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Diversity and distribution patterns of *Solanaceae* in Iran: Implications for conservation and habitat management with emphasis on endemism and diversity in SW Asia

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Abstract

The increasing rate of irreversible damages to natural habitats has reinforced the need for gathering biodiversity fundamental data to conservation. Priority setting is the most important step in protection programs. *Solanaceae* as the the one of important economic families of eudicots distributed throughout North and South America, Europe, Africa, Asia, Australia, and the South Pacific. Up to now, little attention has been paid to the patterns and diversity centers of *Solanaceae* in Iran. The present study describes in as much detail as possible the spatial distribution, areas with greater species richness, and centers of diversity for taxa. An ecogeographical database was developed using the records that corresponds to 3123 herbarium specimens belong to 2560 localities. The localities were marked using ArcView version 3.2 (ESRI 2000) on geo-referenced maps (1/106) of Iran. The distribution patterns of the taxa were mapped per 1° × 1° universal transverse Mercator grid cells (100 km^2 with the exception of boundary area). Threatened categories of Iranian *Solanaceae*, including CR (43.4%) and VU (34%), mainly (58.9%) distributed in Irano-Turanian phytochorion. *Solanaceae* represents the highest richness in the central Alborz, Zagros, Kopet Dagh and Makran Mountains based on recent criteria. The conservation value of habitats of *Solanaceae* in Iran ranges from 0.15 (in coastline of Persian Gulf) to 11.19 (in eastern Alborz).

Keywords: Conservation management, plant diversity, priorities for conservation, red list of species

الگوهای پراکنش تیره سیب‌زمینی در ایران: کاربرد در حفاظت و مدیریت رویشگاه‌ها با تاکید بر اندمیسم و تنوع در جنوب غرب آسیا*

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خلاصه

افزایش نرخ آسیب‌ها به زیستگاه‌های طبیعی نیاز به تدوین اطلاعات پایه جهت حفاظت را تقویت نموده است. الویت، مهمترین فاکتور در برنامه‌های حفاظتی می‌باشد. تیره سیب‌زمینی به عنوان یکی از گروهای دولپه‌ای حقیقی دارای طیف گسترده‌ای از مصارف دارویی، وابستگان وحشی گیاهان زراعی و زینتی می‌باشد. این تیره شامل ۵۵ گونه متعلق به نه جنس از شش طایفه در ایران است. مطالعه حاضر با هدف توصیف ویژگی‌های ژئوبوتانیکی، پراکنش فضایی، مناطق غنای گونه‌ای، مراکز تنوع و اندمیسم و همچنین گونه‌های نادر و در خطر انقراض با رویکرد ژئوبوتانیکی و حفاظت تبیین شده است. این پژوهش براساس ارزیابی ۳۱۲۳ نمونه ثبت شده از ۲۶۵۰ موقعیت جغرافیایی صورت پذیرفته است. این مناطق جغرافیایی در سلول‌های شبکه‌ای 1° × 1° (UTM) با مقیاس ۱۰۰ کیلومتر مربع به استثنای منطقه مرزی برای تعیین الگوی پراکنش و مناطق مهم به منظور مدیریت حفاظت جهت تهیه نقشه‌ها مورد ارزیابی قرار داده شده است. طبقات تهدید آرایه‌های تیره سیب‌زمینی در ایران عبارتند از: بحرانی (۴۳/۴ درصد) و آسیب‌پذیر (۳۴ درصد) که عمده آن‌ها (۵۸/۹) درصد در منطقه ایرانو-تورانی استقرار یافته است. نتایج این مطالعه نشان می‌دهد که بالاترین غنای گونه‌ای این تیره در کوه‌های البرز، زاگرس، کپه‌داغ و مکران تمرکز دارد. علاوه بر این، دامنه ارزش حفاظتی رویشگاه‌ها بین ۰/۱۵ (نوار ساحلی فارسی خلیج فارس و دریای عمان) تا ۱۱/۱۹ (البرز شرقی) متغیر می‌باشد.

واژه‌های کلیدی: الویت‌های حفاظتی، تنوع گیاهی، فهرست سرخ گونه‌ها، مدیریت حفاظت

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Introduction

The increasing rate of irreversible damage to natural habitats has reinforced the need for gathering biodiversity fundamental data to conservation planning (Mutke & Barthlott 2005). Setting priorities is the most important step in protection programs (Lovett *et al*. 2000). Up to now, many conservationists have focused on mapping the centers of endemism (Linder 2001, Jetz *et al*. 2004, Mittermeier *et al*. 2005), biodiversity hotspots (Williams *et al*. 1997, Reid 1998, Meyers *et al*. 2000), diversity centers of rare and endangered taxa (Dobson *et al*. 1997, Prendergast *et al*. 1993, Mittermeier *et al.* 1999), diversity centers of crop wild relatives (Iriondo *et al*. 2008) as well as medicinal plants (Kala 2005, Robenson 2008).

In the conservation approach, all taxa are not of equal significance (Vane-Wright *et al*. 1991, Arponen *et al*. 2005). The vulnerability of a wide range of taxa makes in necessary to assess the important taxa groups (Meyers *et al*. 2000, Negi & Gadgil 2002). Taxon-based diversity mapping (Müller *et al*. 2003) has been used for plant taxa on regional (Wagnetiz 1986, Rechinger 1986, Bischler & Jovet-Ast 1996, Zaharieva *et al*. 2005, Luna Vega *et al*. 2004, Zhonqiag *et al*. 2006, Moreira & Munoz-Schik 2007, Dowe 2010, Marshal *et al*. 2012, Mehrabian 2015) and continental-global (Barthlott *et al*. 1996, Farjon 1998, Jaramillo & Manos 2001, Ortega Baes & Godinez-Alvarez 2006, Olmstead 2013, Laurence *et al*. 2013) scales. Herbarium accessions usually provide the best data accessible for target taxa (Schmidt *et al*. 2005, Applequist *et al*. 2007, Lavoie 2013). The data shows efficiency in distribution patterns and ecological modeling (Heyligers 1998, Crawford & Schulman *et al*. 2007, Hoagland 2009, Fuentes *et al*. 2010, Hiopkins 2007, Raes *et al*. 2009, Droisart *et al*. 2012). Besides, the geodiversity and diversity of topography, climate, and soils correlate with the diversity patterns of vascular plants (Barthlott *et al*. 1996, 2000, Faith & Walker 1996, Jedicke 2001, Braun *et al*. 2002).

Solanaceae as the the one of important economic families of eudicots distributed throughout North and South America, Europe, Africa, Asia, Australia, and the South Pacific (Ladiges *et al*. 2011). It comprise 90 genera with more than 3500 species (D'Arcy 1986) and include some species with medicinal usage and alkaloids resistant to herbivorous (Heiser 1969) and several crop wild relatives (Samuels 2015) that are the focus of pharmacologists, ecologists, and gene breeders. Some species of this family can be used ecologically to maintain the healthy performance of the ecosystem as surrogates for conservation (Heywood & Dullo 1996, Caro 2010). *Solanaceae* exhibits diverse life forms that include trees, shrubs, herbs, climbers, and epiphytes. Worldwide, some taxa are confined to specific ecological niches (D'Arcy 1986) for which it is necessary to provide distribution patterns at the regional scale to determine the centers of diversity, areas of endemism, and categorize their conservation status.

Up to now, little attention has been paid to the patterns and diversity centers of *Solanaceae* in Iran. The present study describes in as much detail as possible the spatial distribution, areas with greater species richness, centers of diversity for medicinal taxa and crop wild relatives, and rare and endangered taxa in a geobotanical and conservation approach. This study summarizes the results of a large-scale survey of diversity patterns of Iranian families in what is recognized as one of the most important diversity centers in the world.

- Study area

Iran covers a total surface area of 1.6 million km^2 at 20°-20° N longitude and 44°-64° E latitude. The political borders of Iran comprise a limited part of the orogenic belt (Zagros, Alborz and other mountain chains) that span the Arabian-African unit and the Asian block (Berberian & King 1981).

