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Species distribution patterns of *Ferula* sect. *Merwia*

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Abstract

Ferula, one of the largest genera of *Apiaceae*, phytogeographically is distributed in the central and eastern parts of the Irano-Turanian, Mediterranean and northern parts of the Saharo-Sindian regions. *Ferula* sect. *Merwia* contains several economically important species that have a distinctive distributional pattern in the Irano-Turanian region. In the present study, a clustering distance analysis was performed with 608 recorded points for 29 species of the sect. *Merwia* and compared with the phylogenetic analysis on nrDNA ITS sequences. Distribution maps of the species together with richness and prediction maps were drawn through DIVA-GIS program. Through clustering analysis, the sect. *Merwia* as an Irano-Turanian element is classified into seven groups and the concentration of several groups correlated with the richness areas. It encompasses three regions as hotspots with the highest species richness, including Zagros Mts., Khorassan-Kopet Dagh, and central Afghanistan. The habitat suitability map follows the richness areas with more widespread towards mountainous district. According to AOO criterion of IUCN, the species of sect. *Merwia* have been categorized as EN and CR that need to be severely conserved from extinction risk.

Keywords: *Apiaceae*, biodiversity hotspot, distribution map, *Ferulinae*, Irano-Turanian, red list, species richness

الگوی پراکنش گونه‌های بخش *Merwia* در جنس *Ferula*

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خلاصه

جنس *Ferula* یکی از بزرگ‌ترین جنس‌های تیره چتریان (*Apiaceae*)، از نظر جغرافیای گیاهی در بخش‌های مرکزی و شرقی ناحیه ایرانی-تورانی، مدیترانه‌ای و بخش شمالی صحرا-سندی پراکنده شده است. در طبقه‌بندی پیشنهادی جدید برای این جنس، بخش *Merwia* دارای چندین گونه مهم از نظر اقتصادی است که الگوی پراکندگی منحصر به فردی در ناحیه ایرانی-تورانی نشان می‌دهند. آنالیز خوشه‌بندی براساس فاصله (عدم تشابه) برای ۶۰۸ نمونه از ۲۹ گونه این بخش انجام شد و نتایج با درخت حاصل از آنالیز تبارشناختی توالی‌های ITS هسته‌ای مقایسه گردید. نقشه‌های پراکندگی، غنای گونه‌ای و پیش‌بینی برای حضور گونه‌های بخش *Merwia* توسط نرم‌افزار DIVA-GIS ترسیم گردید. طبق آنالیز خوشه‌بندی، بخش *Merwia* به عنوان یک عنصر ایرانی-تورانی به هفت گروه تقسیم می‌شود، به طوری که تمرکز چند گروه با نواحی غنای گونه‌ای در ارتباط است. نتایج بررسی حاضر نشان داد که سه ناحیه با غنای گونه‌ای بالا در زاگرس، خراسان-کپه داغ و مرکز افغانستان مشخص می‌گردد. نقشه پیش‌بینی برای زیستگاه‌های مناسب با مراکز غنای گونه‌ای هماهنگی دارد و بیشتر به سمت مناطق کوهستانی گسترش می‌یابد. طبق مقیاس AOO در IUCN، گونه‌های بخش *Merwia* به صورت در معرض خطر انقراض و در بحران انقراض قرار می‌گیرند که این امر نیازمند حفاظت شدید آن‌ها می‌باشد.

واژه‌های کلیدی: ایرانی-تورانی، چتریان، لیست قرمز، نقاط تنوع، نقشه پراکندگی، غنای گونه‌ای، *Ferulinae*

Introduction

Ferula L. as one of the largest genera of *Apiaceae* Lindley, floristically has a broad distribution range in central Asia (Turkmenistan, Tajikistan, Uzbekistan, Kyrgyzstan, and Kazakhstan), Iran, Afghanistan and Pakistan, reaching to eastern boundaries in NW India and W China, extending westward to the Mediterranean region, SW Europe, and N Africa. These broad areas comprise four phytogeographical regions viz., the Irano-Turanian, Mediterranean, southern parts of the Euro-Siberian and northern parts of the Saharo-Sindian (Takhtajan *et al*. 1986). Traditionally, *Ferula* genus is illustrated through morphological aspects in the literature and characterized as monocarpic or polycarpic herbaceous plants often with onion scent. Due to the large size of most of species and unavailability of the complete herbarium specimens that often contain only some lateral branches and lateral divisions of basal leaves (Chamberlain & Rechinger 1987), the determination of *Ferula* species is difficult and sometimes may result in misidentification.

