

Distribution patterns of Iranian species of *Saxifraga* with their phytogeographical significance

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Abstract

Numerical analysis of *Saxifraga* in Iran was carried out on the basis of morphological and chorological data. The cluster analysis confirmed that the genus in Iran includes two distinct groups: Group one consists of two subgroups, a) alpine Irano-Turanian endemic species (*S. ramsarica*, *S. iranica*, *S. wendelboi*, *S. koelzii*), and b) Euxino-Hyrcanian species (*S. paniculata* subsp. *Cartilaginea*, *S. kotschyi*). Group two comprises *S. cymbalaria*, *S. sibirica*, *S. tridactylites*, and *S. exarata* subsp. *moschata*. The original distribution maps for all species are provided.

Keywords: Altitudinal range, climatic needs, endemism, numerical taxonomy, *Saxifragaceae*

الگوهای پراکنش گونه‌های ایرانی جنس *Saxifraga* و اهمیت جغرافیای گیاهی آن‌ها

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خلاصه

آنالیز عددی بر پایه داده‌های ریخت‌شناختی و کورولوژیکی روی گونه‌های ایرانی جنس *Saxifraga* انجام شد. آنالیز خوشه‌ای داده‌ها نشانگر این موضوع بود که گونه‌های این جنس در ایران در دو گروه مجزا قرار می‌گیرند: گروه اول مرکب از دو زیرگروه، زیرگروه (a) شامل گونه‌های اندمیک کوهسری متعلق به ناحیه ایرانو تورانی *S. ramsarica*، *S. iranica*، *S. wendelboi* و *S. koelzii* و زیرگروه (b) شامل گونه‌های اگزینو-هیرکانی *S. paniculata* subsp. *cartilaginea* و *S. kotschyi*، گروه دوم شامل *S. cymbalaria*، *S. sibirica* و *S. tridactylites* و *S. exarata* subsp. *moschata* می‌شود. نقشه‌های اصلی مربوط به پراکنش همه گونه‌ها نیز ارائه گردیده است.

واژه‌های کلیدی: بومزادی، تاکسونومی عددی، تیره خارا شکن، دامنه ارتفاعی، نیازهای اقلیمی

Introduction

Saxifraga L. with 440 species is the largest genus in *Saxifragaceae*. Global distribution of the genus covers a wide range of northern hemisphere. There are different assumptions about the origin of this genus. According to the latest theories, it was first originated from Beringia, the junction between Asia and North America (Kaplan 1995). It has spread out to the east and west sides toward its current territories including North America, east and middle Asia and eventually Europe. By disappearing of forest in the late Miocene and reduction of temperature during the Pliocene and Pleistocene, plant communities started a downward movement toward southern latitudes (Tiffney 1985). These motions were limited by orogenic activities from Alps to Himalaya Mts. Glacial barriers in the north and high mountains in the south provided adequate conditions for evolution and speciation in this genus (Webb & Gornall 1989).

According to Flora Iranica, *Saxifraga* and *Bergenia* Moench are the only genera in *Saxifragaceae* with 21 and three species, respectively (Schönbeck-Temesy 1976). None of the three species of *Bergenia* grow in Iran. Based on Flora Iranica, only 12 species from five sections of *Saxifraga* were recorded in Iran.

Saxifraga is known to be polyphyletic genus but its Iranian species are monophyletic (Soltis *et al.* 1996). In the latest study of the family in Iran (Jamzad 1995), a total number of 10 species of *Saxifraga* were recognized (Table 1).

Local distribution of the species of *Saxifraga* is in the north, northwest and west Iran. There are four endemic species in Iran. According to Flora Iranica, it can be seen that with the exception of *S. sibirica* L. that is distributed both to the east and west of Iran, the other nine Iranian species of *Saxifraga* are not reported in Himalaya Mts. and Eastern part of the Flora Iranica's region.

In the present paper, an attempt has been made to study phenetic relationships by numerical taxonomy among the species of this genus in Iran and utilizing these results and distribution data to infer the geographical distribution patterns of this genus in Iran. The main question of study includes: (a) where is the speciation center(s) for the Iranian endemics, and (b) based on morphological, elevational range and distribution patterns of *Saxifraga* in Iran, how many species groups in this genus can be identified.

