43	0.96	2.06	65.33	7.00	701.00	6.61	0.39	16.95	32.36
	Second sub-cluster	Bayazieh	14.96	0.80	2.30	38.00	1.68	168.53	1.43	0.24	6.03	15.00
		Natanz	14.96	0.50	1.96	36.66	1.61	160.33	1.39	0.22	6.25	14.09
		Zavvareh	21.56	0.36	2.10	22.oo	3.41	342.06	3.23	0.17	19.15	18.75

Table 9 continued

Fruit width (mm)	Stone length (mm)	Stone width (mm)	Length/ width ratio	Leaf length (cm)	Leaf width (cm)	Terminal leaflet length (cm)	Terminal leaflet width (cm)	Petiole length (cm)
16.36	10.41	5.28	1.08	6.36	2.50	3.73	1.76	0.50
19.85	16.85	6.95	1.45	6.03	2.63	2.10	0.96	0.33
15.57	9.43	4.77	1.06	4.83	2.06	2.10	0.96	0.26
15.60	9.17	6.42	0.97	4.23	2.16	1.86	0.96	0.36
17.13	11.05	5.48	1.06	6.63	2.30	2.93	1.46	0.43
19.69	11.73	5.89	1.02	5.73	2.40	1.86	0.60	0.43
15.64	11.67	6.92	1.09	4.26	2.13	2.73	1.10	0.36
17.03	15.31	6.80	1.40	4.76	2.26	3.13	1.50	0.23
21.68	18.46	7.45	1.49	5.66	2.56	2.80	1.10	0.46
15.20	9.81	6.94	0.98	5.40	1.66	2.20	0.66	0.46
15.03	8.98	6.87	0.93	4.96	2.03	1.83	1.26	0.36
18.58	10.35	5.59	1.00	3.80	1.56	2.43	1.16	0.33

Discussion

In our study, there was significant variation among the accessions of jujube. Some authors also reported significant variation among jujube genotypes for thorn length, fruit width, and fruit weight (Obeed *et al*. 2008; Tatari *et al*. 2016). Ganje-Ghobad and Natanz accessions had the highest and lowest fruit weight (7.00 and 1.61 g, respectively) and fruit flesh weight (6.61 and 1.39 g, respectively). The differences in morphological traits may be related to the origins of wild accessions (Khakdaman *et al*. 2007). Brindza *et al*. (2014) also reported large variations in stone weight, stone width, and stone length in jujube, which supported this observation.

There are very few reports about the shoot, thorn, and leaf characteristics in jujube. In the current study, variation among wild jujube accessions was found for shoot, thorn, and leaf traits. Phenotypic variation in growth characteristics can be the result of adapting to growth habitats and competitive survival

(Gurevitch 1992; Ercisli 2007; Luquez *et al*. 2008; Du *et al*. 2014).

The amounts of total soluble solids in the current study were somewhat similar to other reports (Ma *et al*. 2000; Ghosh and Mathew 2002; Gao *et al*. 2003; Jiang *et al*. 2006; Chen *et al*. 2006). The parallel results for total flavonoids were reported by Gao *et al*. (2011) and Zhao *et al*. (2006). Similar to our study, variation was reported for ascorbic acid by Li *et al*. (2007) and Goa *et al*. (2011), and for the titratable acidity content by Guo *et al*. (2016).

The climatic conditions have a large effect on the physiochemical characteristics of genotypes (Khakdaman *et al*. 2007). In our study, accessions from the northern parts of the Isfahan province (Mahabad, Zavare) had different vegetative characteristics in comparison with the accessions from the east (Beyazeh, Anarak) (Ghazaeian 2015; Asadi-Gharneh *et al*. 2017; Mohammadi and Asadi-Gharneh 2018; Javanmard *et al*. 2018).

Important minerals such as K, Ca, and Fe. must be in the human diet to pursue a healthy life (Liu *et al.* 2013). The results of this study demonstrated significant differences among the jujube accessions for these minerals. Significant variation was also found for Mg, Zn, and Cu. The high amount of minerals in jujube (Anarak, Poodeh, Koohpayeh, Ganje-Ghobad) can be useful for the drug and food industries.

In many plants, K is higher than Ca or Mg in the xylem its easy movement. Therefore, it tends to be concentrated in different parts of the plant (Pereira *et al*. 2016). The K content of this study ranged from 162.52 to 698.72 mg/100 g (Tables 2 and 7). The richest source of K was the Anarak accession. K content of the current study was higher than other reports (Li *et al*. 2007; San *et al*. 2009). Ca and Mg may help lower blood pressure. The high Mg content in this study was supported by the findings of San *et al*. (2009), who reported the higher value of this element in jujube as 20.87 mg/100 g. The Fe content of the current study was similar to the results obtained in the Chinese jujube (Li *et al*. 2007).

Zn is needed for all organisms for several reasons. It plays an important role in the immune system, insulin secretion (Chausmer 1998), and release of the vitamin A from the liver (Wang *et al*. 2002). Also, it prevents night blindness and the development of cataracts (Soetan *et al*. 2010). Mn and Zn content in our study of the Iranian jujube was higher than the Turkish or Chinese jujube (Li *et al*. 2007; San *et al*. 2009) (1.19 mg/100 g). The Cu content of this study was higher than the Chinese jujube varieties (Li *et al.* 2007). The variation among the jujube accessions for mineral compositions is related to the species, varieties, and the growth conditions such as soil and geographical conditions (Ercisli 2007). The nutrients can affect the properties of medicinal plants (Mohammadi and Asadi-Gharneh 2018).