Based on the early molecular phylogenetic studies, *Ferula* is placed within the subfamily *Apioideae* Thorne ex P. Royen, tribe *Scandiceae* Spreng., and subtribe *Ferulinae* Engl. (Downie *et al*. 2001, Kurzyna-Młynik *et al*. 2008). After the monograph of *Ferula* and its infrageneric divisions recommended by Korovin (1947), recent molecular investigations of *Ferula* suggested a new classification framework supposed with four subgenera and ten sections (Panahi *et al*. 2018). One of the economical important sections is *Merwia* (B. Fedtsch.) Korovin that includes several medicinal species with wide distributions (Table 1). Recent phytochemical investigations revealed that the presence of numerous chemical compounds such as sesquiterpenes, coumarins, phenolic compounds and specifically organic sulphur compounds concentrated within several members of sect. *Merwia* (Panahi *et al*. 2020) that cause their biological (antibacterial, antifungal, antioxidant, etc.) effects (Iranshahi *et al*. 2018). Several species of the section including *F. assa-foetida* L., *F. badrakema* Koso-Pol., *F. gummosa* Boiss., *F. gabrielii* Rech.f., *F. myrioloba* Rech.f., *F. persica* Willd., and *F. narthex* Boiss. are important medicinally (Sahebkar & Iranshahi 2010, Ali & Qaiser 2009, Panahi *et al*. 2020) by producing gums and resins used in traditional medication (French 1971, Chamberlain & Rechinger 1987).

Currently, the genus *Ferula* contains 180–185 species world widely (Kadereit & Bittrich 2018). A considerable number of newly described species of *Ferula*, have been added to the list of the genus, distributed from E Europe (Mátis *et al*. 2017), SW and E Anatolia (Duman & Sagiroglu 2005, Sagiroglu & Duman 2007, 2010, Akalin *et al*. 2020) to China and N India (She *et al*. 2005, Degtjareva *et al*. 2018, Ma *et al*. 2019). In the Flora Iranica area, it is represented by 53 species with 33 endemics [34 species and 15 endemics in Iran (Mozaffarian (2007)] that mostly distributed in the mountainous regions such as the Alborz, Zagros and Khorassan Mts. (Chamberlain & Rechinger 1987). Despite a very wide geographical distribution range encompassing Europe (W, C, SW, S, SE, and E), Asia (SW, the Caucasus, middle, central, and E), and Africa (N, NE, and NW), the ecological spectrum of the genus is rather narrow as its members are restricted to arid and semi-arid regions in sandy, saline and stony deserts, xerophilic shrub lands and gypsum hills (Korovin 1947). Pimenov & Leonov (2004) reported that, the genus is most diversified in SW Asia and the center of diversity of *Ferula* seems to be the Irano-Turanian region. Through recent biogeographic analyses inferred from molecular data, it has been suggested that the earlier ancestor of *Ferula* group originated mostly in Armeno-Iranian province during early Pliocene (about 4.8 Mya, Panahi 2019).

The Irano-Turanian region is climatically distinct from neighboring Mediterranean, Euro-Siberian, Saharo-Sindian, and central Asiatic regions. Irano-Turanian region is characterized by several features like dominance of steppe vegetation, great species richness, high endemism, and extreme species radiation. Zohary (1973) hypothesized that, this area is a donor of species to the recipient neighboring Saharo-Sindian and Mediterranean regions. This region shows climatic variation compared to the Euro-Siberian region by a lower annual precipitation, lower winter temperatures, higher summer temperatures with longer dry season and a distinctly higher continentally (Djamali *et al*. 2011, Djamali *et al*. 2012a).

It has been suggested that, the Irano-Turanian flora was less affected by late Quaternary glaciations compared to the Mediterranean and Euro-Siberian regions, and its floristic boundaries shifted during the Quaternary (Djamali *et al*. 2012b). This disjunctive distribution pattern suggests that the Irano-Turanian flora might have been much more widespread during the Quaternary glacial periods and probably in the Pliocene. The Irano-Turanian region has a complex topography shaped by its complex tectonic history in the Iranian plateau with the two main mountain ranges; Zagros and Alborz that arose synchronously around the middle Miocene either within the plateau or between the plateau and central Asia, respectively (Djamali *et al*. 2012a). In particular, the Zagros Mts. (W Iran) as the largest mountain belt of the region, are part of the Alpine-Himalayan orogenic system while the Alborz Mts. (N Iran) as an intra-continental with east-west orientated orogen, formed in response to crustal shortening and thickening induced by Arabia-Eurasia plate (Djamali *et al*. 2012b, Noroozi *et al*. 2018). However, geological heterogeneity in the Irano-Turanian region since the early Miocene, combined with a relatively stable continental climate might be considered important factors limiting gene flow among populations and favoring allopatric speciation via both dispersal and vicariant processes (Manafzadeh *et al*. 2013). It seems that these limiting factors have influenced the allopatric separation within the genus *Ferula* that concentrated in local areas and probably this genus had a more widespread distribution before.

As a source of species for the neighboring regions, the Irano-Turanian floristic region requires serious conservation strategies by the governments of those countries that host its major evolutionary and biodiversity centers. Due to the importance of sect. *Merwia* as a monophyletic species rich group with specifically 20 endemics in this region (Mozaffarian 2007, Chamberlain & Rechinger 1987), we provide distribution maps of the species of this group for conservational aims and/or economical usage. Additionally, determining the biodiversity hotspots would be helpful for conservation of the genetic diversity. Informing red list assessments, identifying conservation priorities and gaps in scientific knowledge, and visual representation of a taxon's distribution to highlight areas with high numbers of threatened species are three main reasons for creating distribution map of taxa (IUCN 2019). According to these targets, we make effort to produce a distributional pattern and preliminary assessment of conservation status for this important group of *Ferula*.

