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Evaluation of morphological variation of *Zataria multiflora* populations from different parts of Iran

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Abstract

Zataria multiflora is the only known species of the genus *Zataria*, which usually grows on dry and mountainous areas in the southwest, south and southeast of the Iranian plateau. Excessive harvesting, unfavorable climatic conditions and uncontrolled grazing have endangered its survival in native habitats. Therefore, identifying habitats and investigating morphological diversity are necessary to protect their populations. Between 2018 and 2019, the growth areas of this species were identified in different provinces of Iran and 15 populations in five provinces were selected to evaluate morphological diversity. Twenty-one morphological traits were analyzed by different methods. The number of inflorescences per plant, dry weight, the number of flowers per inflorescences, and fresh weight (coefficient of variation of 93.76, 73.08, 71.01, and 64.25%, respectively) were the main morphological traits with the highest variation among populations. Phenotypic correlation analysis showed a significant correlation among leaf dimensions, biomass parameters and reproductive traits. Cluster analysis, divided the 15 populations into two independent clusters. Thirteen populations with rather low amounts of morphological traits were grouped in the first cluster. In addition, two populations including Khonj and Juyom populations were placed in the second cluster that was characterized by higher values of important morphological traits in breeding programs of medicinal plants. Finally, in the present study it was observed that, high morphological variations in *Z. multiflora* populations from different parts of Iran that may be attributed to their different ecological, geographical origin and genetic factors.

Keywords: Breeding programs, cluster analysis, correlation, *Lamiaceae*, medicinal plants, native habitats

ارزیابی تنوع ریخت‌شناسی جمعیت‌های آویشن شیرازی از مناطق مختلف ایران*

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خلاصه

آویشن شیرازی (*Zataria multiflora* Boiss.) تنها گونه شناخته شده از جنس *Zataria* در تیره نعناییان است که عموما در مناطق خشک و کوهستانی جنوب‌غربی، جنوب و جنوب‌شرقی فلات ایران می‌روید. برداشت بی‌رویه، شرایط نامساعد آب و هوایی و چرای بی‌رویه، بقای آن را در زیستگاه‌های بومی به خطر انداخته است. از این رو، شناسایی رویشگاه‌ها و بررسی تنوع ریخت‌شناسی برای حفاظت از جمعیت آن‌ها ضروری است. بین سال‌های ۱۳۹۶ تا ۱۳۹۷، مناطق رشد این گونه در استان‌های مختلف ایران شناسایی شد و ۱۵ جمعیت در پنج استان کشور برای ارزیابی تنوع ریخت‌شناسی انتخاب شدند. بیست و یک صفت ریخت‌شناختی با روش‌های مختلف آماری مورد تجزیه و تحلیل قرار گرفت. صفاتی نظیر تعداد گل‌آذین در بوته، وزن خشک، تعداد گل در گل‌آذین و وزن تر (به ترتیب ۹۳/۷۶، ۷۳/۰۸، ۷۱/۰۱ و ۶۴/۲۵ درصد) بیشترین ضریب تغییرات صفات را در بین جمعیت‌ها دارا بودند. تجزیه همبستگی صفات فنوتیپی، همبستگی معنی‌داری را بین ابعاد برگ، پارامترهای زیست توده و صفات زایشی نشان داد. تجزیه خوشه‌ای ۱۵ جمعیت را به دو خوشه مستقل می‌توان تقسیم کرد. سیزده جمعیت با مقادیر نسبتا کم صفات ریخت‌شناسی در خوشه اول گروه‌بندی شدند. همچنین، دو جمعیت شامل جمعیت خنج و جویم در خوشه دوم قرار گرفتند که صفات ریخت‌شناختی ارزشمندی را برای استفاده در برنامه‌های اصلاحی گیاهان دارویی دارا بودند. در نهایت، در بررسی حاضر، تغییرات ریخت‌شناختی بالایی در جمعیت‌های آویشن شیرازی جمع‌آوری شده از مناطق مختلف ایران مشاهده گردید که ممکن است به عوامل مختلف بوم‌شناختی، جغرافیایی و عوامل ژنتیکی آن‌ها نسبت داده شود.

