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Capparis spinosa (Capparaceae); A Survey on Morpho-ecologic Variation for Different Populations of Iran

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ABSTRACT

Capparis spinosa grows naturally from the Atlantic coast of the Canary Islands and Morocco to the Black Sea, in Crimea and Armenia, and to the east side of the Caspian Sea in Iran. *Capparis* species are valuable as a resource for medicine, food, improving soil fertility, stabilizing dunes, fuel, timber, and livestock feed. In this research, sixteen populations of *Capparis spinosa* were collected from different locations in Iran and quantitative and qualitative data of morphological characters were revised. A multivariable statistical analysis was performed for the morphological characters of *Capparis* populations. The populations were classified into two main groups using a *Ward's* hierarchical *clustering* method. We showed some of the climatic conditions correlate with morphological characters. Data obtained were standardized (Mean= 0, variance= 1) and used to estimate Euclidean distance for clustering and ordination analyses. PCA (Principal components analysis) was used to identify the most variable morphological characters among the studied populations. The Redundancy Analysis (RDA) was applied to the dataset of nine explanatory environmental variables (annual precipitation and temperature, number of frost days, relative humidity, potential evapotranspiration, minimum and maximum absolute temperatures, minimum temperature of the coldest month of the year, and maximum temperature of the warmest month)**.** In the Flora of Iran and Flora Iranica *C. spinosa* and *C. sicula* are considered as synonyms, which are improved by this study.

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Introduction

The *Capparis spinosa* Linnaeus (1753:503) species belongs to the Capparaceae family. This genus includes about 250 species and subspecies (Fici, 2001). The *Capparis* species are distributed in the subtropical and tropical regions of the world (Raja *et al.,* 2013). De Candolle (1824) proposed the first sectional classification for the genus and included all the worldwide old species in sec. *Eucapparis*. This approach was adopted by Bentham and Hooker (1862) and three new sections were added to the previous sections. Zohary (1960) revised the taxa of *Capparis* species, subspecies, and varieties and divided them into six groups. Jacob (1965) proposed a wider concept where all *Capparis* species of the Mediterranean region were included in one single species, namely *Capparis spinosa.* This species is spread in North Africa, Europe, *Western Asia*, Afghanistan, and Australia (Willis. 1988). Recently, a taxonomic revision has been conducted on the *C. spinosa* group widespread from Europe, North *Africa*, Western and Central Asia, representing a single group and recognizing four subspecies (Fici 2014, 2015). In Syria*,* shrubs of the presented *C. spinosa* were erect, the leaves were ovate with glabrous texture being somewhat fleshy, and the fruits were oblong with the inner white wall. The shrubs of *C. sicula* were procumbent, the leaves were rounded to ovate and herbaceous, and the fruits were obovate to oblong with the inner red wall (Al-Safadi *et al.,* 2014). In Sicily, *C. spinosa* showed remarkable variability concerning growth forms and other vegetative characters. Individual multiramified shoots have been observed on clay soil (Fici, 2001). A systematic revision of *Capparis* did not indicate the existence of *C. spinosa*, in Iran but instead indicated the presence of *C. sicula* from Iran with stipule usually being stout and pubescent on leaves from lax to very dense (rarely very lax). *C. spinosa* presented with usually weak or vestigial stipule or rarely stout (Inocencio *et al.,* 2006). The taxonomy of the genus in Iran was the subject of a long controversy. Boissier (1843) introduced two new species, *C. parviflora* and *C. mucronifolia*, for the flora orientalist area. Later in 1867, he combined them in the *C. spinosa* as varieties (Boissier, 1867). Zohary (1960) reported five species with some varieties in Iran. In Flora Iranica, Hedge and Lamond (1970) cited two species, *C. cartilaginea* Decne and *C. spinosa* with three varieties, var. *spinosa*, var. *parviflora,* and var. *mucronifolia*, which were later recognized as separate species by Saghafi Khadem (2000) in Flora of Iran. Inocencio *et al*. (2006) recognized four species for this group in Iran, *C. cartilaginea, C. sicula* Veill (three subspecies), *C. mucronifolia* and *C. parviflora* (two subspecies). Fici (2014, 2015) combined the above four species into *C. spinosa* with two subspecies and three varieties. These different classifications reflect the taxonomic complexities present in this group. Here we followed the classification of the genus presented in the Flora of Iran (Saghafi Khadem, 2000). *Capparis* species are mostly distributed in the south of Iran, but *C. spinosa* is widely distributed in all regions of Iran.