Materials and Methods

- Study area

Four major phytogeographical regions including Irano-Turanian (IT), Euro-Siberian (ES), Mediterranean (M) and Saharo-Sindian (SS) are covered for distribution area of the elements of sect. *Merwia*. According to White & Léonard (1991), the Irano-Turanian region differentiates into four sub-regions that we used here following with neighbors to determine the distributional areas of *Merwia* elements (Fig. 1). Sub-region IT1 includes Syria, N Jordan, Palestine, and NW Iraq. The second sub-region of IT2 comprises most of Iran, Armenia, Azerbaijan, interior Turkey, N Iraq, Afghanistan, parts of Turkmenistan, and Pakistan. The sub-region IT3 extends to northeast comprising Turkmenistan, Uzbekistan, Kazakhstan, and most parts of Tajikistan and Kyrgyzstan. The easternmost IT sub-region is IT4 that covers Hindu Kush and Tian Shan Mts., Pamir plateau, and eastern parts of Tajikistan and Kyrgyzstan (Fig. 1).

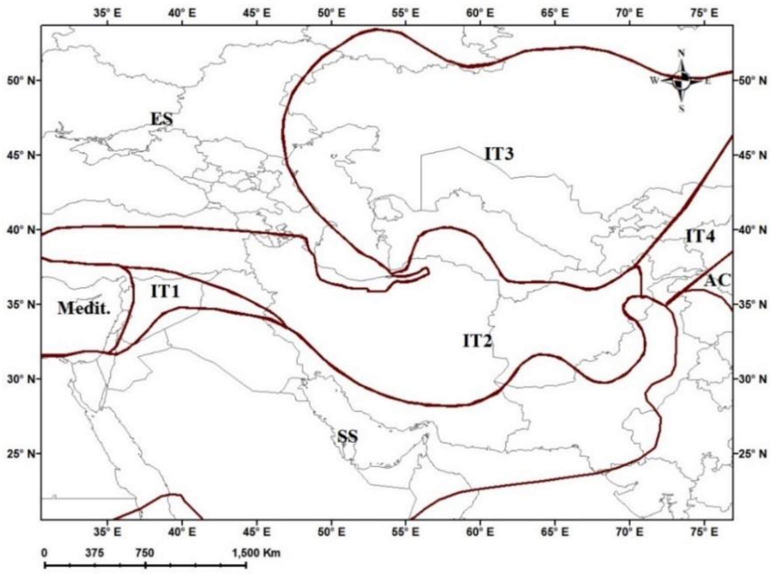

Fig. 1. Phytogegraphical map of SW Asia. IT: Irano-Turanian region as 1–4 sub-regions proposed by White & Leonard (1991), ES: Euro-Siberian, M: Mediterranean, SS: Saharo-Sindian, AC: Central Asiatic.

- Distributional data

The data set of sect. *Merwia* comprises 25 species of *Ferula* that recently indicated (Panahi *et al*. 2018). In this study, four more species are added that is supposed to be included within the section in accordance with the phylogenetic analyses through ITS data (Table 1). The distribution data were taken from the GBIF database, Moscow Digital Herbarium (Seregin 2018) and also the collection of preserved herbarium specimens at different Herbaria viz., W, G, B, E, LE, TARI, IRAN, FUMH, MPH, HUI, and SFAHAN that herbarium codes follow NYBG (Steere Herbarium at http://sweetgum.nybg.org-/science/ih). Moreover, the specimens indicated in the Flora Iranica (Chamberlain & Rechinger 1987), Flora of Iran (Mozaffarian 2007), Flora of Turkey and the East Aegean Islands (Peşmen 1972), and another literature (Zohary 1972, Korovin 1959) as well as our several collected specimens, have been added to the supplemented data matrix. The ambiguity records and misidentified species omitted or reformed from the data matrix after correct identification by the floras and literature. Finally, after determining the correct identification of the species and verifying the accuracy of data (altitude of locations were used as a guideline for geo-referencing); a total of 608 records for all the 29 species were indicated in data matrix. Those records that had not latitude and longitude information were geo-referenced with a precision of at least 0.25º through Google Earth and Gazetteer files (https://www.diva-gis.org/gdata).

- Climate variable data

Temperature, rainfall, geographical barriers and other ecological factors such as underlying geological formations, may influence species distributions. For detecting which environmental variables most influence the distribution of *Ferula* species, we modeled its ecological niche and distribution using 19 bioclimatic variables obtained from WorldClim2 (Fick & Hijmans 2017, www.worldclim.org). The spatial resolution of the data was 30"-s (approximately 1 km^2).

- Data analyses

Species richness is an effective value for considering the taxonomic diversity by occurrence data that we calculated here for the sect. *Merwia* (DIVA-GIS Ver. 7.5, Hijmans *et al*. 2012). Using DIVA-GIS the suitable temperature and precipitation variables were determined by Circular Neighborhood method with an average 0.5 value. To predict the potential distribution of species through the combination of presence-only records and digital layers of environmental variables, we used the models to identify the environmental conditions where a species could survive indefinitely and through predictive variables provides a correct species distribution map. R. Studio (Ver. 1.1.463, 2020) was used for clustering distance with complete linkage method in order to determining the species groups.