Table 1. The list of *Saxifraga* species in Iran (Jamzad 1995) and their altitude average

S. No.	Taxa	Section (Webb & Gornall 1989)	Altitudinal range (m)
1	<i>Saxifraga cymbalaria</i> L.	<i>Ciliata</i>	200–2500
2	<i>Saxifraga kotschy</i> Boiss.	<i>Prophyrion</i>	1900
3	<i>Saxifraga koelzii</i> Schönbeck-Temesy	<i>Prophyrion</i>	3000
4	<i>Saxifraga wendelboi</i> Schönbeck-Temesy	<i>Prophyrion</i>	1900–3000
5	<i>Saxifraga iranica</i> Bornm.	<i>Prophyrion</i>	2800–4200
6	<i>Saxifraga ramsarica</i> Jamzad	<i>Prophyrion</i>	3750
7	<i>Saxifraga paniculata</i> subsp. <i>cartilaginea</i> (Willd. ex Sternb.) D.A. Webb	<i>Ligulata</i>	1200–3000
8	<i>Saxifraga sibirica</i> L.	<i>Saxifraga</i>	1000–4000
9	<i>Saxifraga exarata</i> subsp. <i>moschta</i> (Wulf.) Cavillier	<i>Saxifraga</i>	1100–2900
10	<i>Saxifraga tridactylites</i> L.	<i>Mesogyne</i> (Syn. <i>Saxifraga</i>)	800–3000

Materials and Methods

- Characters and plant material

Thirty-five characters including morphological characters, elevation range and geographical distribution of species were used for numerical analysis (Table 2). The data were collected from c. 60 plant specimens present in the herbaria TARI, IRAN and TUH (abbreviations according to Holmgren & Holmgren 1998).

- Numerical analysis

A hierarchical cluster analysis of 10 taxa belonging to the genus *Saxifraga* in Iran carried out on the basis of multistate or binary qualitative variables. Morphological characters, elevational range, and distribution of each species were analyzed. Presence or absence of characters were coded as 1 or 0, respectively and binary variables and multistate characters were coded as 1 to 8 (Table 3).

The detailed and general distribution data of various species have been extracted from different local floras: Flora Iranica (Schönbeck-Temsey 1967), Flora of Iran (Jamzad 1995), Flora of Turkey (Matthews 1972) Flora Kavkaza (Grossheim 1967) and Flora of USSR (Komarov 1971).

Analysis and generating of dendrograms were carried out by SPSS ver. 17.0 (SPSS Inc. Released 2008) using Euclidean distance and within group average strategy for obtaining the dendrogram. DIVA GIS ver. 5 (Hijmans *et al.* 2005b) was applied for mapping the distribution of species.

Data of annual precipitation and annual mean temperature extracted from Worldclim database using layering observation points of species in DIVA-GIS (Hijmans *et al.* 2005a, and <http://www.worldclim.org>).

Table 2. List of characters and their values for cluster analysis for the taxa of *Saxifraga* in Iran

S. No.	Characters description	Character states
1	Life form	Annual (1), Biennial (2), Perennial (3), 1–2(4)
2	Habit	Cushion form (1), Herbaceous (2)
3	Stem simple or branched	Simple (1), Branched (2), 1–2(3)
4	Stem indumentums	No data (0), Articulate-glandulous (1), Black glandulous (2), Black & long glandulous (3), sub glabrous (4), Black & short glandulous (5), 3–4–5(6)
5	Glandular hair on the stem	Absent (0), Present (1)
6	Leaf shapes	Reniform (1), Circular (2), Ligulate-spatulate (3), oblong-lanceolate (4), Spatulate-rotundate (5), oblong-rotundate (6), 1–2(7), 3–4(8)
7	Imbricate leaves	Absent (0), Present (1)
8	Rosette leaves	Absent (0), Present (1)
9	Leaves with cartilaginous margin	Absent (0), Present (1)
10	Leaf apex reflexed	Absent (0), Present (1)
11	Leaf with fleshy and leathery form	Absent (0), Present (1)
12	Leaves foveolate with pits	Absent (0), Present (1)
13	Leaf margin ciliate in lower half	Absent (0), Present (1)
14	Leaf indumentums	Glabrous (1), Lax sericeus (2), Ciliate (3), Visco-glandulous (4), Lax glandulous (5)
15	Leaf petiole	Absent (0), Present (1)
16	Inflorescence	Cyme (1), Solitary (2), Racemose (3), Corymbose (4), Racemo-corymbose (5), Cymocorymbose (6), 1–2(7), 1–3(8)
17	Curved pedicel	Absent (0), Present (1)
18	Bract	Absent (0), Present (1)