The Flora of Iran and Flora Iranica *C. spinosa* and *C. sicula* are considered as synonyms. The Xeromorphic feature of *C. spinosa* was shown (Rizopolu, 1997). It is present at an elevation ranging from 0 to 1300 m, annual precipitation ranging from 200 to 1200 mm, and annual mean temperature ranging from 12 to 18 ˚C (Chalak *et al.*, 2007). It is adapted to xeric areas, so it can tolerate water stress and temperature exceeding 40 ˚C in the Mediterranean summer (Sozzi and Vicente, 2006). Various parts of the caper have been used as traditional herbs for the treatment of diseases. Fruit and root extracts exhibited good activity against microorganisms (Mahboubi and Mahboubi 2014). Several authors reported that leaf, root, and fruit extracts were effective in the treatment of diabetes and hyperglycemia (Huseini *et al.*, 2013; Rahimi *et al.* 2013; Selfayan and Namjooyan, 2016; Eddouks *et al.,* 2017). *C. spinosa* has been widely produced in Greece, Italy, Turkey, and Spain (Inocensio, 2000). *Capparis spinosa* is taxonomically complicated. It is widely distributed in all regions of Iran. Thus, the aims of this are to study population variation of the species and to evaluate the effect of the climatic factors on the taxonomical features.

Materials and Methods

Plant material and morphological evaluation

To conduct the morphometric studies, 16 populations of *C. spinosa* were collected from different regions of Iran (Table 1; Figs: 1 and 2). We collected five individuals in each location. The samples were identified based on the Flora of Iran (Saghafi Khadem, 2000). Laboratory analyses were carried out at the herbarium of *Islamic Azad University*, *Science and Research* Branch in 2017 and 2018. We studied 21 qualitative and quantitative morphological characters containing number of branching, leaf length (cm), leaf width (cm), leaf thickness (mm), *petiole* length (cm), flowering pedicel length (cm), sepal length (cm), sepal width (cm), petal lamina length (cm), fruit length (cm), fruit width (cm), fruiting pedicel length (cm), gynophores length (cm), number of seed, stipule length (cm), stipule base width (cm), stipule base length (cm), bud length (cm), plant habit, stipule shape, and leaf abaxial indumenta. Also, we studied other morphological features such as leaf shape, fruit shape, stipule color, and stipule decurrent that showed variation in individuals (Table 2). Thus, they were not divisive. To investigate a relationship between morphological features and climatic factors, we received some of the climatic information from the nearest climatic station of habitat.

Table 1. Geographical features of the investigated populations.

Population	Province	City	IAUH*	Latitude	Longitude	Altitude (m)
1	Zanjan	Zanjan	IAUH- 15292	36° 19'36.86"	48°9'18.27"	**1533**
2	Azerbaijan(W)	Khoy	IAUH- 15293	38°52'18.10"	45°10'19.35"	**986**
3	Azerbaijan (E)	Siahroud	IAUH- 15294	38°54'31.33"	45°48'9.16"	**709**
4	Azerbaijan(E)	Ashoghlou	IAUH- 15295	38°59 '8.81"	46°42'9.77"	**373**
5	Golestan.	Gorgan	IAUH- 15288	36°57'5.92"	54°27'5.11"	**83**
6	Golestan	Khoshyeilagh	IAUH- 15289	36° 87'5569"	55°43'1134"	**1206**
7	Khorassan(N)	Bojnoord	IAUH- 15290	37° 34'31.83"	56°59'11.86"	**1730**
8	Khorassan(RZ)	Chenaran	IAUH- 15291	36° 19'47.26"	59°12'39.47"	**1156**
9	Tehran	Varamin	IAUH- 15298	35°20'47.31"	51°39'01.99"	**936**
10	Esfahan	Kashan	IAUH- 15283	34°2'3.44	51° 19'6.92"	**1013**
11	Kermanshah	Kermanshah	IAUH- 15297	34°26'59.68"	47°33'53.77"	**1311**
12	Fars	Arsajan	IAUH- 15287	29°52'32.55"	53°19'11.57"	**1605**
13	Yazd	Taft	IAUH- 15284	31°45'36.23"	44° 12'56.54"	**1496**
14	Yazd	Khezrabad	IAUH- 15285	31°86'07.41"	54°21'69.5"	**1445**
15	Kerman.	Sirjan	IAUH- 15286	29° 34'38.73"	55°33'2.96"	**1715**
16	Boushehr	Boushehr	IAUH- 15296	27°58'13.40"	51°56'48.84"	**12**