واژه‌های کلیدی: برنامه‌های اصلاحی، تجزیه خوشه‌ای، زیستگاه‌های بومی، گیاهان دارویی، نعناییان، همبستگی صفات

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Introduction

The wide geographical and climatic distributions in Iran are indicative of the fact that there is a great genetic diversity among native plants which needs to be identified and studied. Annually, a large quantity of these plants is harvested from nature and leads to the destruction of germplasm. Investigation of morphological diversity is the first step for the classification and description of germplasm (Lamine *et al.* 2014). In addition, this is a useful tool for screening the germplasm to identify the accessions with the most useful traits for use in breeding programs to develop and to cultivate new suitable cultivars which helps to conserve and sustainable production of native plants (Khadivi-Khub *et al.* 2014).

Zataria multiflora Boiss. is the only known species of the genus *Zataria* in the *Lamiaceae* family that mostly found growing on dry and mountainous areas in the SW, SE, and south of the Iranian Plateau (Afghanistan, Iran, Oman, Pakistan, and W Himalaya) (https://powo.science.kew.org/taxon/urn:lsid:ipni.org :names:461954-1). The name of the genus is derived from the Arabic word "Zaetar" meaning thyme and the common Persian name is "Avishan-e-Shirazi" (Najafpour Navaei & Alahverdi 2019).

Zataria multiflora is a perennial shrub with 25–100 cm height, stems branched and white in color, the leaves can be identified by the orbicular, densely gland-dotted, grey-green ovate, and the thickly white hairy round buds in the leaf axils. Its inflorescence is verticillate and the flowers are white in color (Jamzad 2012).

The different parts of this plant are used in Iranian traditional medicine for the treatment of cold, antiseptic and continuous pain relief. Fresh and dry leaf powder is used as spice for a wide variety of foods (Iranian Herbal Pharmacopoeia Committee 2002, Mojaddar Langroodi *et al.* 2019). Recent studies have shown that the essential oils and extracts of this species are rich in anti-nociceptive, spasmolytic, anti-inflammatory, anti-microbial and antioxidant properties that can be used in the medicine, cosmetic and food industries (Sajed *et al.* 2013, Khazdair *et al.* 2018). Nowadays, the tendency to consume this plant is increasing and completely harvested from nature. Therefore, there is a possibility of its extinction in some habitats due to improper harvesting (Meamari *et al.* 2021). Morphological diversity has been widely studied in several medicinal plants such as *Melissa officinalis* L. (Pouyanfara *et al.* 2018), *Satureja khuzistanica* Jamzad. (Hadian *et al.* 2011), *Thymus daenensis* Celak. (Heydari *et al.* 2019), and *Mentha spicata* L. (Mokhtarikhah *et al.* 2022).

Zataria multiflora has a wide geographical range in Iran that can make a high variation in morphological parameters. Hence, the study of these variations in various populations of this species collected from different parts of Iran is an important step towards identifying desirable populations with valuable traits that can be used in future breeding programs.

Materials and Methods

- Plant materials

The aerial parts of 15 *Z. multiflora* populations were collected from five provinces across Iran including Yazd (Behabad), Fars (Abadeh, Pasargad, Tashk, Fasa, Khafr, Jouyom, and Khonj), Kerman (Kerman and Jiroft), Hormozgan (Faryab, Tang-e Zagh, Roudkhaneh, and Bashagard), and Sistan & Balouchestan (Fanouj) at full blossom stage. Geographical distribution of the studied plant populations were presented in figure 1.