- Geomorphology and geology

The Zagros is a section of the Alpine-Himalayan orogenic belt and is the most extensive mountain range system in Iran and has a NW-SE orientation that stretches about 2000 km from eastern Turkey to the Makran Mountains. It provides a geomorphological separation between the Iranian plateau to the northeast and the Mesopotamian and Persian Gulf basins to the southwest. The system has a mean elevation of ~1305 m with the highest point being 4408 m at Zard Kooh peak in Bakhtiari province (Homke 2007). The Alborz mountain range is an active, arcuate fold-and-thrust belt (Stocklin 1974, 1977, Axen *et al*. 2001). As the northern part of the Alpine-Himalayan belt, its gently sinuous east-west range extends into the north of Iran below the Caspian Sea. This system faces the depressed Caspian block to the north and is confined to the central Iranian plateau to the south (Stöklin 1974). This mountain chain is about 950 km in length and its width varies from 15 to 110 km (Ghorbani 2013). The average elevation of >2000 m has as its highest peak Mt. Damavand, a dormant volcano with 5670 m in elevation.

Another important orogenic belt is Kopet-Dagh that stretches from the eastern margins of the Caspian Sea into northeastern Iran, Turkmenistan, and northern Afghanistan (Afshar-Harb 1979, Buryakovsky *et al*. 2001). Other mountains ranges in Iran include the Makran in central, Jebal Barez in Southeastern, and Azarbaijan in northwestern Iran. Interior basins, lowlands, coastal, and riverine zones are surrounded by these mountain systems (Fischer 1968).

Iran's habitat is classified as upland with an average altitude of 1000 m, with the exception of the limited plains of the Caspian Sea, Persian Gulf, and Khuzestan (Ghorbani 2013). Elevation varies from 27 m below sea level in the Caspian basin to 5671 m above sea level at Mt. Damavand. Iran, as a section of the Alpine-Himalayan orogenic belt (Ghorbani 2013) and has been divided into 10 structural zones (Stoklin & Nabavi 1973). A series of more recent studies (Nabavi 1978, Alavi 1994) recognizes the structural zones of central Iran including Sanandaj-Sirjan, Zagros, Alborz, Azarbaijan, eastern Iran, southeastern Iran, and Kopet-Dagh (Fig. 1).

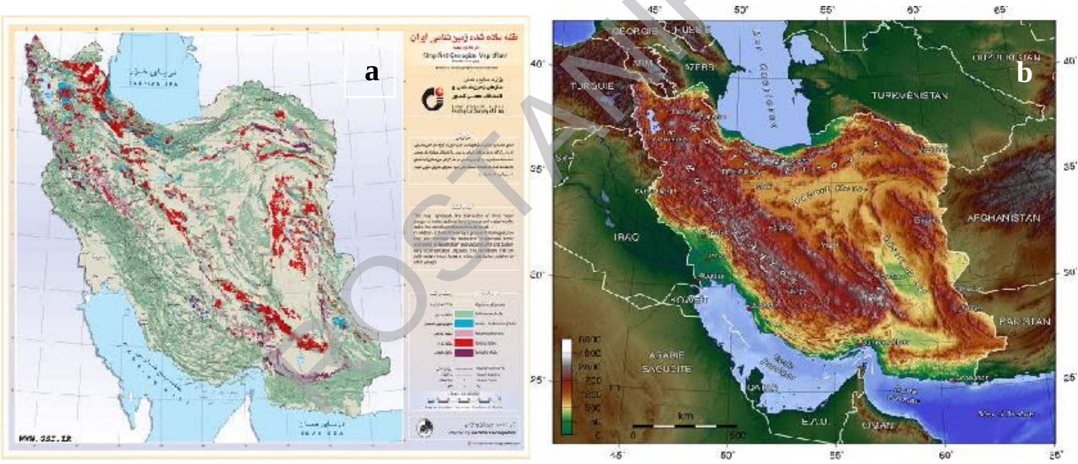

Fig. 1. a. Simple geological map of Iran, b. Geomorphological map of Iran (www.ngdir.ir).

- Climatology

Climate is a chief component of ecology and affects the growth of plants and their distribution patterns. Other environmental factors, such as land-forms, habitat types, and soil characteristics demonstrate their effects locally (Zahran 2010). The topographic heterogeneity of Iranian ecosystems exhibit great diversity of climatic conditions. Mountainous massifs enclose the central parts of the country as a natural barrier and prevent penetration of moisture-bearing clouds into the interior of central Kavir and Dasht-e Loot. These orographic features experience variation in rainfall (Djamali *et al.* 2011) as followed: Abali (2465 m asl, northeastern Iran, 534 mm), Astara (18 m bsl, northwestern Iran, 1380 mm), Bandar Abbas (10 m asl, southern Iran, 182.5 mm), Chabahar (8 m asl, southeastern Iran, 111 mm), Tabas (711 m asl, central Iran, 83 mm), Ilam (1337 m asl, western Iran, 616 mm) and Mashhad (999 m asl, northeastern Iran, 255.2 mm).

Djamali *et al.* (2011) classified Iranian ecosystems into macro-bioclimatic as follows: temperate (north), Mediterranean (west, northwest), and tropical (south accordant to zones of the Persian Gulf and Gulf of Oman). Breckle (2002) classifies Iranian habitats as situated in zonobiom III to the south and zonobiom VII (rIII) to the north. The climatic heterogeneity, floral history, evolutionary potential (Frey & Probst 1986), complex interaction between climatic zones, and bio-geographical regions in the orographic context (Zohary 1973) has produced many heterogenic habitats and plant formations (Frey & Probst 1986). Flora of Iran comprise 7300 plant taxa (Akhani 2006) and 1727 endemic species (Jalili & Jamzad 1999), and it has made Iran as an important center of endemism (Heywood 1994) with valuable zones of plant diversity (Barthlott *et al*. 1996).

Iran is an arid land with an annual rainfall that is less than one-third of the world average (Shakur *et al*. 2010). The hot southern gulf region, with its higher winter and summer temperatures and scant rainfall, displays a climate regimen similar to that of the tropical northeast African and the hot Sindian deserts, but with occasional more extreme maxima and minima (Zohary 1973).

Materials and Methods

The present study examined 3123 herbarium specimen records from HSBU, W and WU (herbarium abbreviation according to Thiers 2008) and several scientific resources (Schönbeck-Temesy 1972, Khatamsaz 2002) on the vegetation and flora of Iranian habitats to provide distribution and ecological data on *Solanaceae* in Iran. Climate factors were provided by the Iranian Climatological Organization (average of 50 years (1955–2005) for rainfall and temperature. Rivas-Martínez *et al*. (1997, 1999) developed a novel method of global classification for detailed bioclimatic analysis. Djamali *et al*. (2011) adapted it for the Iranian ecosystems that used in this study. Assessment of the conservation status was based on the IUCN Red List at regional scale (IUCN 2011). We classified Iranian plant formations based on Frey & Probst (1976) and plant habitats based on a combination of Zohary (1973) and Bailey (2009).

An ecogeographical database was developed using these records that corresponds to 2560 localities. The localities were marked using ArcView version 3.2 (ESRI 2000) on geo-referenced maps ($1/10^6$) of Iran. The distribution patterns of the taxa were mapped per 1° × 1° universal transverse Mercator grid cells (100 km^2 with the exception of boundary area) to determine the distribution pattern and the most important areas for conservation management.

The criteria for scoring were the index of species rarity in the study area (RI) based on Williams *et al*. (1996), index of species distribution (SDE) based on Selvi (1997), Sapir *et al*. (2003), and Solymos & Feher (2005). Scoring ranged from zero (0) to one (1) for both indices and the vulnerability of the species increases as the score increases. The RI is calculated as the inverse of the number of cells having species recorded the target area as RI=1/Ci, where Ci is the number of grid cells and l is the number of present taxa. The SDE is calculated as SDE=l-Ci/C where C is the total number of grid cells. To calculate the conservation value (CV), the RI and n (SDE of each grid cell) were summed up. The higher scores represent a higher CV. Biological forms were assessed based on Raunkaier (1934). Flora Iranica (Schönbeck-Temesy 1972) was the most important reference used for assessment and taxonomical nomenclature.