The cluster analysis showed that the wild jujube accessions were diverse and variation among them was high. This variation can provide a possibility to select higher-quality wild genotypes. The jujube fruits that were collected from the Isfahan province showed higher levels of macro-elements such as K, Ca, and Mg.

Conclusions

According to our results, there was a high variation among the jujube wild accessions. This variation can be useful for selecting specific genotypes for special purposes in the breeding programs of the jujube. Also, some accessions could be used directly as commercial varieties for jujube producers. In addition, jujube can be a good source for drug industries. Ganje-Ghobad, Poodeh, Koohpayeh, Anarak, and Zavvareh, showed higher values for morphological, and biochemical traits, which can be used further selection programs.

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Conflict of interest

The authors declare that they have no conflict of interest with any organization concerning the subject of the manuscript.

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مطالعه ژنوتیپ‌های عناب وحشی ایرانی با استفاده از صفات مورفولوژیکی و بیوشیمیایی

گشتاسب جلایی اسفندآبادی[1]، حسین علی اسدی قارنه[1*] و المیرا ضیاء مطلبی پور[2،3،4]

۱- گروه باغبانی، واحد اصفهان (خوراسگان)، دانشگاه آزاد اسلامی، اصفهان

۲- گروه تولید و ژنتیک گیاهی، واحد اصفهان (خوراسگان)، دانشگاه آزاد اسلامی، اصفهان

۳- مرکز تحقیقات گیاهان دارویی، دانشگاه آزاد اسلامی اصفهان (خوراسگان)، اصفهان

۴- قطب علمی انتقال ژن، واحد اصفهان (خوراسگان)، دانشگاه آزاد اسلامی، اصفهان

*مسئول مکاتبه؛ Email: h.asadi@khuisf.ac.ir

چکیده

عناب (*Ziziphus jujuba* Mill.) با ارزش غذایی بالا، یک گیاه دارویی مهم است و به صورت میوه تازه و خشک در سراسر جهان مصرف می‌شود. ایران یکی از مهمترین مراکز ژرم پلاسم عناب است. میوه عناب سرشار از مواد مغذی معدنی، پروتئین، کربوهیدرات و ویتامین C است. در این مطالعه ۱۲ نمونه مختلف وحشی عناب از مناطق مختلف استان اصفهان جمع آوری شد و در مجموع ۳۴ صفت مورفولوژیکی و بیوشیمیایی مورد ارزیابی قرار گرفت. با توجه به نتایج حاصل، تفاوت معنی‌داری بین نمونه ها مشاهده شد. بیشترین میانگین طول میوه، عرض میوه، وزن میوه، درصد رطوبت، وزن گوشت میوه، نسبت گوشت به هسته، وزن هسته، طول هسته و عرض هسته به ترتیب ۳۲/۳۶ میلی‌متر، ۲۱/۶۸ میلی‌متر، ۷ گرم، ۸۷/۱۱ درصد، ۶/۶۱ گرم، ۱۹/۱۵، ۰/۳۹ گرم، ۱۸/۴۶ میلی متر و ۷/۴۵ میلی متر بود. بیشترین میزان اسیدیته کل در نمونه مهاباد (۱/۳۸ درصد) و بیشترین میزان مواد جامد محلول کل در نمونه پوده (۳۹/۶ درصد درجه بریکس) مشاهده شد. بیشترین میزان اسید اسکوربیک و فلاونوئید به ترتیب در نمونه زواره (۴۰۳/۶۲ میلی‌گرم بر کیلوگرم وزن خشک) و نمونه گنجه قباد (۲۵۰/۱۲ میلی‌گرم بر کیلوگرم وزن خشک) اندازه‌گیری شد. دامنه ترکیبات فنلی کل و محتوای موسیلاژ به ترتیب از ۸/۸ تا ۳۷/۹۷ (میلی‌گرم بر کیلوگرم وزن خشک) و ۱۸/۸۵ تا ۳۷/۹۷ (میلی‌گرم بر کیلوگرم وزن خشک) متغیر بود. نمونه انارک دارای بیشترین مقدار روی (۰/۸۲ میلی گرم در ۱۰۰ گرم)، منگنز (۵۸/۳۷ میلی گرم در ۱۰۰ گرم) و پتاسیم (۶۹۸/۷۲ میلی گرم در ۱۰۰ گرم) بود. از طرف دیگر بیشترین مقدار آهن (۱۱/۲۸ میلی گرم در ۱۰۰ گرم) و کلسیم (۱۲۰/۰۹ میلی گرم در ۱۰۰ گرم) به نمونه پوده تعلق داشت. همچنین غنی‌ترین منبع فسفر (۱۱۹/۹۴ میلی‌گرم در ۱۰۰ گرم) در نمونه کچومثقال شناسایی شد. گنجه قباد، پوده، کوهپایه، انارک و زواره از نظر صفات مورفولوژیکی و بیوشیمیایی ارزش بالاتری نشان دادند که می‌توان از آن‌ها به منظور انتخاب ژنوتیپ‌های خاص برای اهداف ویژه در برنامه‌های اصلاحی و صنایع دارویی استفاده کرد.

واژه‌های کلیدی: تجزیه کلاستر؛ ژنوتیپ؛ صفات بیوشیمیایی؛ مواد مغذی؛ همبستگی؛ *Ziziphus jujuba* Mill.