Table 1. List of *Ferula* species in the sect. *Merwia*. Four species that has been supposed to add to the section (based on ITS data by the author PM), are in bold [distribution areas referred to Chamberlain & Rechinger (1987), Korovin (1947), Zohary (1972)]

Taxon	Region/Country
F. alliacea Boiss.	Iran
F. assa-foetida L.	Iran
F. badrakema Koso-Pol.	Iran, Afghanistan, Turkmenistan
F. behboudiana (Rech.f. & Esfand.) D.F. Chamb.	Iran
F. blanchei Boiss.	E Mediterranean
F. flabelliloba Rech.f. & Aellen	Iran
F. gabrielii Rech.f.	Iran
F. gummosa Boiss.	Iran, Turkmenistan
F. hirtella Boiss.	Iran
F. karakalensis Korovin	Iran
F. latisecta Rech.f. & Aellen	Iran, Turkmenistan
F. lehmannii Boiss.	Afghanistan, Pakistan!, Kazakhstan
F. linczevskii Korovin	Tajikistan
F. litwinowiana Koso-Pol.	Turkmenistan, Kazakhstan
F. lutensis Rech.f.	Iran
F. myrioloba Rech.f.	Afghanistan
F. narthex Boiss.	Afghanistan, Pakistan
F. negevensis Zohary	Palestine
F. persica Willd.	Iran
F. pseudalliacea Rech.f.	Iran
F. racemoso-umbellata (Gilli.) Rech.f.	Afghanistan, Pakistan!
F. rubricaulis Boiss.	Iran
F. rutbaensis C.C. Towns.	Iraq
F. sharifii Rech.f. & Esfand.	Iran
F. stenoloba Rech.f.	Afghanistan
F. szowitsiana DC.	Iran, Afghanistan, Turkmenistan
F. trachelocarpa Rech.f.	Afghanistan
F. undulata Pimenov & J.V. Baranova	Turkmenistan
F. xanthocarpa Rech.f.	Afghanistan

Considerably for determining the correctness of clustering analysis, we presented the first phyto-geographical delineation of the sect. *Merwia* compared with the evolutionary relationships of species. Therefore, a briefly phylogenetic analysis was performed using available and new earned nrDNA ITS data (including 174 accessions of *Ferulinae* with four species as outgroups according to our recent results; Panahi *et al.* 2018). The matrix of molecular data was prepared and aligned in Mesquite 3.6 (Maddison & Maddison 2017), then using Maximum Likelihood (ML) method in IQ-tree (Nguyen *et al*. 2015) they were analyzed. ML analyses included 100 searches and branch support (BS) was evaluated based on 1000 rapid bootstrap replicates. The analysis was performed with SYM + G substitution model, which was selected before for ITS data (Panahi *et al*. 2018). Ultrafast bootstrap approximation results were presented in consensus tree. Species names with authorities, voucher information and GenBank accession numbers for the samples of sect. *Merwia* included in this study, are listed in Appendix 1.

- Conservation status

The conservation status of the species within sect. *Merwia* was evaluated using Kew GeoCAT (http://geocat.kew.org) to calculate EOO (the extend of occurrence) and AOO (the area of occupancy) criteria. It has considered 4 km^2 for calculating AOO of each occurrence point by default. The red list categories were assigned for each species viz., Least Concern (LC), Data Deficient (DD), Near Threatened (NT), Vulnerable (VU), Endangered (EN), and or Critically Endangered (CR).

Results

- Comparing clustering distance with molecular phylogenetic analysis

A clustering analysis for *Merwia* through latitude and longitude variables was performed for distancing points in R. Studio (Ver. 1.1.463). Seven groups of related species from distributional standpoint are determined (Fig. 2). These results compared with inferred molecular phylogenetic tree (Fig. 3) in order to present insights to distribution pathways:

Group 1: The elements that concentrated in E Mediterranean sea contain *F. blanchii* Boiss., *F. rutbaensis* C.C. Towns., and *F. negevensis* Zohary (distributed in M and IT1 regions) as the westernmost boundary of *Merwia* (Fig. 2, circles in blue sky color). On the basis of phylogenetic tree, *F. blanchii* and *F. rutbaensis* are gathered in one subclade of *Merwia* while *F. negevensis* has a basal position with *F. rasemoso-umbellata* (Gilli.) Rech.f. (Fig. 3). These three former species are geographically assembled in E Mediterranean areas as sandy-desert elements.

Group 2: The elements that have distributed in Anatolian and Caucasus to Aralo-caspian region (Fig. 2, circles in yellow color) (northern border of IT2 and SE Euro-Siberian region to southern part of IT3). Populations of *F. szowitsiana* DC. and *F. persica* distributed in Anatolian-Caucasus region that accompanied by *F. lehmanii* Boiss., *F. litwinowiana* Koso-Pol. and one record of *F. assa-foetida* which are scattered in IT3 subregion. From the phytogeographical point of view, the species of *F. szowitsiana* have a wide distribution from Anatolia, Caucasia, Iran to E Turkmenistan, and Afghanistan (Fig. 8) that is introduced as an indicator of the Irano-Turanian region especially in IT2. *Ferula persica* reported from Transcaucasia and N, W, and central parts of Iran, shows a disjunctive distribution as well (Chamberlain & Rechinger 1987). In our data, the specimens of *F. persica* recorded from Azerbaijan and NW Iran were accompanied by this group while the others contributed with group 3 (black dots in Fig. 2, also see Fig. 8). We attempt to find the whole records of herbarium specimens from afore-mentioned localities but only three samples have preserved specimens that were incomplete (without leaves and inflorescences), therefore, probably they were misidentified.