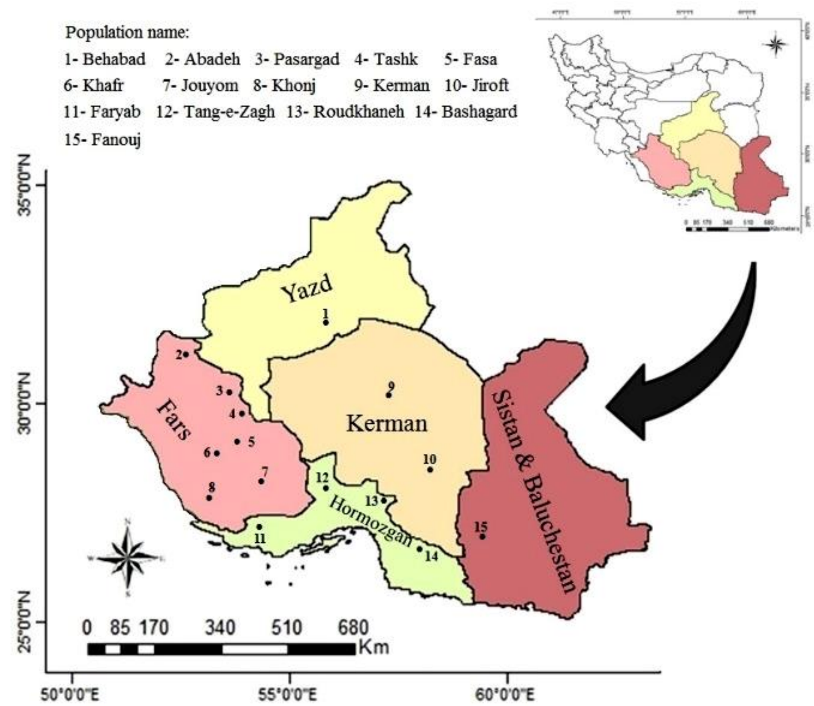

Fig. 1. Geographical locations of studied habitats of *Zataria multiflora*.

Voucher specimens were authenticated and deposited in the Herbarium of Faculty of Agriculture & Natural Resources, University of Hormozgan, Bandar Abbas, Iran (Table 1). Geographical data and altitude for each natural habitat were recorded using GPS (Table 1). Besides, climate data for 15 years were taken from meteorological stations closest to the sampling areas (Table 1).

- Measurement of morphological traits

Twenty-one morphological traits were considered to measure the phenotypic diversity among the plant populations (Table 2). The traits including plant height, crown diameter, inflorescence length and diameter of crown cover were measured using a ruler with an accuracy of 0.5 mm. Leaf length, leaf width, internode length, bract length, bract width, the distance between the two inflorescence cycles and corolla length were also measured by a digital caliper with an accuracy of 0.10 mm (Fig. 2). Biomass yields (Fresh and dry weight) were measured using an analytical balance with a sensitivity of ± 0.01 g.

- Statistical analysis

Coefficient of variation (CV) percentage, standard deviation (SD), minimum and maximum values, were determined for 21 morphological traits as indicators of variability. The data were statistically evaluated by analysis of variance ($p<0.05$) and significant differences between means were estimated by Duncan's multiple range test in SAS (Ver. 9.1.3). Pearson correlation coefficients between the traits and principal component analysis (PCA) were determined using IBM SPSS (Ver. 23) software. Cluster analysis and scatter plot of the first two PCs were performed using PAST statistics software. In addition, the Ward method based on the Euclidean distances was used for drawing the dendrogram.

Table 1. Habitats information and climatic conditions of the studied *Zataria multiflora* populations in Iran

Habitat	Locality	Voucher No.	Altitude (m)	Longitude (E)	Latitude (N)	Mean annual temperature (°C)	Mean annual rainfall (mm)
Abadeh	Fars prov.: Sechah mountain, 10 km from Abadeh	346	2056	52º 64´	31º 16´	14.8	307
Bashagard	Hormozgan prov.: Biskav, 30 km from Sardasht to Bashagard	347	735	57º 89´	26º 45´	29	133
Behabad	Yazd prov.: Zardabad village	348	1432	56º 01´	31º 87´	19.2	153.9
Fanouj	Sistan & Baluchestan prov.: Patkan village	349	725	59º 38´	26º 35´	19.6	145
Faryab	Hormozgan prov.: Faryab village, Roudan	350	492	57º 27´	27º 82´	27.3	180
Fasa	Fars prov.: Zar mount, 25 km SE of Fasa	351	1380	53º 64´	28º 94´	24.9	250
Jiroft	Kerman prov.: Anbarabad village	352	603	57º 48´	28º 33´	25.6	198
Jouyom	Fars prov.: Jouyom, Khonj	353	856	53º 98´	28º 25´	27.5	201.5
Kerman	Kerman prov.: Zangiabad village, 40 km NW of Kerman	354	1769	57º 07´	30º 28´	16.9	132
Khafr	Fars prov.: Nematabad, 20 km W of Khafr	355	1296	53º 20´	28º 97´	23.5	235
Khonj	Fars prov.: Hengo village, 45 km SW of Khonj	356	668	53º 43´	27º 88´	28.4	180.6
Pasargad	Fars prov.: Akbarabad, 10 km W of Sa'adat Shahr	357	1867	53º 18´	30º 19´	18.8	264
Roudkhaneh	Hormozgan prov.: Between Sarab and Bashkardan,	358	485	57º 22´	27º 74´	28.3	188.5
Tang-e Zagh	55 km above the tunnel Hormozgan prov.: From Sirjan to Bandar Abbas	359	894	55º 97´	27º 84´	26.8	188.7
Tashk	Fars prov.: Khaj-e Jamali suburb, 35 km E of Abadeh Tashk	360	1591	53º 72´	29º 80´	19.4	245