This is worthy to state that, all taxonomical information given here is merely on conservation-based approach, as the basic needs of the survey carried out in the present study.

Results

- Diversity and distribution patterns

Solanaceae is widely distributed in Iran. The family includes 55 species belonging to nine genera classified into six tribes (Schönbeck-Temesy 1972, Khatamsaz 2002, Akhani & Ghorbani 2003, Dinarvand& Howeizeh 2104) (Table 1). The taxa occur in diverse abundance in Iranian habitats, especially in the mountainous habitats of Taftan (East), central Alborz (North), and western slopes of central Zagros (West). Jebal Barez shows the greatest abundance and central Kavir shows the least at the family level (Figs 3–4).

The *Solanum* taxa are crop wild relatives (up to 13 per grid cell) in the western zones of the central Alborz, central Zagros, and Taftan (Figs 3–4), *Atropa* (up to 11 per grid cell) in central Alborz, *Datura* (up to 8 per grid cell) in central Alborz and western zones of central Zagros (Fig. 2), *Withania* (up to 13 per grid cell) in Makran and central Taftan (Figs 3–4), *Lycium* (up to 19 per grid cell) in Kopet Dagh, northern and southern Zagros, and Taftan (Figs 3–4), and *Hyoscyamus* (up to 41 per grid cell). Central Alborz and Kopet Dagh show the highest frequency. *Solanaceae* (up to 55 per grid cell) shows the highest abundance in central Alborz, Kopet Dagh and Taftan. The highest richness of species and genera among the geographical latitudes are 14–15 (35º-37º) and 6 (36º-37º), respectively. The lowest number of species and genera per grid cell is one and reflects an irregular pattern in Iran. The species and genera vary from 1 to 15 and 1 to 6 per grid cell, respectively. The highest richness of species and genera is focused in the Alborz and Zagros regions.

This family is distributed over 155 of 171 grid cells as follows: *Hyocyamus* (110), *Lycium* (109), *Solanum* (71), *Withania* (25) *Atropa* (7), *Datura* (32), *Mandragora* (2), *Physochlaina* **(**Schönbeck-Temesy 1972) (1) (Figs 3–4). The genera distribution by geographical latitude is: *Hyocyamus* 26º-40º, *Lycium* 26º-39º, *Solanum* 26º-39º, *Withania* 26º-32º, *Atropa* 36º-38º, *Datura* 27º-40º and *Mandrogora* 37º-38º and 32º-33º (Fig. 2). Moreover, the genera and species show irregular variation over the latitudinal gradient. A maximum of 1–15 species and a minimum of 1–5 genera occupy each grid cell. These taxa are diversely abundant in Iranian habitats. Taftan (East), central Alborz (north), the western slopes of central Zagros (west) and Jebal Barez show the greatest abundance. The central Kavir represents the lowest abundance at the family level (Figs 3–4). *Solanum* (up to 13 in grid cells) is found in western zones of the central Alborz, central Zagros and Taftan (Figs 3–4), *Atropa* (up to 11 in grid cells) in the central Alborz, *Datura* (up to eight in grid cells) in central Alborz and western zones of central Zagros (Figs 3–4), *Withania* (up to 13 grid cells) in Makran and central Taftan (Figs 3–4), *Lycium* (up to 19 in grid cells) in Kopet Dagh, the northern and southern Zagros and Taftan (Figs 3–4), *Hyocyamus* (up to 41 in grid cells) in the central Alborz and Kopet Dagh showed the greatest abundance. *Solanaceae* (up to 55 in grid cells) showed the greatest abundance in central Alborz, Kopet Dagh and Taftan.

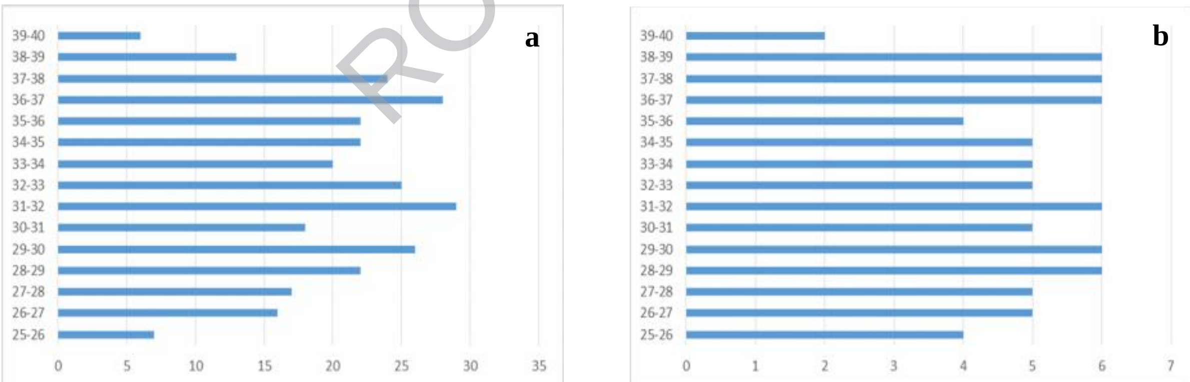

Fig. 2. a. Species profile along latitude, b. Genera profile along latitude.