Table 2. (contd)

19	Bract shape	Elliptical-Linear (1), Linear (2)
20	Bract color	Dark red (1), Green (2)
21	Bract indumentum	Glabrous (1), Glandular (2)
22	Calyx indumentum	Glabrous (1), Glandular (2)
23	Sepals connate at the base	Absent (0), Present (1)
24	Sepal shape	Oblong (1), Ovate-triangular (2), Ovate (3), Oblong-ovate (4), Triangular (5), 1-2(6)
25	Petal shape	Linear-ovate (1), Elliptical-ovate (2), Oblong-elliptical (3), Obovate-spatulate (4)
26	Petal margin	Crisped (1), Entire (0)
27	Petals with blotch at the base	Absent (0), Present (1)
28	Petal color	White (1), Whitish purple (2), Yellow (3), Pinkish white (4), Yellowish pink (5), 3-5(6), 1-2(7)
29	Stamen size according to petal	Shorter (1), Longer (2)
30	Stamen size according to style size	No data (0), Stamen longer (2), Stamen equal (3), Stamen equal or longer (4)
31	Position of ovary	Sub-superior (1), Superior (2), Sub-inferior (3), Inferior (4)
32	Ovary indumentums	Glabrous (1), Glandular (2)
33	Bulbils	Absent (0), Present (1)

Table 3. Data matrix of 10 species of *Saxifraga* in Iran according to Table 1. Each species was treated as operational taxonomic units (OTUs)

(OTUs)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
<i>S. cymbalaria</i>	4	2	2	1	0	7	0	0	0	0	0	0	0	2	1	7	0
<i>S. kotschyi</i>	3	1	2	3	0	8	1	0	1	1	0	1	1	1	0	9	0
<i>S. koelzii</i>	3	1	2	0	1	8	1	0	1	0	0	1	1	1	0	3	0
<i>S. wendelboi</i>	3	1	2	5	0	5	1	0	1	1	0	1	1	1	0	8	0
<i>S. iranica</i>	3	1	2	2	1	3	1	0	1	0	0	1	1	3	0	1	0
<i>S. ramsarica</i>	3	1	2	2	0	4	1	0	0	0	0	1	1	3	0	2	0
<i>S. paniculata</i>	3	1	1	4	0	8	0	1	1	0	1	1	1	3	0	3	0
subsp. <i>cartilaginea</i>																	
<i>S. sibirica</i>	3	2	1	6	0	1	0	0	0	0	0	0	0	5	1	5	0
<i>S. exarata</i>	3	1	3	4	1	6	1	0	0	0	0	0	0	4	1	7	0
subsp. <i>moschata</i>																	
<i>S. tridactylites</i>	4	2	1	2	1	5	0	0	0	0	0	0	0	5	1	1	1

Table 3. (contd)

(OTUs)	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
<i>S. cymbalaria</i>	0	0	0	0	1	0	2	3	2	0	6	1	1	2	1	0
<i>S. kotschyi</i>	0	0	0	0	2	0	5	4	2	1	3	2	2	3	2	0
<i>S. koelzii</i>	1	2	2		2	0	6	4	2	1	3	1	0	3	1	0
<i>S. wendelboi</i>	1	2	2	2	2	0	5	4	2	0	1	1	1	3	2	0
<i>S. iranica</i>	1	2	2	2	1	0	2	4	2	1	2	1	2	3	2	0
<i>S. ramsarica</i>	1	1	1	2	1	0	2	4	1	1	4	1	2	3	2	0
<i>S. paniculata</i>	1	2	2	1	2	0	2	2	2	0	2	1	3	3	2	0
subsp. <i>cartilaginea</i>																
<i>S. sibirica</i>	0	0	0	0	2	1	4	4	2	1	1	1	1	1	2	1
<i>S. exarata</i>	0	0	0	0	2	0	6	3	2	1	3	2	1	3	2	0
subsp. <i>moschata</i>																
<i>S. tridactylites</i>	0	0	0	0	1	0	3	1	2	0	1	1	1	4	2	0