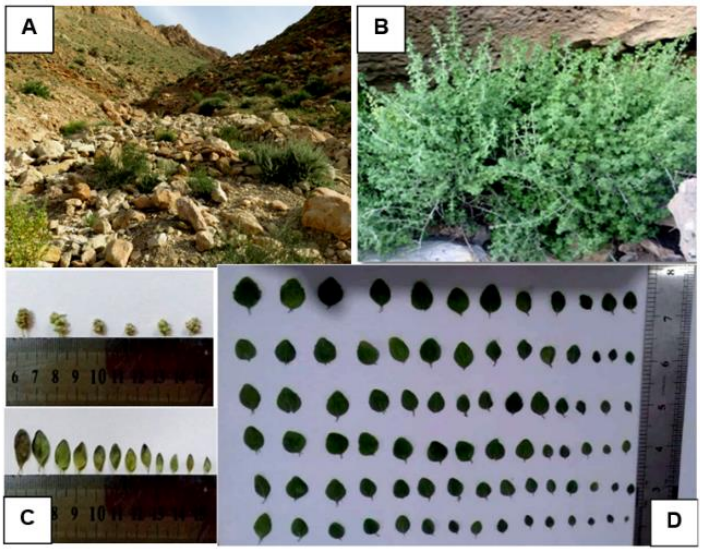

Fig. 2. *Zataria multiflora*: A. & B. Natural habitats, C. Different plant parts, D. Leaves & flowers.

Table 2. Descriptive statistics of 21 morphological traits studied populations of *Zataria multiflora*

Trait	Abbreviation	Unit	Min.	Max.	Mean	SD*	CV** (%)
Plant height	PH	cm	23	105	43.86	14.77	33.68
Leaf length	LL	mm	5.38	14.68	9.05	1.48	16.24
Leaf width	LW	mm	3.40	12.11	5.91	1.20	20.30
Leaf length/width ratio	LL/WR	-	0.98	2.26	1.56	0.23	14.10
Internode length	InL	mm	6.34	34	15.50	3.77	24.32
Crown diameter	CD	mm	40.5	370	157.70	78.38	49.71
Number of subdivisions	NS	No.	1	12	4.51	1.70	37.69
Number of nodes	Nn	No.	2.33	11	5.43	1.46	26.70
Fresh weight	FW	gr	31.38	477.60	163.51	105.05	64.25
Dry weight	DW	gr	17.68	320.95	82.10	60.01	73.08
Percent of dry weight	PDW	-	21.04	205.47	51.77	19.02	26.73
Bract length	BL	mm	1.90	4.48	3.23	0.40	12.38
Bract width	BW	mm	0.92	3.24	1.88	0.34	17.55
Bract length/width ratio	BL/WR	-	0.94	2.87	1.75	0.30	16.67
Inflorescence length	IL	mm	23.5	229.5	91.70	42.33	46.17
Distance between the two inflorescence cycles	DbtC	mm	5.23	34.09	12.42	3.17	25.44
Number of inflorescence per plant	NIP	No.	42	798	185.80	174.23	93.76
Number of flowers per inflorescence	NFI	No.	9.33	123.20	34.99	24.85	71.01
Corolla length	COL	mm	1.00	9.27	2.34	0.86	36.32
Diameter of crown cover	DC	mm	40	395	147.44	78.55	53.27
Number of stem branches from the base	NSBB	No.	10	194	52.24	32.38	61.99

Results and Discussion

- Morphological diversity

Twenty one distinctive morphological traits were evaluated in four hundred-fifty individuals of *Z. multiflora* were across Iran (Table 2). The coefficient of variation (CV) value is variable based on the trait diversity. Traits with CV values higher than twenty percent indicated a wider range of quantitative characteristics, which give to breeder a broader range of selection for the domestication programs (Hashemi & Khadivi 2020). Among the assessed traits, 15 out of 21 traits exhibited CV values higher than twenty percent (Table 2). Traits with the highest CV values were related to the number of inflorescences per plant (93.76%), dry weight (73.08%), number of flowers per inflorescence (71.01%), fresh weight (64.25%), number of stem branches from the base (61.99%), and diameter of crown cover (53.27%), while the lowest CV belonged to bract length (12.38%), leaf length/width ratio (14.10%), leaf length (16.24%), bract length/width ratio (16.67%), and bract width (17.55%). These traits have a key role in the separation of populations, but the traits with lower CVs may be important because indicated that the genetic effects for these traits are greater than the environmental effects (Rhazi *et al.* 2021). In general, a wide variation of vegetative and reproductive traits was observed that can help to select a population with suitable amounts of these traits to use in future breeding programs.