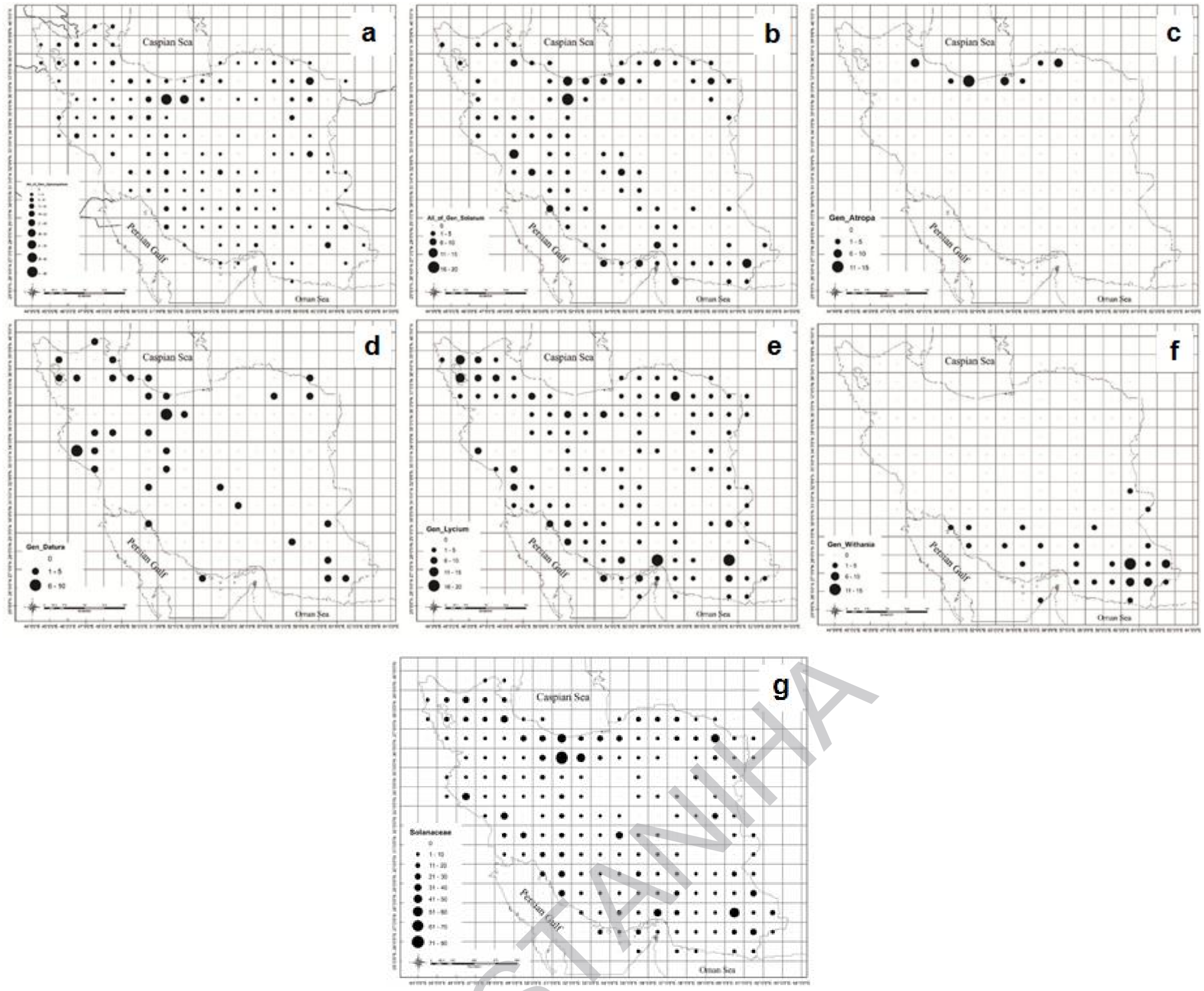

Fig. 3. Abundance pattern of the genera of *Solanaceae* in scale of Iran: a. *Hyocyamus*, b. *Solanum*, c. *Atropa*, d. *Datura*, e. *Lycium*, f. *Withania*, g. *Solanaceae*.

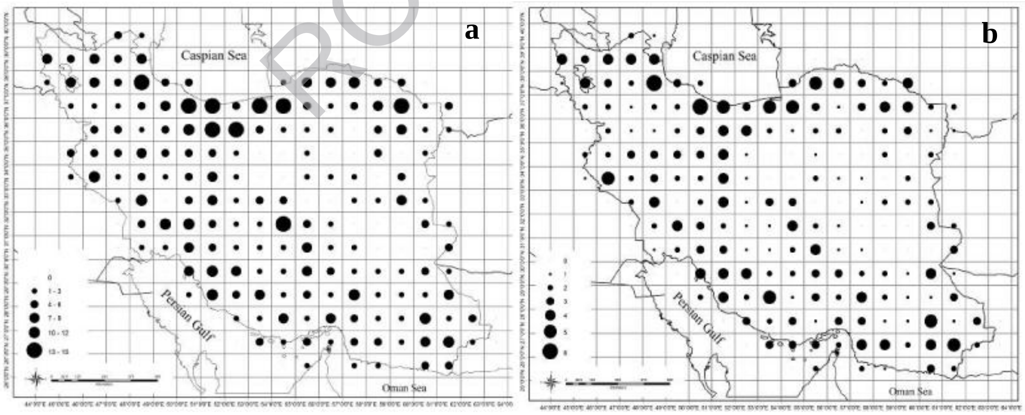

Fig. 4. a. Richness of species, b. Richness of genera inside occupied grid cell.

The elevation patterns of the taxa can be classified as alpine (>2500 m), sub-alpine (1200–2500 m) and mountain slopes-to-lowlands (<1200 m), (Kapos *et al.* 2000), although many taxa show transitional habitats and occupy all three life zones. The taxa represent a range of elevations as follows: *Solanaceae* (*Solanum* species only) 6–3650 m, *Physaleae* 10–1800 m (comprising *Physalis* at 10–1750 m and *Withania* at 10–1800 m), *Atropeae* 0–2200 m (comprising *Lycium* at 0–2200 m, *Atropa* at 8–1960 m, and *Mandragora* at 185 m)

Datureae at 1400 m, *Hyoscyamine* at 5–3800 m, *Physochlaina* at 640 m (Schönbeck-Temesy 1972), *Hyoscyamus* at 10–3800 m (Fig. 6). *Solanaceae* is distributed across an altitudinal range of 0 to 3800 m within the Iranian geographic borders.

Solanaceae shows distribution patterns in quaternary deposits and sedimentary, volcano-sedimentary, metamorphic, igneous, and ophiolitic rock. *Atropa* occurs in sedimentary and volcano-sedimentary rock only (simplified geological map of Iran www.ngdir.ir). The other genera inhabit a wide range of distribution in geological rock. *Solanaceae* is distributed in diverse geomorphological units in northern, northwestern, northeastern and central Iran, the Zagros, the coastlines of the Persian Gulf and Caspian Sea, and southern, southwestern and southeastern Iran. *Withania* is located in southwestern and southern geo-morphological units and the others are established in a varied scope of geomorphological units.

The life forms of the plant taxa illustrate adaptation to environmental agents (Lande 1982, Galan de Mera *et al*. 1999). These forms represent the peak of adaptation of a plant to climatic conditions (Raunkiare 1908), therefore, assessment and analysis the life forms can help identify ecological features of the habitats (Diaz & Cabido 1997). *Solanaceae* in Iran features therophytes with 12 (19%), hemicryptophytes with 28 (45.7%), and chamaephytes with 25 (35.3%) (Fig. 7). *Solanum* features the highest abundance rates of hemicryptophytes (8), chamaephytes (4) and therophytes (4). The life forms diversity showing a peak at 1000–1500 m and sharply decrease over 2000 m. Besides, showing a peak between 29° to 32° latitude and with a clear decrease at the higher and lower latitudes (Fig. 7).

- Endemism

Most endemic taxa are belong to *Hyocyamus* including *Hyoscyamine kotschyanus*, *H. malekianus*, *H. orthocarpus*, *H. natans*, and *H. rosularis* at 27º to 38º N latitude and 15 to 3800 m in elevation. This covers the Irano-Turanian and Sudano-Zambezian regions accordant to the Mediterranean pluviseasonal-continental, Mediterranean desertic-continental, and tropical desertic bioclimates. *H. kotschyanus* is found in metamorphic and sedimentary rock, *H. malekianus*, *H. orthocarpus*, and *H. rosularis* in sedimentary rock and quaternary deposits, *H. natans* in sedimentary and igneous rock and infrequently in metamorphic rock.

- Rare taxa and conservation status

Rare taxa show greater extinction risk than common taxa in similar conditions of ecology (Johnson 1998, Matthies *et al*. 2004) because of high sensitivity to demographic and environmental events (Boyce 1992). *Solanaceae* taxa were, categorized based on RI. The rare classes were the very rare (10) to rare (7) and comprise 37% of Iranian *Solanaceae*. These taxa are distributed across the different bioclimatic, geomorphologic, and geologic units of Iran. The species occur at 18 to 3800 m in elevation. The rare taxa are found in *Solanum*, *Atropa*, *Mandrogora*, *Physochlaina*, and *Hyoscyamus* genera.

Assessment of the conservation status of the plant taxa and developments of red lists are the first step in management. The IUCN Red List of threatened species is the most respected base for assessment of conservation categories. Endemic species are distributed from 8 to 3800 m.

- Phytogeography

Solanaceae include several widespread, cosmopolitan, and some bi-regional taxa. This family is found in the Irano-Turanian region (Holarctic kingdom) in the northern, western, eastern, and central parts and the Sudano-Zambezian region (Pleotropic Kingdom) in the southern parts. The first region comprises the Irano-Turanian regional center of endemism and second region comprises the Saharo-Sindian local center of endemism (Léonard 1989, White and Léonard 1991). The Irano-Turanian region shows clear climatic, vegetative, and floristic properties characterized by diurnal and annual variation in temperatures, low precipitation, hot summers, and cold extreme winters. This region shows little affinity to neighboring regions that featured with climax vegetation dominated by hemicryptophytes and chamaephytes (Zohary 1973) The Irano-Turanian (48.07%) and multi-regional elements (32.69%) have the highest contribution of phytochorions. The

Hyrcanian (7.69%), Irano-Turanian-Hyrcanian (5.76%), cosmopolitan (2%), and Sudano-Zambezian (1.88%) comprise other phytogeographical elements.