Results and Discussion

- Phenetic relations between the species

Cluster analysis of the data matrix shows that, *Saxifraga* species in Iran are placed in two main branches (Fig. 1). The species belonging to sect. *Prophyrion* with similar life form (cushion form) and the single species of sect. *Ligulata* stand in one branch and the other

remaining species are grouped in the second branch. Although we have no species outside the group to conclude that this phenogram can support previous studies but this phenogram can be supported by the occurrence of these two sections in a monophyletic group (Soltis *et al.* 1996) with Asian origin (Web & Gornall 1989).

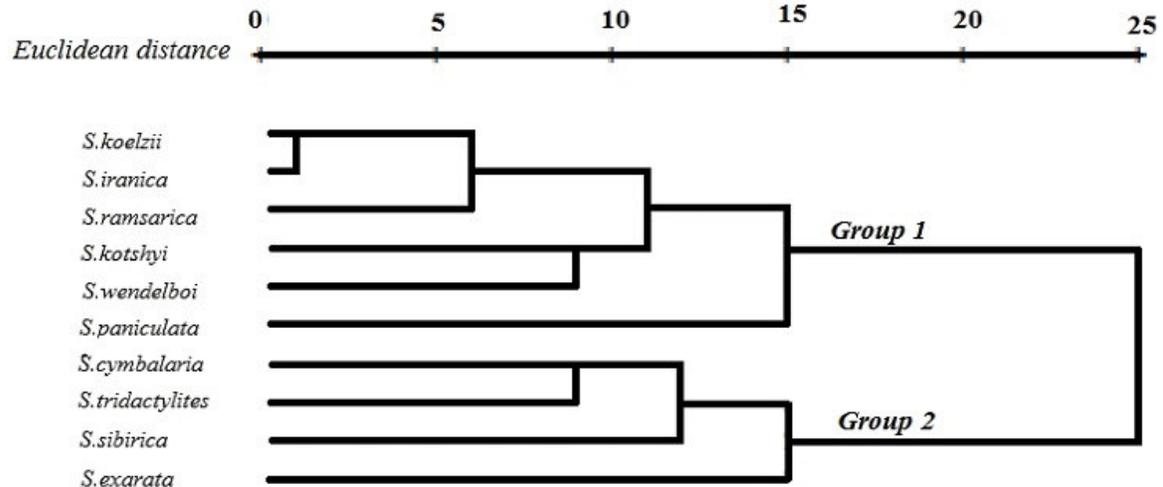


Fig. 1. Relationship among the species of *Saxifraga* in Iran based on morphological and non-morphological similarities.

- Relationships between the clusters and general distribution in species of *Saxifraga* in Iran

The general distribution of species shows also evidences for the origin of the endemic species of Iran and their putative relationships. Study on *S. paniculata* suggests vast expansion of this species in alpine slopes in Europe before Pleistocene's glaciations (Reisch *et al.* 2003). Due to the climatic and environmental conditions during the Pleistocene, this species was compelled to migrate toward southern latitudes and to fragment in different parts of new habitats as a refugee and evolved to various species in these areas (Conti *et al.* 1999). This pattern of movement happened for many other species such as *Abies*, *Betula*, and *Hippophae* during the Pleistocene glaciations (Huntley 1988). This species is introduced as a glacial relict in central Europe (Kaplan 1995). After the glaciations, this species in different part of its new habitat created a heterogenic segmentation and isolated population (Reisch *et al.* 2003). The same

situation can be considered for *Saxifraga paniculata* in this area.

The altitudinal range of Iranian endemic species also represents the direction of morphological changes (like perennial life form, imbricate leaves and cushion habit) in this genus in Iran. Table 1 demonstrates the average altitude of Iranian species c. 3000 m.