In the phylogenetic tree, different accessions of *F. szowitsiana* and *F. persica* placed far from their co-accessions that confirmed the variability of these species within *Merwia* (Fig. 3) and their disjunctive distributions need more investigations to resolve the species position. Our findings determined another misidentification in specimens of two close species *F. lehmanii* and *F. litwiniwiana* that geographically distributed in Aralo-caspian region but *F. lehmanii* was reported in a wider distribution by Rechinger (1987), which will be discussed later on.

Group 3: This group contains those species distributed from west and central to east parts of IT2 (Fig. 2, circles in black color) including different taxonomic units viz., *F. gummosa*, *F. persica*, and *F. szowitsiana*, following with central Iranian plateau elements, viz., *F. hirtella* Boiss., *F. gabrielli*, *F. lutensis* Rech.f., and *F. karakalensis* Korovin, as well as some western (Zagrosian) elements viz., *F. rubricaulis* Boiss., *F. pseudalliacea* Rech.f., *F. behboudiana* (Rech.f. & Esfand.) D.F. Chamb, and *F. assa-foetida*. Three Zagrosian elements viz., *F. assa-foetida*, *F. behboudiana*, and *F. pseudalliacea* with a close phylogenetic relationship (Fig. 3) have overlapping distribution area in the Zagros region.

Group 4: The elements of southern part of IT2 distributed from west to east (Fig. 2, circles in blue color), contain different species populations of *F. assa-foetida*, *F. pseudalliacea*, *F. alliacea*, *F. persica*, *F. hirtella*, *F. szowitsana*, *F. rubricaulis*, *F. lutensis*, *F. gabrielii*, *F. latisecta* Rech.f. & Aellen, and one species endemic of Makran (in S Iran) i.e. *F. sharifii* Rech.f. & Esfand. which scattered in Saharo-Sindian region. According to phylogenetic tree (Fig. 4), *F. sharifii* placed in one clade following with *F. pseudalliacea*, *F. behboudiana*, and southern specimens of *F. assa-foetida* that introduce the southern border of distribution path of these species.

Group 5: The elements in NE Iran and Turkmenistan (E IT2 + IT3 distributed toward west side of IT4) (Fig. 2, circles in green color) including: *F. badrakema*, *F. gummosa*, *F. undulata* Pimenov & J.V. Baranova, *F. karakalensis*, *F. szowitsiana*, *F. latisecta*, *F. alliacea*, *F. flabelliloba* Rech.f. & Aellen, *F. assa-foetida*, *F. lehmanii*, and *F. litwinowiana* (species relationships will be discussed later).

Group 6: The elements with distribution in central Afghanistan (eastern part of IT2) (Fig. 2, circles in red color) comprised these species viz., *F. assa-foetida*, *F. alliacea*, *F. badrakema*, *F. szowitsiana*, *F. racemoso-umbellata*, *F. narthex*, *F. lehmanii*, *F. stenoloba* Rech.f., *F. myrioloba*, *F. trachelocarpa* Rech.f., and *F. xanthocarpa* Rech.f. This group, contains several species distributed mainly in Afghanistan (from west to east) reaching to Hindu Kush Mts. named here as Afghani elements. The endemic species *F. myrioloba* and *F. stenoloba* from Afghanistan (Chamberlain & Rechinger 1987), *F. xanthocarpa* as an endemic of SE Afghanistan (Schischkin 1951) with *F. trachelocarpa* as an endemic of SW Afghanistan accompanied in this group as well as *F. racemoso-umbellata* (endemic of NW, SW, SE, E, and central parts of Afghanistan and Baluchistan of Pakistan) (Chamberlain & Rechinger 1987). In the inferred ITS tree, three Afghani elements viz., *F. stenoloba*, *F. trachelocarpa*, and *F. xanthocarpa* placed in one sub-clade (with 95% support in Fig. 3).

Group 7: The elements that have distributed in western part of IT4 in Pamir-Alai and Hindu Kush Mts. (Fig. 2, circles in purple color). It is considered that, the Himalayan samples of *F. narthex* are probably form a disjunction or moving apart. Another species located within this group is *F. linczevskii* that scattered in stony slopes in subalpine belt of Pamir-Alai (Schischkin 1951) and phylogenetically related to *F. gummosa* subclade (Fig. 3). However, in this group there are several specimens of *F. assa-foetida* that would be the most eastern borderline of its distribution.