- Priorities for conservation

Myers (1988, 1990) classified hotspots for regions with specific concentrations of species richness, restricted endemics, and threatening factors. The factors considered for selection as priorities for conservation follow:

a. Richness-based

Solanaceae shows a regular pattern of species richness in the central Alborz, Zagros, Kopet Dagh and Makran mountains in Iran and have the highest rank for CV.

b. Rarity-based

The taxa classified that ranked highest for rarity have the highest priority for conservation. The most highly ranked are *Solanum* (6), *Hyoscyamus* (3), *Atropa* (2), *Mandrogora* (2), and *Physochlaina* (1), respectively.

c. Endemism-based

Endemism- taxa of *Solanaceae* all belong to *Solanum* (1), and *Hyoscyamus* (7) that are mainly centered in the Sudano-Zambezian region.

d. Habitat-specificity based

This category refers to the habitat for each taxon based on SDE. The taxa can be classified as high specificity, medium specificity, low specificity, and widespread.

- Conservation value

CV ranged from 0.15 (coast of Persian Gulf) to 11.19 (central Alborz) show an irregular pattern in Iran (Fig. 8).

Discussion

This is the first study on the distribution patterns of *Solanaceae* in Iran based on the geographic information system (GIS). The family comprises 55 species (0.82% of Iranian plant taxa) with eight endemic species (0.46% of Iranian endemic taxa) (Hedge & Wendelbo 1978, Jalili & Jamzad 1999). This is a higher rate of endemicity than in neighboring countries in southwest Asia. The center of origin of *Solanaceae* in South America (Hunziker 1979) shows a wide distribution (Barroso *et al*. 1991) and several species are distributed in limited and specific habitats around the world (Albuquerque *et al*. 2006).

Some insist on a Gondowanan origin for *Solanaceae* (e.g. Symon 1991) and others (Raven & Axelrod 1974) believe it is even younger. The high power dispersal and variance are important reasons for modern-day distributions (D'Arcy 1991). The prominent zones of endemism for *Solanaceae* are located in the Zagros mountainous ecosystem, the center of endemism of the Irano-Turanian region (Davis *et al*. 1994, Jalili & Jamzad 1999, Mehrabian *et al*. 2015), and the ecotonic zones (Clements 1905, Risser 1995) at the crossroads of the Irano-Turanian and Sudano-Zambezian regions.

The Irano-Turanian and Mediterranean regions (Takhtajan 1986, Zohary 1973) show higher diversity and endemicity than adjacent areas (Clement, Hochstrasser & Peters). These centers encompass the richness of endemic monocotyledons in Iran (Mehrabian *et al*. 2015). *Hyoscyamus* L. and *Solanum* L. are endemic at 15 to 3800 m and create a wide and sensitive conservative zone along this elevation gradient. Geology is highly effective for delimitation of ecosystems and analysis of distribution patterns (Parenti & Ebach 2009). The endemic zones of *Solanaceae* are situated mainly in sedimentary (quaternary deposits) and ophiolitic formations in Iran. Geological evidence confirms the belief of Rechinger (1961) that specific soils can be used to delineate high endemicity in Iran. Endemic *Solanaceae* shows a slight decrease from the Iranian plateau (Schönbeck-Temesy 1972) to the Anatolian plateau (Davis 1978) (Fig. 5).

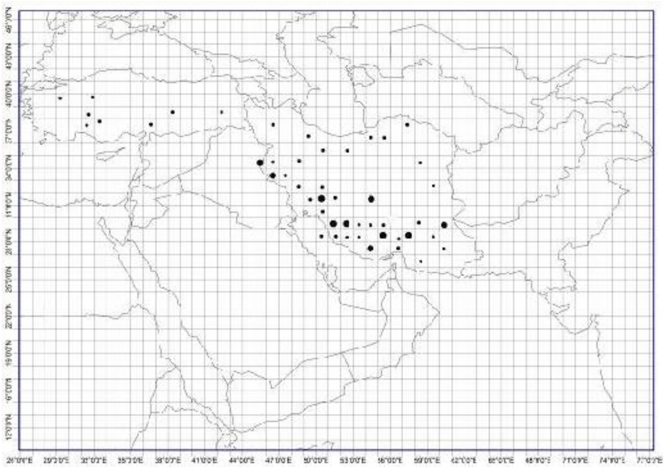

Fig. 5. Endemism pattern of *Solanaceae* in SW Asia.

Table 1. A comparison of *Solanaceae* members among some country of SW Asia

Genus	Iran	Iraq	Afghanistan	Pakistan	Russia	Syria and Palestine	Turkey	Saudi Arabia
Solanum	14	4	8	12	22	6	8	1
Physalis	2	-	1	1	6	1	1	-
Hyoscyamus	19	11	7	4	8	5	7	1
Atropa	4	-	1	1	3	1	1	-
Physochlaina	1	-	-	-	3	-	1	-
Lycium	7	3	4	6	5	2	8	2
Datura	2	1	3	3	3	2	3	2
Mandragora	2	-	-	-	1	1	1	-
Withania	2	1	2	2	-	1	1	1
Total	**54**	**20**	**26**	**29**	**52**	**19**	**31**	**7**

Table 2. Conservation and rarity of studied taxa. SDI (Index of Species Distribution), RI (Rarity Index) and CV (Conservation Value)

Taxon	SDE	RI	CV	Taxon	SDE	RI	CV
Solanum pseudocapsicum	0.984	1	1.984	*Atropa acuminata*	0.938	0.142	1.081
S. nigrum	0.476	0.029	0.506	*Mandragora turmanica*	0.892	1	1.892
S. carmanicum	0.984	1	1.984	*M. autumnalis*	0.892	1	1.892
S. transcaucasicum	0.984	1	1.984	*Datura stramonium*	0.984	0.043	1.028
S. olgae	0.907	0.166	1.074	*D. innoxia*	0.646	0.066	0.712
S. alatum	0.846	0.1	0.946	*Physochlaena orientalis*	0.984	1	1.984
S. luteum	0.876	0.125	1.001	*Hyoscyamus arachnoideus*	0.415	0.026	0.441
S. kieseritzkii	0.953	0.333	1.287	*H. turcomanicus*	0.753	0.062	0.816
S. persicum	0.600	0.038	0.638	*H. niger*	0.553	0.034	0.588
S. asiae-mediae	0.969	0.5	1.469	*H. kurdicus*	0.661	0.045	0.706
S. incanum	0.984	0.06	1.051	*H. leucanthera*	0.784	0.071	0.856
S. dulcamara	0.769	0.047	0.816	*H. squarrosus*	0.676	0.047	0.724
S. sisymbriifolium	0.907	0.5	1.407	*H. reticulatus*	0.476	0.029	0.506
S. surattense	0.953	0.2	1.153	*H. pojarkovae*	0.969	0.5	1.469
Physalis alkekengi	0.923	0.090	1.013	*H. kotschyanus*	0.938	0.25	1.188
P. divaricate	0.830	0.125	0.955	*H. pusiilus*	0.138	0.017	0.156
Withania somnifera	0.876	0.090	0.967	*H. senesionis*	0.461	0.028	0.490
W. coagulans	0.830	0.047	0.878	*H. leptocalyx*	0.984	1	1.984
Lycium ruthenicum	0.676	0.027	0.704	*H. malekianus*	0.969	0.5	1.469
L. depressum	0.446	0.015	0.461	*H. rosularis*	0.984	1	1.984
L. kopetdaghi	0	0.076	0.076	*H. tenuicaulis*	0.676	0.047	0.724
L. dasystemun	0.8	1	1.8	*H. orthocarpus*	0.830	0.090	0.921
L. makranicum	0.984	0.2	1.184	*H. insanus*	0.584	0.037	0.621
L. shawii	0.923	0.033	0.956	*H. nutans*	0.846	0.1	0.946
L. edgeworthii	0.538	0.062	0.600	*H. bonmiillerianus*	0.984	1	1.984
Atropa belladonna	0.753	0.2	0.953				
A. pallidiflora	0.923	1	1.923				
A. komaroxii	0.984	0.25	1.234				