- Distribution patterns of *Saxifraga* species in Iran

Two patterns of distribution among Iranian species of *Saxifraga* can be distinguished:

Group one: The species of this group are distributed from Caucasus to Alborz. This area as one of the six plant diversity centers in Asia (Barthlott *et al.* 2005) covers an area between Black sea to Caspian sea and Alborz Mts that is the border line between two Euro-Siberian and Irano-Turanian regions (Zohary 1973). On the other hand, the Irano-Turanian floristic region is a

major center of endemism in the Holarctic of Eurasia (Akhani *et al.* 2013).

This group can be divided into following subgroups:

(a) Alpine endemic species

The major part of endemism in Alborz occurs in alpine and nival belt. About 32% of alpine endemic species in Iran are restricted to the Alborz, which this is near 126 species (Noroozi *et al.* 2008). These results are consistent with previous studies on the relationship between increasing of endemism and altitude (Pauli *et al.* 2003).

In comparison with other species of *Saxifraga*, the Iranian endemics (include *S. iranica*, *S. ramsarica*, *S. wendelboi*, and *S. koelzii*) have some exclusive ecological characters like elevational range, geographical distribution and morphological structure. Altitude range for these four endemic species of *Saxifraga* is within 1900–4200 m, whereas for other six species of *Saxifraga* in Iran, it is between 250–4000 m (only *S. sibirica* could be found higher than 3000 m) and we can consider these four species as part of the alpine flora in Alborz Mt. This pattern of distribution is similar to many other alpine endemic species in Alborz like: *Acantholimon damavadicum*, *Ligularia persica*, *Scutellaria glechomoides*, *Senecio vulcanicus* etc. (Noroozi *et al.* 2008).

For modeling climatic needs of species of group one, we plotted the observation points in relation with

annual precipitation and annual mean temperature (Fig. 2). Our analysis showed that, all members of alpine endemic subgroup of *Saxifraga* which grow on the border line between Euro-Siberian and Irano-Turanian regions, have adapted with climatic conditions of this part like low precipitation (150–250 mm/year) and temperature (2–12° C) unlike other subgroup, especially *S. kotschyi*, which has less tolerance for harsh ecological conditions (Fig. 2). As a result, Alborz highlands and NW of Iran can be assumed as a diversity center of *Saxifraga* in Iran.

(b) Euxino-Hyrcanian species

This subgroup includes *S. paniculata* subsp. *cartilaginea* and *S. kotschyi*. In our dendrogram (Table 2), *S. paniculata* subsp. *cartilaginea* appeared as a sister group for other five species. More evidence i.e. molecular data for supporting this hypothesis is needed (Figs 3 & 4).

Saxifraga paniculata subsp. *cartilaginea* covers an area from southeastern coasts of Black sea to central part of Alborz in south of Caspian Sea and can be introduced as Euxino-Hyrcanian elements (Matthews 1972). *Saxifraga kotschyi* is distributed from northeastern beaches of Mediterranean Sea, southern coasts of Black sea to northwestern of Iran and south of Caucasias (Fig. 4.). Iran is the easternmost range of this species in the border line of Iran and Turkey, therefore, this species can be named as an Euxinain element.

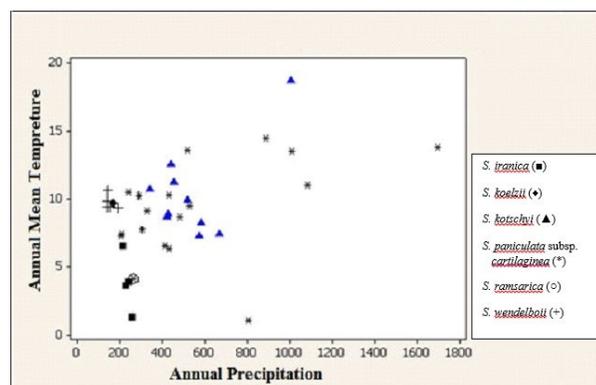


Fig. 2. Scatter plot of climatic needs in the species of group one.