* Islamic Azad University of Herbarium (IAUH) -herbarium code

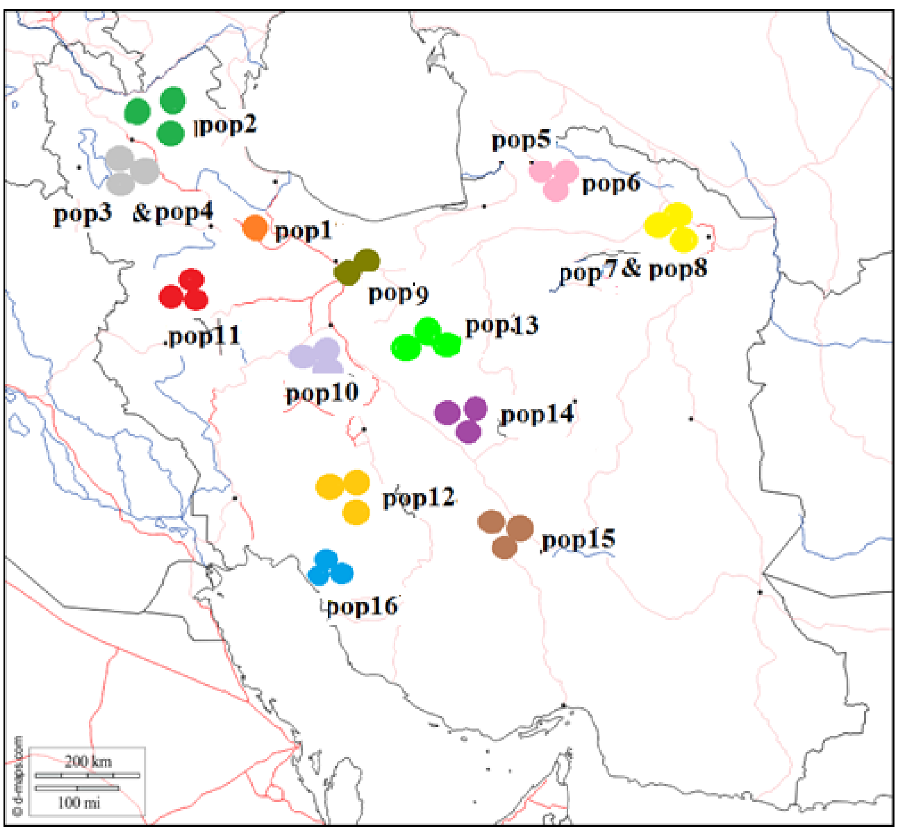

Fig. 1. Distribution map of the studied populations.