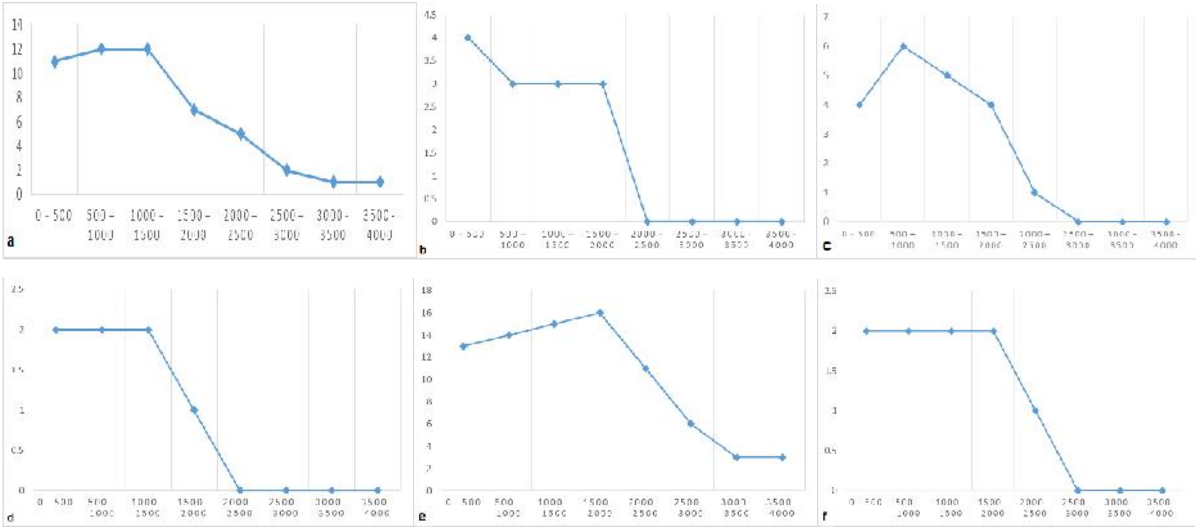

Fig. 6. Genera richness in altitudinal profile: a. *Solanum*, b. *Atropa*, c. *Lycium*, d. *Physalis*, e. *Hyocyamus*, f. *Datura*.

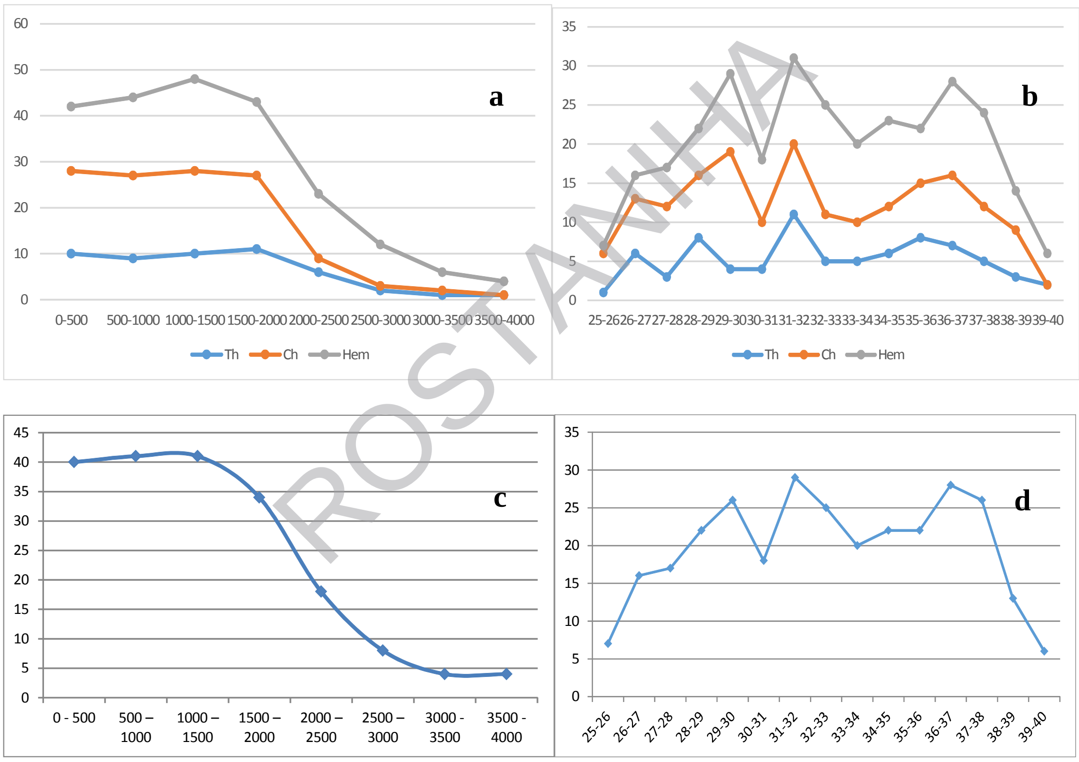

Fig. 7. Comparative life form diversity in: Altitudinal profile (a), Latitudinal profile (b), Wholly richness variation of *Solanaceae* along latitudinal (c) and altitudinal (d) profiles.
(Th: Therophyte, Ch: Chamaephyte, Hem: Hemicryptophyte).

The genus *Lycium* L. comprises about 70 species in a disjointed distribution in arid and semi-arid regions and the saline habitats of coastlines in temperate and subtropic zones in America, Africa, and Eurasia (Hitchcock 1932, D'Arcy 1979, 1991, Hunziker 1979). *Lycium* in Iran (7) and Eurasia (10) shows less diversity than in North (20) and South America (30) and North Africa (20). The disjointed dispersal of *Solanaceae* has been hypothesized as being caused by continental drift (Symol 1991) or long-distance dispersal (Raven & Axelord 1974). *Lycium* forms known plant communities in Irano-Turanian (*L. kopetdaghi*, *L. ruthenicum*), and

Sudano-Zambezian (*L. shawii*, *L. makranicum*) regions in Iran (Zohary 1973). Some are umbrella taxa (Groom *et al*. 2006, Christopher 2007) that support lower plant communities. They are influenced by wildlife that feed upon their fruit and shape their refuge (Mostafavi *et al*. 2006, Abdoli *et al*. 2008) to conserve biodiversity. They are surrogates of biodiversity (Santi *et al*. 2010, Chiarucci *et al*. 2015) and keystones to sustainability and protect the ecosystem (Paine 1995, Mills *et al*. 1993). Zohary (1973) classified *Lycium shawi* as an important element in steppe-scrub of *Juniperus-Pistacia-Amygdalus* and oligo-hydric communities along the coastlines of the Persian Gulf and Sea of Oman. Modern species are considered indicators of former connections between Iran and east Africa through tropical Arabia (Zohary 1973) as the red fruit is easily dispersed by birds over long distances. *Lycium kopetdaghi*, and *L. ruthenicum* are Irano-Turanian elements and, in their eastern-most distribution range, cover the northeast and east, respectively.

Atropa is a forest-sub-forest element distributed in limited localities of Hyrcanian forests. *Atropa belladonna* is situated in the most eastern portions of the distribution range and *A. acuminata* in the most western portion of the distribution range in Iran. Unfortunately several populations of recent taxa have failed during the widespread destruction of the Hyrcanian forests.

Hyoscyamus, comprising about 20 species with a distribution throughout Eurasia, except for disjunctions caused by deserts (Tu *et al*. 2010). This genus is represented by 19 species (as a center of diversity) in Iran, including seven endemic species. Tu *et al*. (2005) have been suggested that divergence among *Hyoscyameae* may have resulted from the rise of the Himalayan-Hengduan mountain ecosystem alongside the Tethys margins and the extension the dryness in central Asia. Polyploidy is a common occurrence in *Hyocyameae* and plays a role in harsh habitats (Hanelt 1966). It is also common in *Hyoscyameae*, especially in the Hyocyamus that restricted to Iran (Sheidai *et al*. 1998). Some have classified them into the following anthropogenic communities in Iran (Zohary 1973, Khatamsaz 1998): *H. reticulatus*, *H. Turcomanicus*, and *H. arachnoides.* The negative effects of agricultural ecosystems means that distribution data on recent taxa is necessary to their conservation and management (Mack *et al*. 2000).