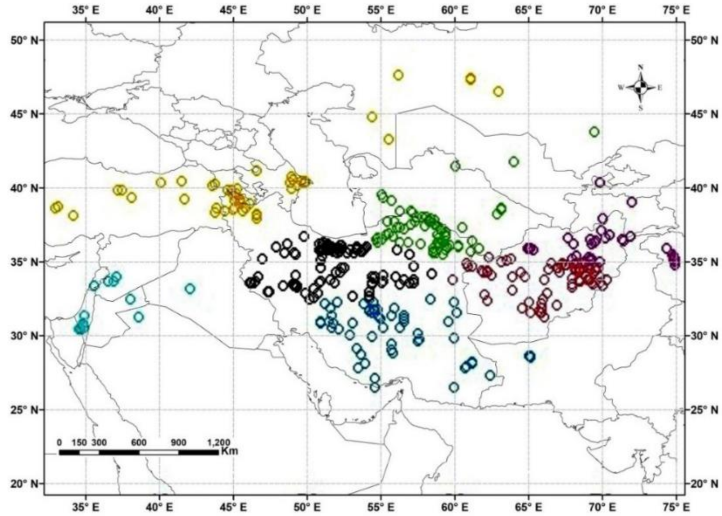

Fig. 2. Clustering map of distributional pattern of the members of sect. *Merwia* based on distance and complete linkage method performed in R package.

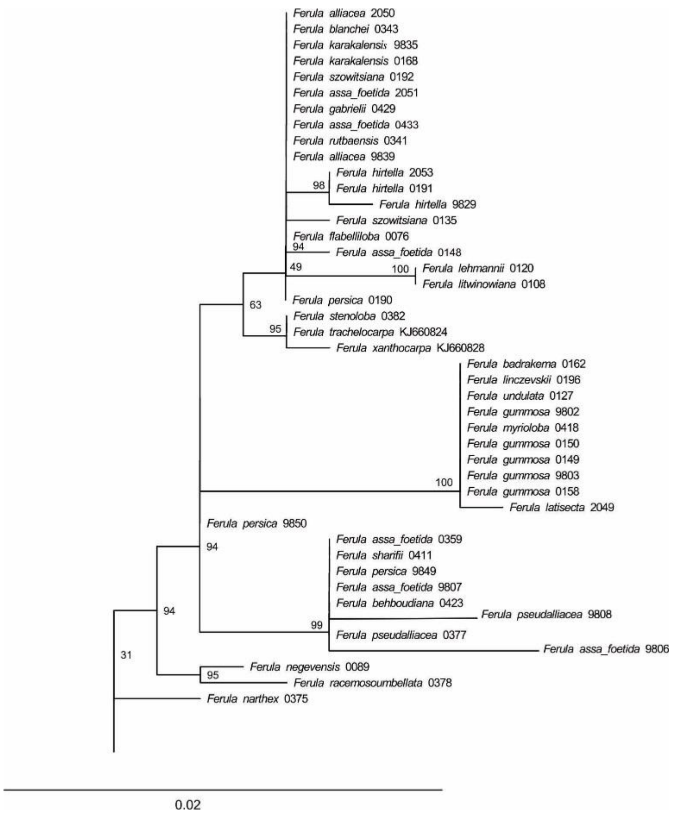

Fig. 3. Bayesian majority-rule consensus tree inferred from analysis of nrDNA ITS sequence data of *Ferulinae* that only Sect. *Merwia* presented here. Bootstrap support for nodes indicated for each node.

- Distribution pattern

The distribution areas of elements within sect. *Merwia* have been determined and the richness pattern with predicting the suitability of distribution area demonstrated in figures 4–6, respectively. In addition, species distribution map of each species within sect. *Merwia*, have been drawn by DIVA-GIS (Fig. 8). According to distribution pattern of *Ferula* species in sect. *Merwia*, it was displayed that, there are three centers of richness with 7–8 species (the highest) in the red grid cells, including Zagros Mts., Khorassan-Kopet Dagh, and central Afghanistan (Fig. 5). In *Ferula* sect. *Merwia*, the prediction map represents those habitats with highest potential suitability cover the species have overlapping area distribution in three mountainous regions viz., northern parts of Zagros, Khorassan-Kopet Dagh region, and some parts of Pamir-Alay Mts. (Fig. 6) with the highest percentage.

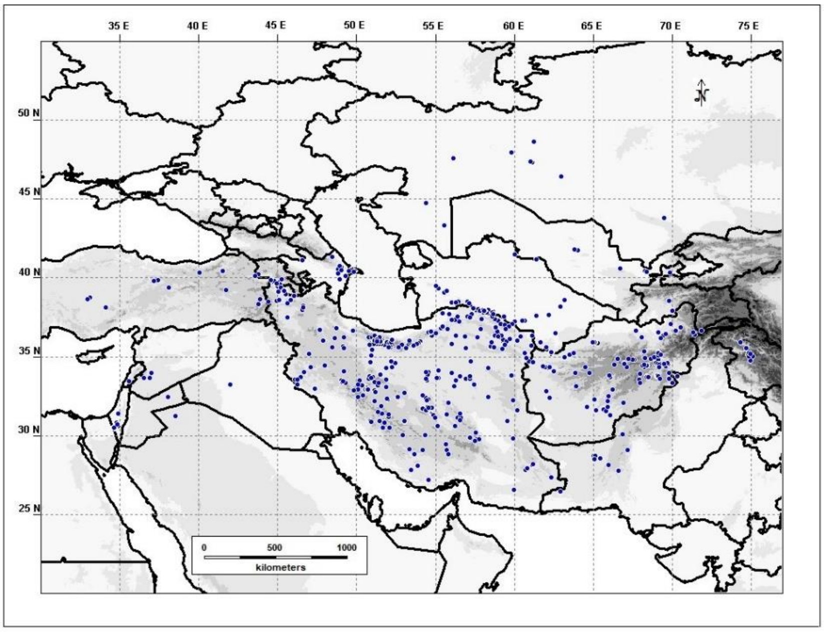

Fig. 4. Species distribution map of *Ferula* sect. *Merwia* (drawn by DIVA-GIS).