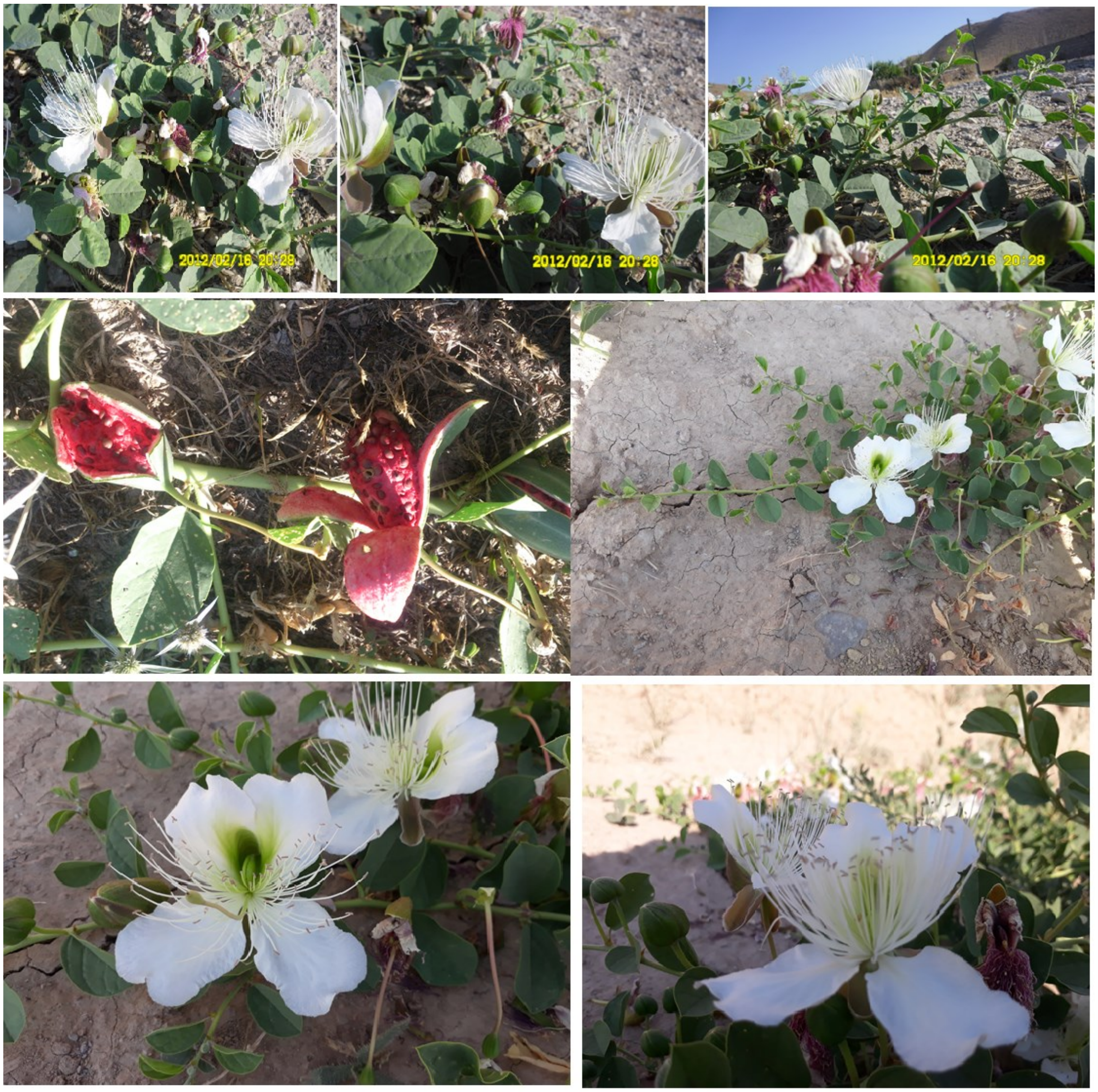

Fig. 2. Habit, leaf, and Flower of the *Capparis spinosa*.

Table 2. List of qualitative characters.

Character	States
Plant habit	Erect(0), somewhat erect(1), procumbent(2)
Leaf abaxial indumenta	Lax(0), very lax(1)
Stipule shape	Straight(0), somewhat curved(1), curved(2)

Climatic factors were annual precipitation and temperature, the number of frost days, relative humidity, evapotranspiration potential, minimum and maximum absolute temperature, minimum temperature of the coldest month of the year, and maximum temperature of the warmest month and then, we drew the *Embrothermic* diagram.

For grouping of the plant specimens based on morphology and micro-morphology, WARD (Minimum spherical characters) was used. Morphology data were standardized (mean = 0, variance = 1) for these analyses (Podani, 2000). PCA (Principal components analysis) was used to identify the most variable morphological characters among the studied populations (Podani 2000).