- The simple correlations among traits

The significant correlation between morphological traits is an important indicator for trait selection in breeding programs. Several factors can affect the correlations between traits including trait-controlling genes placement close together on a chromosome (gene linkage) as well as control of several seemingly unrelated phenotypic traits by one gene (pleiotropy), and traits are quantitative or qualitative. It should be noted that, changes due to environmental conditions may modify the value of phenotypic correlations (Khadivi-Khub *et al.* 2012). There was a significant correlation between leaf dimension, biomass parameters, and reproductive traits (Table 3).

Plant height which has a key role in mechanical harvest, showed a positive correlation with leaf length, leaf width, internode length, crown diameter, fresh weight, dry weight, percent of dry weight, bract length, inflorescence length, number of inflorescence per plant, number of flowers per inflorescence, corolla length and diameter of crown cover. Increasing plant height and internode length will be reduced competition between leaves to obtain sunlight for photosynthetic activity and consequently provides the condition to extend leaf dimensions and traits related to the inflorescence. Thus, it has directly affected the secondary metabolites production and biomass yields by increasing primary metabolites. Our findings agreed with the results of Hadian *et al.* (2010) in *Satureja hortensis* L. They were reported that, the leaf length was a significant correlation with leaf width and stem internode length. Similarly, another study in *Thymus migricus* Klokov & Desj.-Shost showed that, the essential oil yield is significantly correlated with the stem length, length of inflorescence, leaf length, and leaf width. Hence, selection for a higher value of these traits leads to improvement of essential oil yield (Yavari *et al.* 2010). Our result showed a negative correlation between the number of stem branches from the base with plant height, leaf length, leaf width and percent of dry weight. In other words, this plant tends to enhance the number of stem branches from the base by decreasing the plant height, leaf dimensions and percent of dry weight, because assimilates have to be distributed into a larger number of branches. This is reflected in plants with more branches, leaves shading will be increased and enhance competition to obtain sunlight for photosynthetic activity.

- Principal component analysis

Principal component analysis (PCA) is a basic multivariate statistical method that is used to reduce many variables into fewer numbers components and it has proven to be a useful tool to understand relationships between morphological traits (Khadivi-Khub *et al.* 2014). Principal component analysis showed eight components with explaining 77.07% of the total variance (Table 4).

Table 3. Pearson's correlation coefficients between the morphological traits in studied populations of *Zataria multiflora*

	PH	**LL**	**LW**	**LL/WR**	**InL**	**CD**	**NS**	**Nn**	**FW**	**DW**	**PDW**	**BL**	**BW**	**BL/WR**	**IL**	**DbtC**	**NIP**	**NFI**	**COL**	**DC**	**NSBB**
PH	1																				
LL	0.16**	1																			
LW	0.13**	0.66**	1																		
LLWR	0.01	0.20**	-0.57**	1																	
InL	0.01*	0.27**	.028**	-0.06	1																
CD	0.28**	-.012*	-0.07	-0.05	-0.02	1															
NS	-0.25**	-0.09	-0.11*	0.06	0.05	-0.11*	1														
Nn	0.06	0.04	0.11*	-0.11*	0.06	0.01	0.01	1													
FW	0.48**	0.01	0.06	-0.07	0.03	0.76**	-0.18**	-0.07	1												
DW	0.63**	0.01	0.02	-0.04	-0.01	0.68**	-0.24*	-0.02	0.86**	1											
PDW	0.35**	0.01	-0.07	0.07	-0.09	0.00	-0.15**	0.07	-0.07	0.36**	1										
BL	0.15**	0.05	0.00	0.06	-0.06	0.02	-0.07	-0.15**	0.04	0.16**	0.23**	1									
BW	0.05	-0.06	0.14**	-0.22**	-0.01	0.01	0.03	0. 1*	0.01	0.1*	0.13**	0.40**	1								
BLWR	0.06	0.08	-0.14**	0.27**	-0.03	-0.02	-0.04	-0.21**	0.01	0.01	0.03	0.31**	-0.77**	1							
IL	0.30**	-0.02	-0.02	0.01	0.01	0.13**	0.03	-0.21**	0.27**	0.23**	-0.03	0.28**	0.12**	0.02	1						
DbtC	-0.09	0.13**	0.10*	0.03	0.22**	0.04	0.14**	0.00	0.05	-0.08	-0.27**	-0.17**	-0.15**	0.01	0.12*	1					
NIP	0.29**	-0.08	-0.07	0.00	0.00	0.68**	-0.06	0.00	0.72**	0.61**	-0.02	0.00	-0.03	0.03	0.25**	0.1*	1				
NFI	0.42**	-0.04	-0.04	0.00	-0.02	0.22**	-0.02	-0.22**	0.37**	0.42**	0.12**	0.17**	0.10*	0.02	0.70**	-0.09	0.32**	1			
COL	0.17**	-0.04	0.10*	-0.19**	0.01	0.10*	-0.12*	0.19**	0.00	0.13**	0.28**	0.19**	0.24**	-0.14**	0.03	0.01	0.03	0.01	1		
DC	0.54**	-0.03	0.06	-0.11*	0.07	0.72**	-0.29**	0.11*	0.77**	0.78**	0.15**	0.09	0.10*	-0.04	0.17**	-0.04	0.71**	0.30**	0.27**	1	
NSBB	-0.11*	-0.22**	-0.20**	0.00	0.04	0.50**	0.04	-0.08	0.43**	0.28**	-0.21**	-0.09	-0.04	-0.04	0.12*	0.18**	0.43**	0.08	-0.03	0.30**	1