Group two: Four species in this group are identified. With the exception of *S. sibirica*, other three species

show Euro-Siberian distribution (Figs 5a, b & d). They can further be subdivided into two subgroups:

a) Species for which Iran is the eastern border of their distribution. These species include *S. cymbalaria* (subsp. *cymbalaria* according to Flora Iranica) (Fig. 5a) with Turkey and eastern coast of Mediterranean Sea as its core distribution. It has a disjunct distribution in SW of Europe (Webb & Gornall 1989). *Saxifraga exarata* subsp. *moschata* occupies vast areas of west, south and east of Europe, coast of Mediterranean Sea, Turkey and north of Iran (Fig. 5b). *Saxifraga tridactylites* covers large parts of west and south of Europe, North Africa, Turkey, Caucasus and Iran in south, west and northeastern parts (Fig. 5c).

b) *S. sibirica* which has two distribution cores in eastern part of Europe extending to N Iran and in Siberia, central Asia to west of Himalayan Mts. with altitude range between 1000–4000 m which is the maximum range among the species of *Saxifraga*. (Fig. 5d).

Conclusion

According to morphological and chorological data, the Iranian species of *Saxifraga* can be divided in two groups. First group includes four Iranian endemic species in Alborz highlands along with two other regional endemic species that are distributed between south coasts of Black sea to south coast of Caspian Sea and alpine and nival belt of Alborz Mountains. Therefore Alborz highlands can be introduced as a diversity center for Iranian endemic species of this genus. Second group includes four other species of *Saxifraga* that are widespread in Europe and Iran. Except for *S. sibirica* that grows in Himalaya and central Asia, Iran is eastern boarder of distribution range for species of this group. More studies about the route of migrations in both groups and relations between the species in group one are needed.

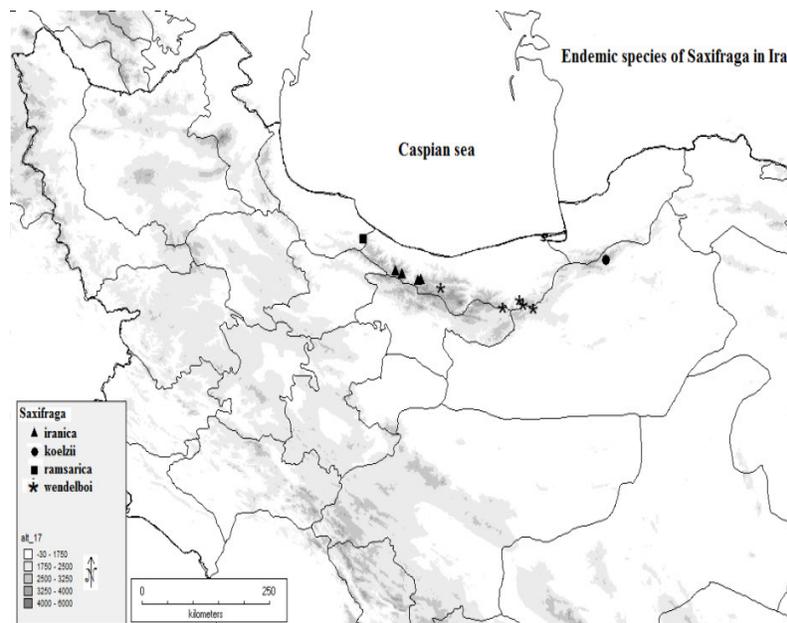


Fig. 3. Distribution of Iranian endemic species of *Saxifraga*: *S. iranica* (▲), *S. koelzii* (●), *S. ramsarica* (■) and *S. wendelboii* (*).

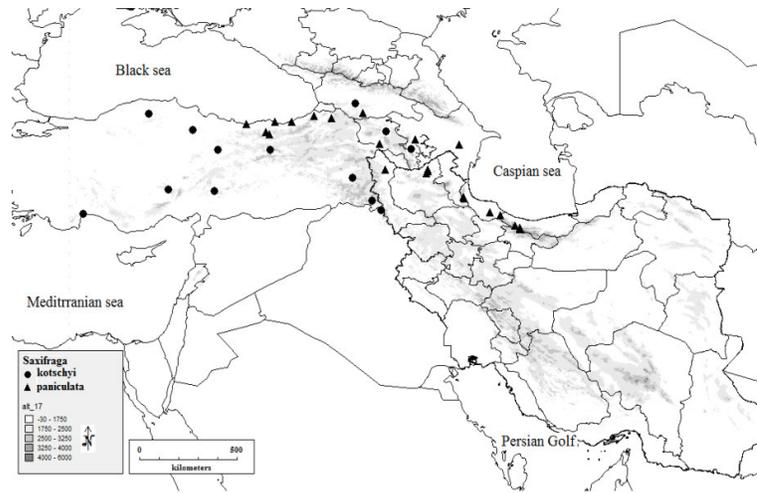


Fig. 4. Distribution of *S. paniculata* subsp. *cartilaginea* (▲) and *S. kotschyi* (●).