Data analysis

A redundancy analysis in Canoco 5 (Ter Braak *et al.,* 2002) was used to identify the subset of environmental factors that were responsible for the variation in morphological attributes of *C. spinosa* across locations. Response data (morphological trait) had a gradient of 0.4 SD units long, so the linear method (RDA) was suggested by Canoco 5. The RDA was applied to the dataset of nine explanatory environmental variables in climate (*i.e.*), annual precipitation and temperature, number of frost days, relative humidity, potential evapotranspiration, minimum and maximum absolute temperatures, minimum temperature of the coldest month of the year, and maximum temperature of the warmest month. A manual forward selection process in Canoco 5 was used to select the subset of environmental variables. Before the analysis, data on environmental variables and morphological traits were long transformed.

Results

In our study, we observed a high variation in leaf shape, fruit shape, stipule shape, flower bud, apex, stipule color, and leaf abaxial indumenta.

The results of the principal component analysis of the data on *C. spinosa* populations are presented in Table 3 and Fig. 3. It is clear that the data on the first principal component of *C. spinosa* populations accounts for 36.30% of total variability related to petal lamina length, stipule shape, leaf abaxial indumenta, the number of branching stem, and sepal length, the second data accounts for 17.72% which is related to plant habit, and leaf length and the third one accounts for 14.24% which is related to fruit length, stipule base length, and gynophores length. Data analysis using WARD methods in sixteen populations is shown in Fig. 3. A cluster analysis categorized the genotypes into two groups. Cluster one contains Khoy, Siahroud, Ashoghloo, Zanjan, and Gorgan populations that show different genotypes, and cluster two is divided into two groups. It is largely compatible with geographical distribution. We observed a wide range of climatic factors in the habitats of this species (Table 4) because this species is widespread in the North, South, West, East, and center of Iran. As embriotermic diagrams show, there is a significant difference in the drought intensity and the length of the drought period (Fig. 4).

Environmental variables underlying morphological attributes

The results of RDA revealed that three environmental variables i.e. humidity, precipitation, the average temperature of the warmest month, and climate were significantly responsible for the variation in the spatial pattern of morphological attributes.

Table 3. Vector loadings explained by the first three PCs.

Traits	PC1	PC2	PC3	Traits	PC1	PC2	PC3
NB	0.794	-0.421	0.197	FPL	0.838	0.102	-0.011
PH	-0.552	0.703	-0.024	PLL	0.908	-0.029	0.06
SS	0.899	0.072	0.188	SEL	0.793	-0.06	0.208
LAI	0.812	0.021	-0.163	SW	0.563	0.137	0.251
SL	0.12	-0.451	-0.015	BL	0.489	0.486	0.067
SBL	-0.214	-0.41	0.44	FL	-0.445	0.545	0.665
SBW	0.115	-0.294	0.694	FW	-0.363	0.144	0.721
LL	0.583	0.706	-0.157	FRPL	0.603	0.321	0.394
LW	0.395	0.73	-0.11	GL	0.431	0.113	0.679
PL	0.323	0.675	-0.487	NS	-0.523	0.54	0.497
LTH	-0.827	0.326	-0.006	-	-	-	-

NB= Number of Branching; PLH= Plant Habit; SS= Stipule Shape; LAI= Leaf Abaxial Indument; SL= Stipule Length; SBL= Stipule Base Length; SBW= Stipule Base Width; LL= Leaf Length; LW= Leaf Width; PL= Petiole Length; LTH= Leaf Thickness; FPL= Flowering Pedicel Length; PLL= Petal Lamina Length; SL= Sepal Length; SW= Sepal Width; FL= Fruit Length; FW= Fruit Width; FPL= Fruiting Pedicel Length; GL= Gynophores Length; and NSE= Number of Seed.