The morphological traits symbols explained in table 1.
** Correlation is significant at the 0.01 level and * Correlation is significant at the 0.05 level.

Table 4. Eigen values and cumulative variance for eight major factor achieved from the principal component analysis and significant parameters within each component for the studied traits in *Zataria multiflora* populations

Trait	Component							
	1	2	3	4	5	6	7	8
Fresh weight	**0.91**	0.20	0.09	-0.01	-0.04	-0.10	-0.05	-0.01
Crown diameter	**0.88**	-0.02	-0.10	0.02	0.04	0.00	-0.02	0.02
Diameter of crown cover	**0.86**	0.11	0.06	0.02	-0.13	0.26	-0.09	0.00
Dry weight	**0.83**	0.25	0.09	0.02	-0.26	0.19	0.06	0.05
Number of inflorescence per plant	**0.82**	0.14	-0.06	-0.03	0.11	-0.02	0.03	-0.03
Number of stem branches from the base	**0.58**	-0.12	-0.29	0.04	0.40	-0.23	0.00	0.07
Plant height	**0.47**	0.41	0.31	-0.07	-0.33	0.37	0.09	-0.08
Number of flowers per inflorescence	0.24	**0.87**	-0.04	0.03	-0.08	-0.03	0.01	0.05
Inflorescence length	0.13	**0.86**	-0.03	0.03	0.19	-0.05	-0.03	0.15
Leaf length	-0.05	-0.04	**0.91**	-0.05	-0.02	-0.07	0.11	0.06
Leaf width	-0.03	-0.02	**0.74**	0.10	-0.03	-0.01	-0.61	0.01
Internode length	0.04	0.01	**0.52**	0.02	0.42	0.11	-0.01	-0.05
Bract width	0.01	0.07	0.02	**0.90**	-0.07	0.13	-0.09	0.35
Bract length/width ratio	-0.01	0.02	0.02	**-0.90**	-0.03	-0.04	0.15	0.30
Distance between the two inflorescence cycles	0.06	0.03	0.19	-0.16	**0.75**	0.03	-0.04	-0.10
Number of subdivisions	-0.23	0.09	-0.14	0.19	**0.51**	-0.08	0.22	-0.04
Corolla length	0.08	-0.02	-0.08	0.08	0.11	**0.77**	-0.26	0.23
Percent of dry weight	0.01	0.11	0.01	0.01	-0.46	**0.60**	0.24	0.12
Number of nodes	0.02	-0.28	0.09	0.21	0.06	**0.52**	0.00	-0.41
Leaf length/width ratio	-0.03	-0.02	0.03	-0.17	0.03	-0.08	**0.93**	0.07
Bract length	0.02	0.12	0.05	0.04	-0.13	0.16	0.06	**0.91**
Total	4.37	1.99	1.95	1.78	1.66	1.61	1.49	1.34
%age of variance	20.82	9.48	9.27	8.48	7.92	7.64	7.07	6.39
Cumulative %age	20.82	30.29	39.57	48.05	55.97	63.61	70.68	77.07