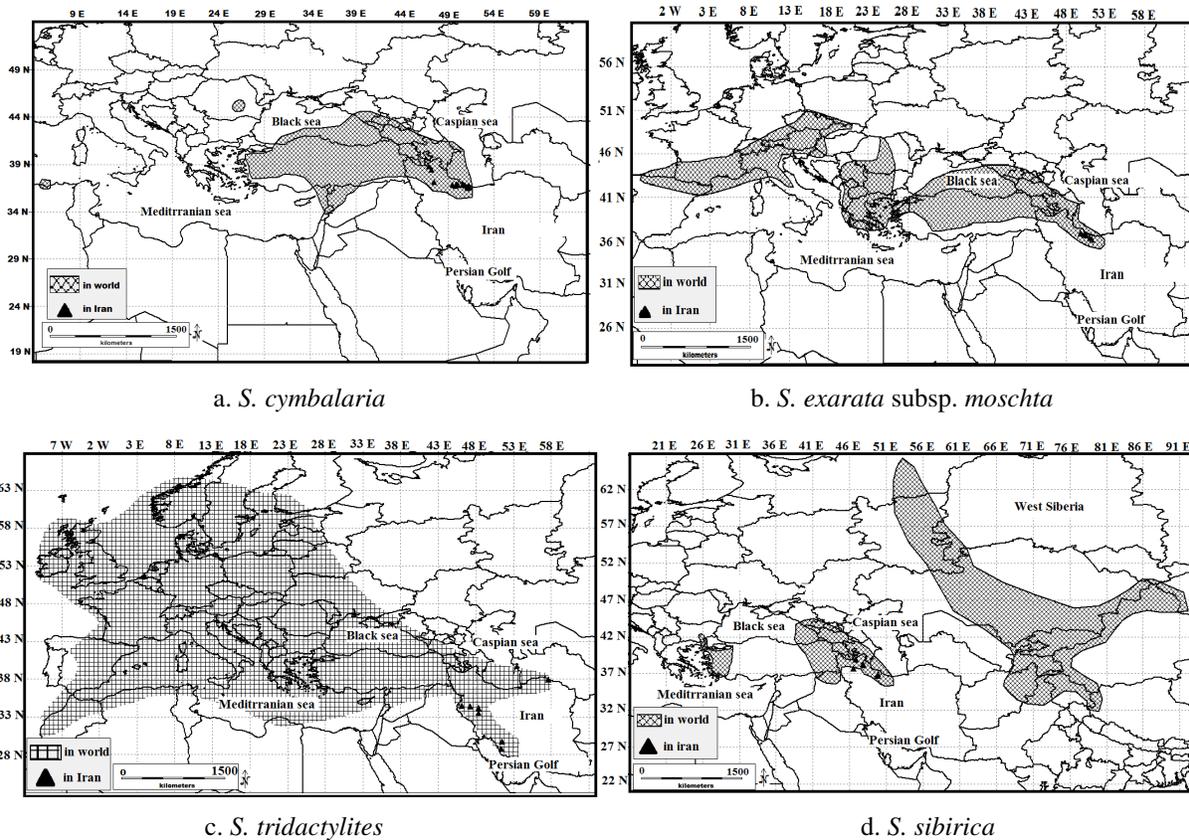


Fig. 5. Global distribution maps of widespread *Saxifraga* species in Iran (Group 2) in the world and Iran: a. *S. cymbalaria*, b. *S. exarata* subsp. *moschta*, c. *S. tridactylites*, d. *S. sibirica* world distribution data are from Webb & Gornall (1989) and distribution data of Iranian localities are added (with some modification).

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