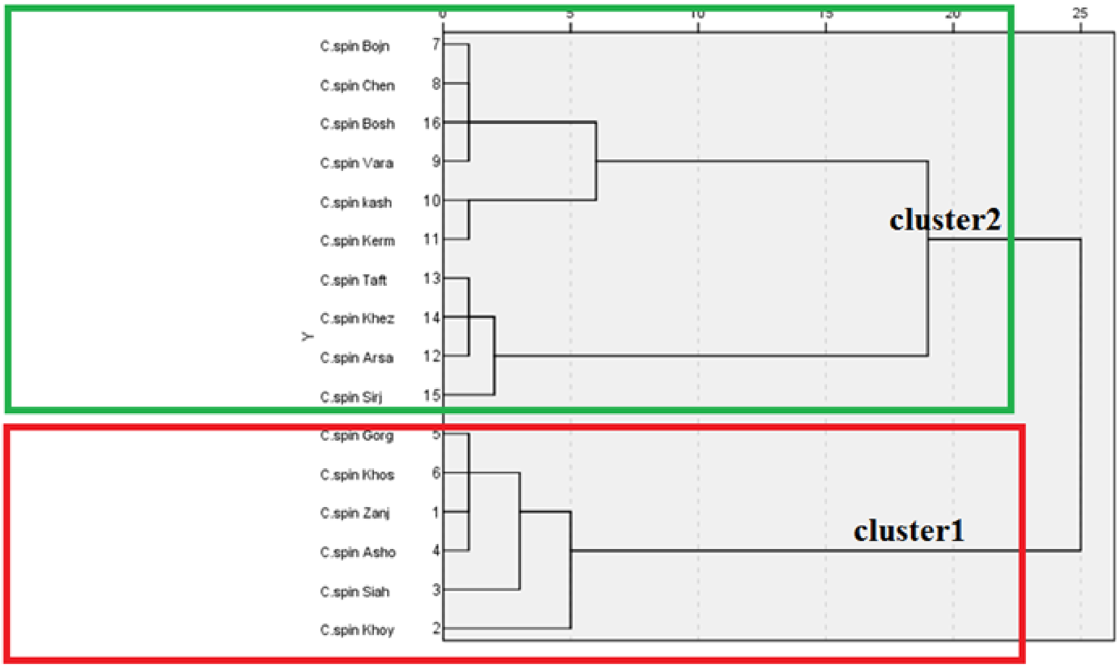

Fig. 3. Cluster analysis of genotypes based morphological traits by using Ward's method: Abbreviations: *C. spinosa* Bojnoord (*C. spin* Bojn); *C. spinosa* Chenaran (*C. spin* Chen); *C. spinosa* Boushehr (*C. spin* Bosh); *C. spinosa* Varamin (*C. spin* Vara); *C. spinosa* Kashan (*C. spin* Kash); *C. spinosa* Kermanshah (*C. spin* Kerm); *C. spinosa* Taft (C. spin Taft); *C. spinosa* Khezrabad (C. spin Khez); *C. spinosa* Arsajan (C. spin Arsa); *C. spinosa* Sirjan (*C. spin* Sirj); *C. spinosa* Gorgan (*C. spin* Gorg); *C. spinosa* Khoshyeilagh (*C. spin* Khos); *C. spinosa* Zanjan (*C. spin* Zanj); *C. spinosa* Ashoghlou (*C. spin* Asho); *C. spinosa* Siahroud (*C. spin* Siah); *C. spinosa* Khoy (*C. spin* Khoy).

Table 4. Range of climatic factors in *C. spinosa* population

Climatic factor	Ann.pre	Ann.tem	RH	EP	Ab.min.tem	Ab.max.tem	NFD	Avg.max.tem	Avg.min.tem
Maximum	713.90	27	69	261	-25	49.9	119	-2.17	23.8
Minimum	46.94	11.6	27	92	5.2	40	0	17.56	34.5

Ann.pre= Annual precipitation; Ann.tem= Annual temperature; RH= Relative Humidity; EP= Evapotranspiration Potential; Ab.min.tem= Absolutly minimum temperture; Ab.max.tem= Absolutly maximum temperature; NFD= Number of Frost Days; Avg.max.tem= Average maximum tempreture of the warmest month; and Avg.min.tem.= Average minimum tempreture of the coldest month