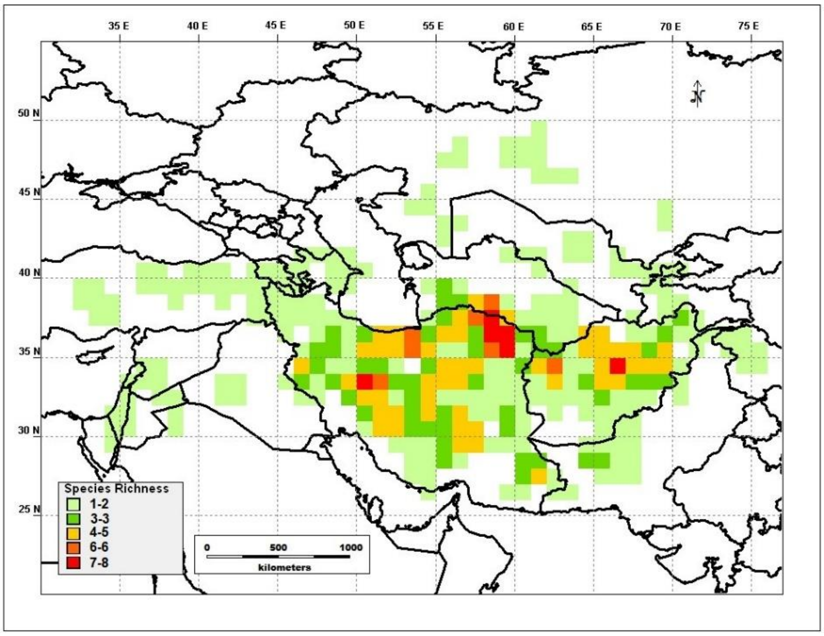

Fig. 5. Map of the richness and hotspots of species diversity in *Ferula* sect. *Merwia*.

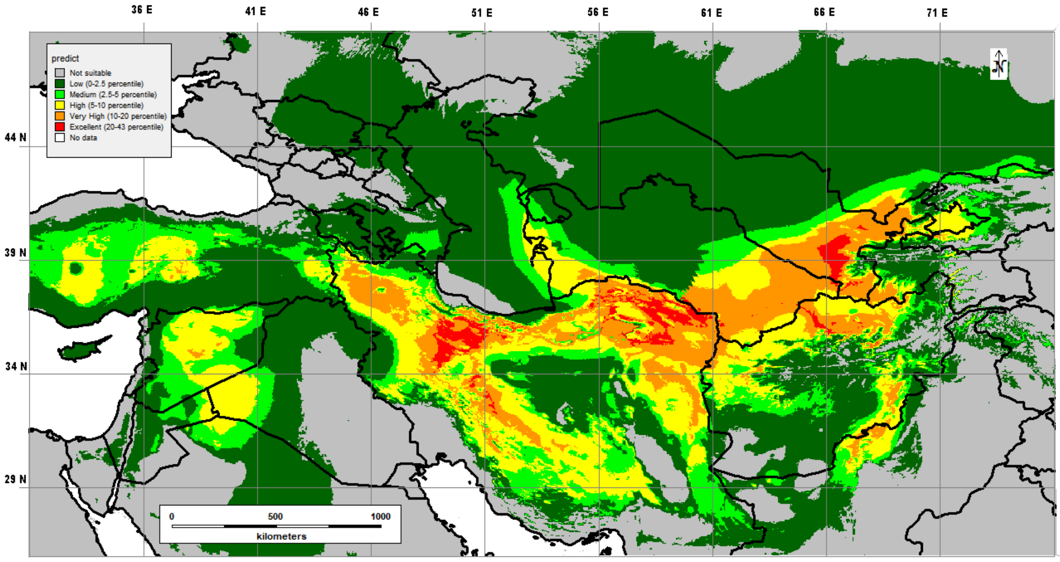

Fig. 6. Prediction map of suitability habitats for *Mewia* members.

- Conservation status and climate variable analysis

The number of occurrences of each species in the four phytogeographical regions was represented in tables 2 & 3 with their conservation status and chorotype. Most species of *Merwia*, have occurred in IT2 sub-region. *F. szowitsiana* has wide distribution with the most collecting efforts (Fig. 7a). The least records belong to *F. trachelocarpa* with one record from Afghanistan and *F. myrioloba*, *F. rutbaensis*, and *F. linczevskii* with two records indicated as rare species in the section (Fig. 7a). Low occurrences of these species may relate to political difficulties and severe mountainous passages for collectors to reach the samples or limiting environmental factors for their distributions. As indicated for distribution of the genus *Astragalus*, it seems that, the absent points of the species mostly refer to rare collections of some area especially in E Afghanistan, NW Iran, etc. (Mahmoodi *et al*. 2012). The conservation status of sect. *Merwia* is assessed based on IUCN criteria including Area of Occupancy (AOO), Extent of Occupancy (EOO) for the first time and the results are shown in table 2. Previous threatened categories were reported by Jalili & Jamzad (1999) for eighteen species of the *Ferula*, that it was included only 10 species for sect. *Merwia* (Table 2). Now all the species of sect. *Merwia* have been classified based on AOO criterion as Endangered (EN) or Critically Endangered (CR). According to IUCN guidelines, the highest category of threat has considered in the final assessment of the conservation status of the species. Therefore, *Ferula* species need to be severely conserved because the species are faced under extremely high risk of extinction (Table 2) due to overgrazing, mining and other extending human impacts (Tojibaev *et al*. 2020).