Mandragora L. is an old world taxa of *Solanaceae* that include 6 species (Dinarwand & Howizeh 2014) distributed in the circum-Mediterranean, Irano-Turanian, and Sino-Himalayan regions (Ungricht *et al*. 1998). *M. turcomanica* Mizg is a neglected and underutilized plant (IPGRI 2002) with a limited distribution in Turkmenistan (Kurbanov 1994) from a small zone in Golestan in northern Iran (Akhani & Ghorbani 2003), and *M. autumnalis* Bercol have recently been reported by Dinarwand & Howizeh (2014) in oak forests in the Shimbar Preserve in Khuzestan (SW Iran). Traditional societies of Iran could be the reason for the decrease in distribution because of overharvesting. Establishment of a preserve has given *M. autumnalis* a better chance of conservation. *M. turcomanicum* is found in home gardens (Watson *et al*. 2001) and the support of local offices of the environment can improve protection by the owners. Penetration of this Mediterranean element into western regions of Iran confirms the belief of Zahran (2010) and Zohary (1973) that the western slopes of the Zagros have been affected by the Mediterranean region. A sister affinity between two recent taxa as well as their disjunction patterns (in the eastern Mediterranean basin and Irano-Turanian region) empowered a hypothesis that includes vicariance of Mediterranean flora and fauna (Kadereit & Yapark 2008). The Mediterranean-Himalayan dispersal of *Mandragora* may have been caused by periodical fluctuations in the Caspian Sea during the Pliocene and Quaternary that simulated divergence and allopatric speciation in recent taxa as well the following taxa: *Mespilus germanica*, *Sorbus graeca*, *Evonimus velutina*, *Crataegus androssowi*, and *Rhus coriaria* (Fet & Atamuradov 1994). Others (Proskurayakova & Belyanian 1985, Kurbanov 1994) insist on the role of fauna on their dispersal and believe on a younger distribution. In traditional societies of Iran, they are called “Mehr-e giah”, which could be the reason for the overharvest and decrease in the distribution range in the region. Regardless of its limited distribution in Iran, establishment of a protected area has preserved the conservation status of *M. autumnalis*.

The genus *Datura* includes 10 to 12 species (Geeta and Gharaibeh 2007) that are mainly distributed in southern North America (Bye 1986). *D. ferox* L., *D. stramonium*, and *D. metel* L. are distributed in China, Eurasia and south and west Asia, respectively. Symon (1991) insisted that the origin of diversification *Datura* is in the New World.

Solanum is the largest genera in *Solanaceae* and one of the largest taxa of angiosperms (Olmstead *et al*. 1999) and shows less diversity in Iran than in other regions of its distribution. Several *Solanum* species are distributed mainly in Iranian protected areas (Fig. 9). These taxa are located in highly enriched zones that can be suggested as gene sanctuaries (Singh 1981) or gene micro-reserves (Serra *et al*. 2004) for protection of these valuable wild relatives of crops. They are valuable for breeding plants for resistance to disease and environmental stresses and potential uses for agronomy (Jansky 2000). *Solanum* subgenus *Leptostemonum* (Dunal) Bitter. is a large group of monophylytes (ca. 350–450 taxa) with worldwide dispersal centered dominantly in South and Central America, Africa, Australia and Asia. It can be recognized by the presence of prominent epidermal thorns that cover the stems and leaves (Levin *et al*. 2006, Olmstead 2013). *Solanum incanum* is a member of this subgenus and is a common species in association with *Ziziphus spina-christii* in the Sudano-Zambzian in the Middle East, especially in Iran (Zohary 1973). This stretches to Saudi Arabia, Africa, Pakistan and India. Another spiny species (*Solanum surattense*) distributed in southeastern Iran shows wide distribution in America, Europe, Africa and southwest Asia (Levin *et al*. 2006). *Solanum sisimbryfolium* Lam. (spiny *Solanum*) is a newly penetrated taxon recorded from the lowlands of the Caspian Sea and is widely distributed in ruderal habitats along roadsides and sand dunes in northern Iran (Eslami & Naqinezhad 2010 and personal observation of second author). This recent species is native to South America but has naturalized in Europe, some habitats of Africa and Australia as well as having a wide distribution in the US (Karaer & Kutbay 2007). This pioneer taxon was dispersed through the fleshy and red fruit by birds (Hill & Hulley 2000) and mice (Bryson 2011). *Solanum sisimbryfolium* appears to have invasive effects in Africa (Hill & Hulley 1995, Byrne *et al*. 2002), and US (USDA 2013). The ability of this species to spread to new areas indicates that, ecological considerations should be considered to control it in relict Hyrcanian forests.

Physalis with about 70 species is centered in Mexico and is endemic to this region. Only two of these species occur jointly in America and Asia (*P. divaricata*) along with an isolated Asiatic-European species (*P. alkegengi*) (Olmstead *et al*. 2008) distributed in northern, western, and southern parts of Iran. Substantial changes in natural habitats mean these rare taxa are faced with a reduction in distribution range and population size to the point where only a few individuals have been observed in reported sites. Overharvesting for medicinal use is also a threat in Iran.

Withania has 10–18 species (based on diverse systematic classifications) and is distributed throughout the Canary Islands, the Mediterranean region and northern Africa to India, China, and Japan (Hepper 1991, Hunziker 2001). Some species, especially *W. somnifera* have ethno-botanical uses and medicinal properties (Chevallier 1996, Darias *et al*. 2001). Modern species have been classified as farm grown (segetal) in tropical areas in the Middle East (Zohary 1973).

Iran is located at the crossroads of diverse phytochorions (Zohary 1973). A wide spectrum of phytogeographical elements applies to the *Solanaceae* of Iran. Irano-Turanian (48.07) and multi-regional elements (32.69) contribute most significantly to phytochorions. The Hyrcanian (7.69), Irano-Turanian-Hyrcanian (5.76), cosmopolitan (2), and Sudano-Zambezian (1.88) are other phytogeographical elements. The Mediterranean elements distributed in the northern forests of Iran (Hyrcanian) confirm recent studies (Rechinger 1989, Akhani & Ziegler 2002).

The 21 taxa (40.7%) of *Solanum* (8), *Hyoscyamus* (7), *Lycium* (2), *Atropa* (3), and *Physalis*, each represented by only one species and are the most threatened (critically endangered and endangered) taxa of *Solanaceae* in Iran. A high percentage of threatened taxa are situated in preserves. The central Alborz, central Zagros, and some central mountains of Iran cover the most important conservative zones for *Solanaceae* in Iran. The most threatening factors of land-use change, deforestation, and overgrazing place serious pressure on the habitats of these taxa. Providing a conservation plan for protection of the endangered taxa is necessary. *Ex situ* methods can be used for conservation of several taxa of *Solanaceae* (Sponer *et al.* 2000, Sarasan *et al.* 2006) and are important support for improvement of crops against biotic and abiotic stress.

The present study established the most important centers of diversity for *Solanaceae* in Iran accordant to central Asia and the Middle East (Vavilov 1951). Fortunately, a broad area is situated inside Iranian Protected Areas (Bali & Bahmapour 2012). *Solanaceae* in Iran shows greater diversity of species/genera (53/9) than Afghanistan (26/7), Pakistan (29/7), Syria, Palestine (19/8), and Turkey (36/12) in southwestern Asia, with the exception of the USSR (14:62). The species *Solanum* and *Hyoscyamus* are clearly declining from eastern and western parts of southeastern Asia (Afghanistan and Pakistan) to eastern parts of southwest Asia (Syria and Palestine). Ecotonical conditions caused by penetration of the Mediterranean climate (Zahran 2010) and the intersection of the Irano-Turanian and Mediterranean phytochorions (Takhtajan 1986) is a possible reason behind its richness in the Zagros. Alborz and the Majoran mountains are centers of Iranian plant diversity (Davis *et al*. 1994) and an important part of the Saharo-Sindian local center of endemism (Zohary 1973). The Mediterranean and tropical bioclimatic units (Djamali *et al*. 2011) are optimal climates for *Solanaceae* as in Europe and South America.