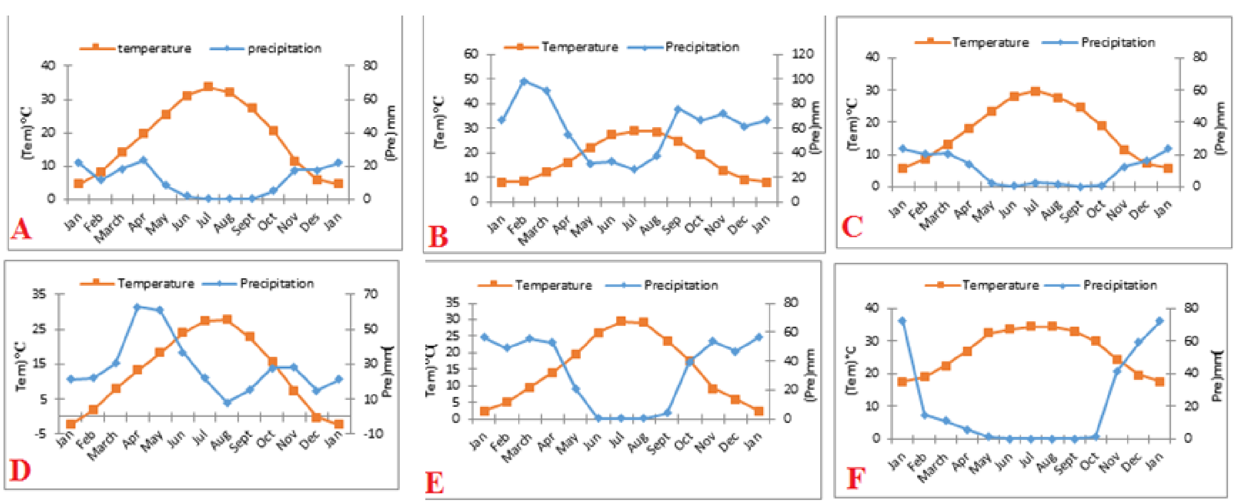

Fig. 4. Embriotermic diagrams: A) Kashan; B) Gorgan; C) Sirjan; D) Khoy; E) Kermanshah; and F) Bushehr.

Using the environmental variables as independent variables, axes 1(λ1=.054) and (λ2= 0.18) explained 0.83% of the variance in morphological attributes. Petal lamina length and number of branching followed by humidity were negatively affected by stipule base length and leaf thickness. Stipule shape, sepal length, flowering pedicel length, and leaf abaxial indument, followed by precipitation and the average temperature of the warmest month were negatively affected by stipule shape, sepal length, leaf abaxial indument, and the flowering pedicel length (Fig. 5).

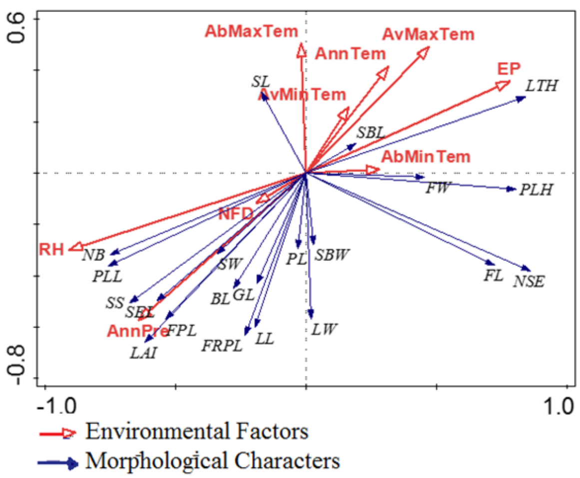

Fig. 5. Redundancy analysis plot showing an association among environmental variables in climate and morphological attributes of *C. spinosa* concerning the first two ordination axes.

Discussion

The taxonomic treatment of the *C. spinosa* group is still critical in the Mediterranean region and the Middle East. Many taxa at various ranks of classification have been described (Zohary, 1960; Maire, 1965; Inocencio *et al.,* 2006; Danin, 2010; Chedraoui *et al.,* 2017).

Capparis spinosa has a wide geographical distribution in Iran. In this study, we showed most of the climatic conditions and some of the morphological features followed by the climatic factors.