The PC1explained 20.82% of the total observed variability that can be related to fresh weight, crown diameter, diameter of crown cover, dry weight, number of inflorescences per plant, number of stem branches from the base and plant height. All of these traits have an effect on increasing the yield of vegetative biomass. The PC2 showed 9.48% of the total morphological variation and it was presented traits relevant to reproductive organs including the number of flowers per inflorescence and inflorescence length. Also, the PC3 accounted for 9.27% of the total variance and was most strongly associated with leaf dimensions (leaf length and leaf width), and internode length. The other components (PC4-PC8) indicated 37.50 of the total variance and these components include traits that don't have much effect on distinguishing the populations. In general, principal component analysis was able to identify important traits in the separation of *Z. multiflora* populations and theirs placed in the first three factors. In previous studies, the populations of different medicinal plant species such as *Satureja mutica* (Fathi *et al.* 2021), *Thymus daenensis* (Heydari *et al.* 2019), and *Leonurus cardiaca* (Soorni *et al.* 2014) were evaluated using principal component analysis and their conclusions were similar to our results.

- Cluster and scatter plot analysis of morphological traits

Cluster analysis from morphological data grouped all populations into two main clusters, and the first and second cluster included 13 & 2 populations, respectively (Fig. 3).

The first cluster, was divided into two groups. The first group included six populations from Jiroft, Kerman, Khafr, Tashk, Behabad, and Fanouj habitats which were separated from other populations by number of sub-divisions, number of flowers per inflorescence, number of stem branches from the base, and diameter of crown cover. Besides, the Fanouj population formed a separate subgroup distinct from other populations by higher internode length, higher bract width, higher number of nodes, lower number of inflorescence per plant, lower number of flowers per inflorescence, lower fresh weight, lower dry weight, lower leaf length/width ratio, and lower bract length/width ratio. The second group of the first cluster contained seven populations from Pasargad, Fasa, Faryab, Abadeh, Roudkhaneh, Tang-e-Zagh, and Bashagard habitats, which were similar in traits including plant height, internode length, dry weight, and diameter of crown cover. In this group, the Bashagard population was divided into one subgroup which showed the highest inflorescence length, highest bract length, lowest crown diameter, lowest number of nodes, lowest corolla length, and lowest percent of dry weight.

The second cluster, contained two populations from Jouom and Khonj habitats which were superior in most of the studied traits such as fresh weight, dry weight, number of inflorescences per plant, crown diameter, and the diameter of crown cover. Among all populations, Khonj population had particularly, the highest values of plant height, percent of dry weight and number of flowers per inflorescence. Increasing values of these traits led to enhance yields in vegetative biomass. In addition, the highest amount of essential oil in *Z. multiflora* produced and stored in the epidermal glands in the leaves and inflorescences, hence populations which are superior in these traits, can be used in breeding programs. It is also concluded that, the climatic conditions of the Khanj habitat are very suitable for the growth of *Z. multiflora* in Iran. Najafpour Navaei & Alahverdi (2019) being agree with our results, showed that, the Maharloo region (Fars province) has provided more favorable vegetative conditions than the other areas in Esfahan, Yazd and Hormozgan provinces.

The populations grouping in scatter plot base on PC1 and PC2 were similar with the pattern as cluster analysis (Fig. 4). Similarly, the separation of populations using morphological traits in scatter plot may be related to their geographical distance. Thus, some populations of adjacent habitats were located in close areas on the scatter plot, which can be caused by similar environmental conditions and gene flow among these populations. Karimi *et al.* (2020) showed that, the cluster analysis of different populations of *Z. multiflora* was in agreement with their geographical origin.