Analysis shows that the richness of *Solanaceae* undergoes minor changes at 1500 m and sharply decreases at above 1500 m. *Solanum* and *Hyoscyamus* have the widest world distribution (Simpson 2007) that reaches the highest elevations and geographic range of distribution. *Nicaandrea* has a reported limited range (0–500 m) in Iran. At 0–500 m, 40 species form the highest and at 3500–4500 m, four species form lowest zones of richness for *Solanaceae*. It mainly occupies lowlands to semi-mountainous habitats in Iran, but shows wide distribution across the elevations. Their habitats are primarily igneous and sedimentary-volcanic sediment (Iranian Department of Geology).

Several taxa of *Solanaceae* crop wild relatives (e.g. *Solanum*, *Hyocyamus*, *Datura*, *Atropa*, and *Mandragora*) have valuable potential for improvement of the crop gene pool (Anjula *et al*. 2008). They should be clearly mapped for selection of important zones as possible plant micro-reserves (Heywood and Dullo 2005) and genetic reserves in Iran. These zones cover parts of two important centers of diversity in central Asia and the Middle East based on the Vavilov classification (Ladizinsky 1998).

Solanaceae classified in anthropogenic communities of Iran (Zohary 1973, Khatamsaz 1998) are *Hyoscyamus reticulatus*, *H. turcomanicus*, *H. archnoides*, *Datura inoxia*, and *D. stramonium.* Several taxa of *Solanaceae* as crop wild relatives have valuable potential for improvement of the crop gene pool (Anjula *et al*. 2008). The results of this study map important zones for the possible establishment of plant micro-reserves (Heywood & Dullo 2005), genetic reserves, and gene sanctuaries (Sing 1981, Laguna & Lumberas 2001, Tan & Tan 2002) for *Solanaceae* in Iran.

Life forms show adaptation of plant taxa to environmental agents (Lande 1982, Galan de Mera *et al*. 1999) and ecological features of habitats (Diaz & Cabido 1997). These forms characterize the peak of adaptation of a plant to climatic conditions (Raunkiare 1908) and as an adaptive strategy to hydrothermic gradients plays an important role in distribution patterns (Wang *et al*. 2002).

Hemicryptophytes at 46.7% and therophytes at 20% are the highest and lowest spectra of life forms for *Solanaceae*. Hemicryptophyes decrease sharply above

2000 m asl compared with chamaephytes and therophytes. Hemicryptophytes at 46.7% and therophytes at 20% cover the highest and lowest spectra of life forms in *Solanaceae*. Moreover, therophytes with highest richness between 1000–1500 m asl and at 29°-32° in latitude decrease sharply at above 2000 m asl (Fig. 8). The peak lies in the southern segment of the endemic zone (Hedge & Wendelbo 1978) as well southern zone of center of plant diversity (Boulus *et al*. 1994) in Iran.

Almost half of Iranian *Solanaceae* appear to have very rare to rare distributions and face several challenges to survival. Assessment of the conservation status of the plant taxa is a preliminary step in management plans and selection of priorities for conservation. Threatened categories of Iranian *Solanaceae*, including CR (43.4%) and VU (34%), mainly (58.9%) distributed in Irano-Turanian phytochorion. They are distributed at <2500 m asl, which is a sensitive zone that must be included in conservation plans. Severe destruction of habitat has been caused by overgrazing and land use changes (Mehrabian 2014) and *Solanaceae* is considered to be a threatened family on the regional scale of Iran. Disregard to this, only *M. turcomanicum* with a restricted distribution in northeastern Iran and southern Turkmenistan is critically endangered on the global scale. Recent taxa in northeastern Iran are situated in home gardens only; therefore, urgent support, notification by the local offices of the environment, and establishment of micro-reserves seems necessary for *in situ* conservation.

Myers (1988, 1990) classified hotspots for regions with specific concentrations of species richness, restricted endemics, and threatened taxa. Rarity (Williams *et al*. 1996) and conservation value (Tsifits *et al*. 2009) are the other criteria for selection of priorities. When resources for conservation are narrow, identification priorities play a key role in conservation (Myers 2000, Brummitt & Lughadha 2003). In Iran, *Solanaceae* represents the highest richness in the central Alborz, Zagros, Kopet Dagh and Makran Mountains based on recent criteria. Based on endemism, the mountainous ecosystem of the central Zagros as the most important center of Irano-Turanian region should be included in these priorities. The conservation value of habitats ranges from 0.15 (coastline of Persian Gulf) to 11.19 (eastern Alborz) and show irregular patterns in Iran (Table 2).

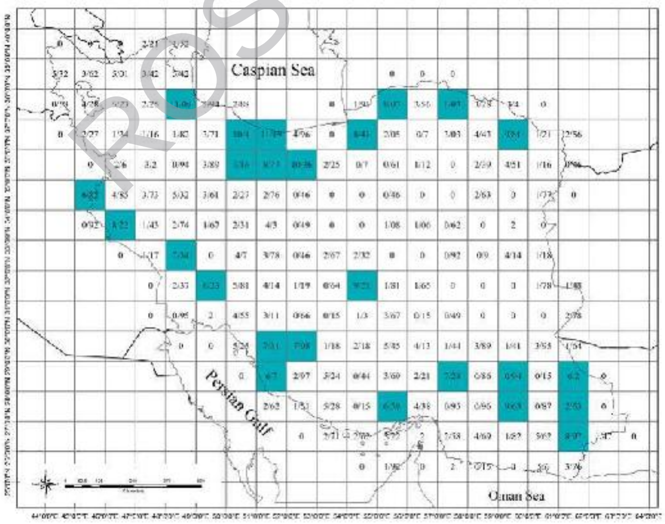

Fig. 8. Conservation value of different parts of Iran based on distribution of *Solanaceae* species.

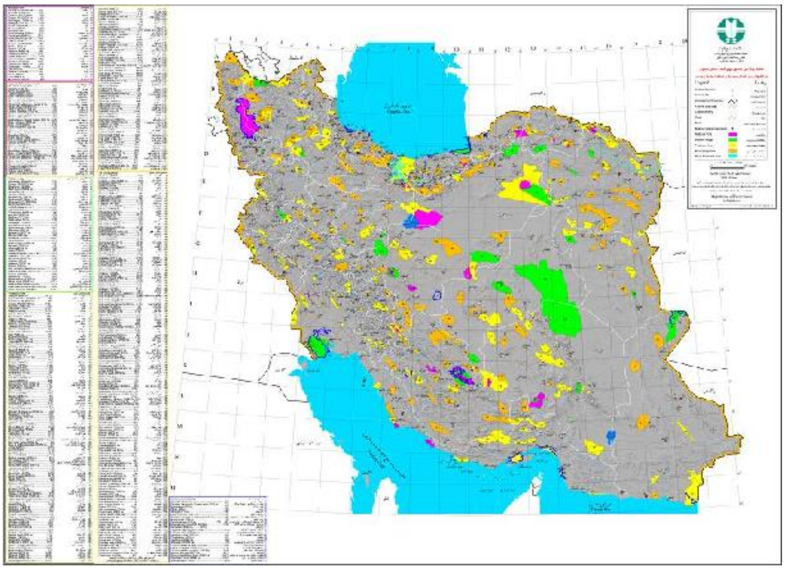

Fig. 9. Iranian Protected Areas (Bali & Bahmanpour 2012).

A considerable percentage of threatened taxa are situated in Iranian protected areas; however, several factors continue to be a threat to them, including land use change, deforestation and overgrazing. A conservation plan to protect recent taxa seems necessary. *Ex situ* methods have been used for conservation of several members of *Solanaceae* (Sponer *et al*. 2000, Sarasan *et al*. 2006) as complementary to *in situ* protection. These achievements create valuable data with which to manage the endemic, rare, crop-wild relatives and medicinal taxa of *Solanaceae* and prioritize habitats and geographical zones to design conservation plans for this family in Iran.

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