Capparis spinosa is well known as a highly drought-tolerant plant and is a species of arid and semi-arid climate zones (Rhizopolu and Psaras, 2003; Sakcali *et al.,* 2008; Ghayour *et al.,* 2013; Ahmadi and Saeidi, 2018). It tolerates summers at temperatures above 40°C and winters at temperatures below -8°C (Ozdemyr and Ozturk, 1996). It tolerates hot summers and cold winters well (Khoshsima *et al.,* 2017). It requires a semi-arid climate at the mean annual temperature above 14°C and mean annual rainfall not less than 200 mm and resists temperature exceeding 40 °C in dry Mediterranean summers (Sozzi and Vicente, 2010). It usually grows at low altitudes which are sometimes found up to 1000 m above sea level (Barbera, 1991). The height of the habitats is recorded from 800 to 2800 m. Precipitation ranged from 200 to 350 mm (Panico *et al*., 2005; Fakhri *et al.,* 2006). In our study, the average temperature 11.6-27°C, maximum absolute temperature 49.9°C, minimum absolute temperature 25°C, precipitation 46.94-713 mm, and altitude 83-1600 m were recorded. Embriotermic diagrams showed a wide range of drought intensity and dry period length. We observed a wide range of climatic factors that presented the range of ecological tolerance and adaptation to environmental conditions in different geographical areas.

In Syria, the presented shrubs of *C. spinosa* were erect, the leaves were ovate with a glabrous texture that was somewhat fleshy, and the fruits were oblong with the inner white wall. *C. sicula* shrubs were procumbent; its leaves were rounded to ovate and herbaceous; and the fruits were obovate to oblong with an inner red wall (Al-Safadi, *et al.* 2014). We observed plant habit to be procumbent to erect. The leaves with different shapes were herbaceous to fleshy. The fruits had different shapes with the inner red wall. In Sicily, *C. spinosa* showed remarkable variability concerning growth forms and other vegetative characters. Individual multiramified shoots have been observed on clay soil (Fici, 2001). We observed variability in the number of branches in different habitats from the North to the Center of Iran.

Recently, a taxonomic revision has been conducted on the *C. spinosa* group widespread from the Mediterranean to Central Asia. *C. spinosa* is represented by four subspecies (*C. spinosa* subp. *spinosa C. spinosa* subp. *rupestris C. spinosa* subp. *cordifolia C. spinosa* subp. *himalayaensis*) within subspecies, *C. spinosa* subp. *spinosa* with three varieties represented from Iran (Fici, 2014). Fici separated vars. *spinosa*, *herbacea,* and *canescens* in terms of stipule shape, leaf size and leaf shape. We compared descriptions of these varieties with the populations collected from different habitats of Iran. We observed a high variation in leaf shape and leaf size. Also, we observed a stipule that is straight and somewhat curved in the plants from the North of Iran and a stipule curved in other regions, besides our results showed a stipule shape correlate with humidity and precipitation. *C. spinosa* and *C. canescens* were considered synonyms in the Flora of Iran and Flora Iranica (Saghafi Khadem*,* 2000, Hedge and Almond, 1970; Ahmadi *et al.,* 2020. A systematic revision of *Capparis* (Inocencio *et al.,* 2006) did not indicate the existence of *C. spinosa* in Iran; instead, *C. sicula* cited from Iran with usually stout stipule and indumentum on leaves is lax to very dense (rarely very lax). *C. spinosa* presented with usually weak or vestigial, and rarely were stout stipule and leaf indumentum always very lax. We observed weak stipule and stout stipule in the Northern and Central regions of Iran, respectively and indumenta on leaves were very lax to lax. In the Flora of Iran and Flora Iranica *C. spinosa* and *C. sicula* are considered synonyms, which are in line with our study results. The insertional dynamic of transposable elements could promote morphological and karyotypic changes, some of which might be potentially important for the process of microevolution allowing species with plastic genomes to survive as new forms or even as new species during rapid climatic changes (Belyayev *et al*., 2010). As noted in the results, morphological features were influenced by climatic factors that can cause a taxonomical controversy.

Conclusion

In this research, the diversity and morphological characteristics of *C. spinosa* in Iran have been shown, and the relationship between morphological and climatic characteristics was studied. Considering the very high morphological diversity of this species, it was confirmed that some varieties were synonymous. We suggest studying the effect of other environmental factors such as soil characteristics on morphological characteristics and conducting molecular studies and comparing it with morphological studies to investigate this plant more carefully. It is also suggested that a molecular study be conducted to investigate the relationship between *C. spinosa* and *C. mucronifola* and *C. parviflora.*

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Conflicts of interest

The authors declare that they have no conflictsof interest.

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