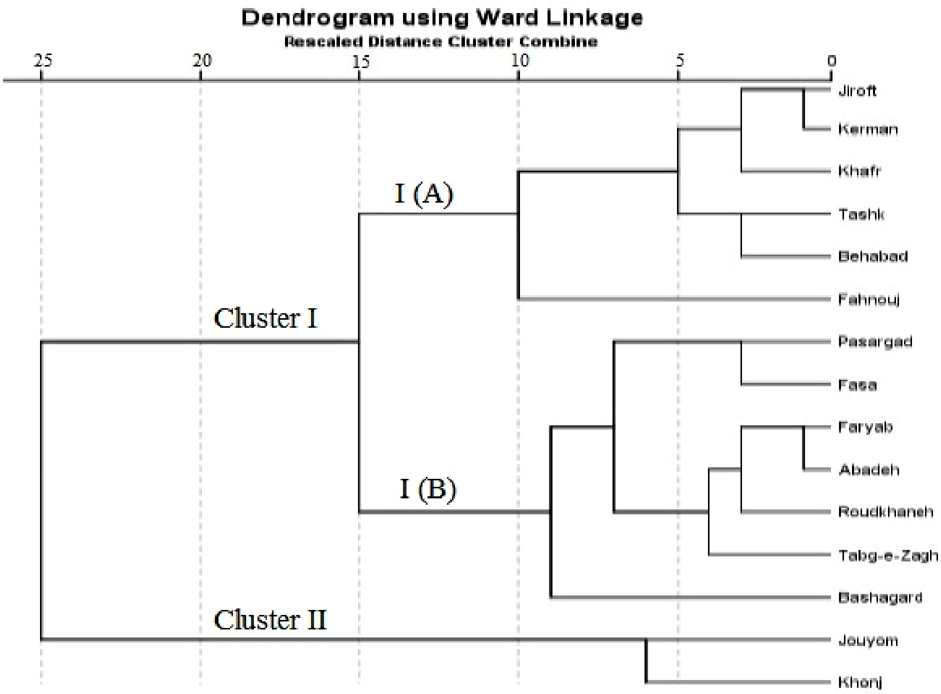

Fig. 3. Dendrogram of cluster analysis for the studied populations of *Zataria multiflora* using morphological traits based on the Euclidean distances by Ward method.

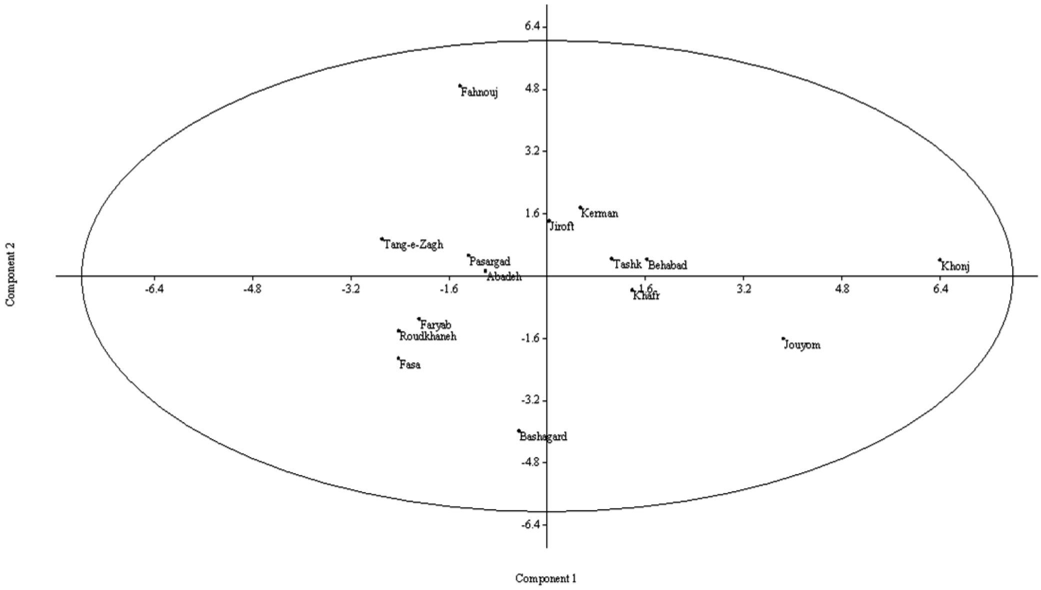

Fig. 4. The scatter plot constructed by PC1and PC2 using morphological traits of the studied *Zataria multiflora* populations.

Conclusions

Increasing knowledge about the dangers of using synthetic materials has accelerated the use of medicinal plants in the pharmaceutical, cosmetic and food industries. Most plant raw materials which were harvested from natural habits, led to the destruction of these plants. Therefore, more studies should be done on medicinal plant domestication. Before entering plants into the domestication and cultivation process, native populations should be assessed in various aspects such as morphological and genetic diversity. *Zataria multiflora* is one of the important native medicinal plants in Iran that can be widely used in the food, perfume, spice, and medicine industries, so it is necessary to study the morphological diversity among wild populations. In this study, most the morphological traits indicated notable variation among the populations of *Z. multiflora* that could be explained by adaption of ecological and climatic conditions in their habitats. According to the optimum indices for morphological traits in medicinal plant products such as plant high, leaf dimension, biomass parameters and reproductive traits, two populations, including Jouom and Khonj from Fars province were superior and can be used for domestication programs.

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