Two bioclimatic variables were selected with a good influence on species distribution of *Ferula* sect. *Merwia* (Fig. 7b). Annual mean temperature ranges from 4 to 20 ºC, and annual precipitation ranges from 50 to 600 mm (green points within the blue rectangle of the climatic niche, have been considered of those presence points with a climate profile within the range limits of all 19 Bioclim climatic variables, Fig. 7b). These two general factors are as the effective variables in determining the borderline of geographic distribution of the *Merwia* species. It means that, the elements of *Merwia* can tolerate from 4 to 20 ºC, and the temperature more than 20 ºC is a limiting factor for the growth of plants. In addition, the species of sect. *Merwia* are capable to survive in xerophytic condition with minimum mean precipitation in 50 mm.

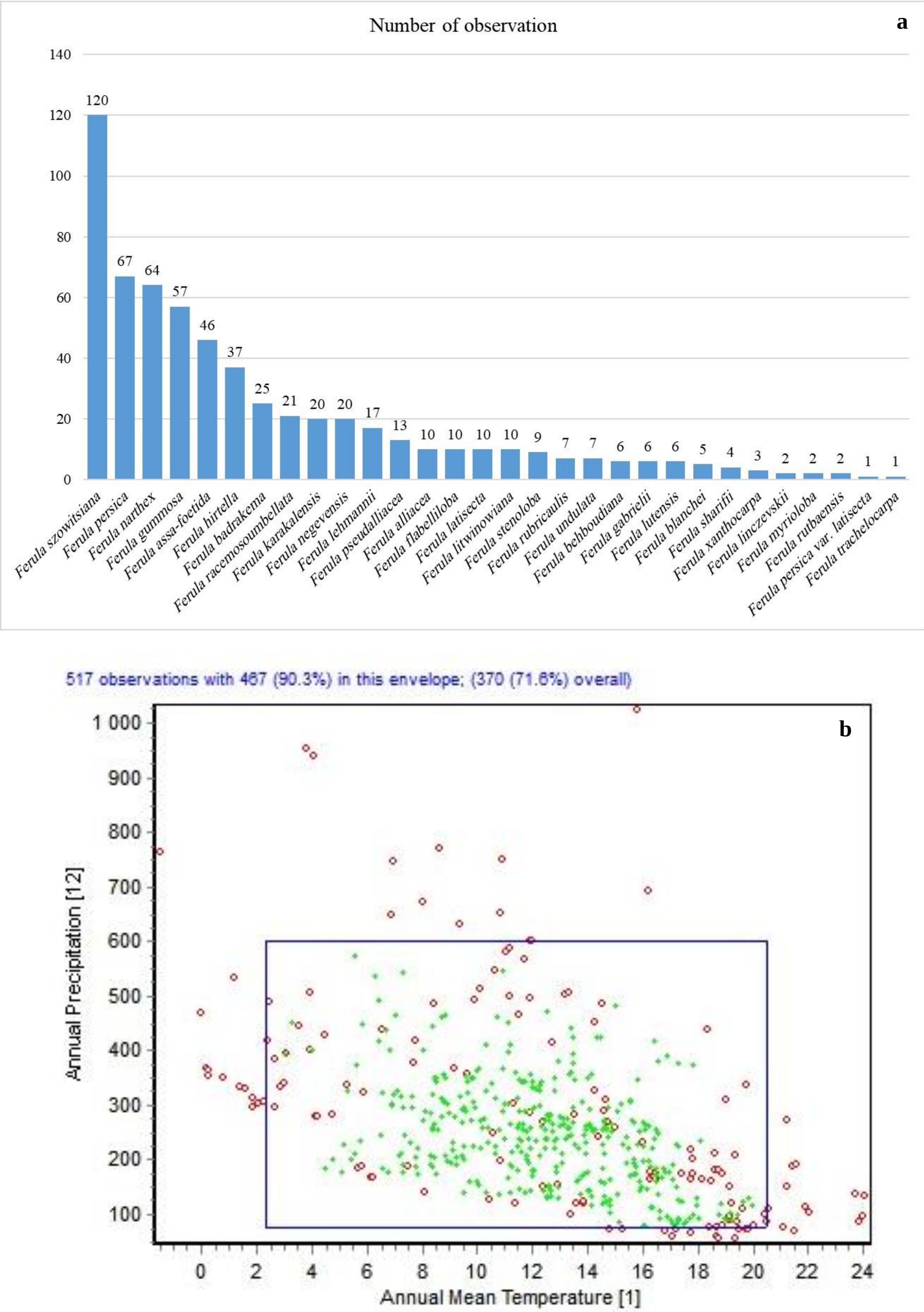

Fig. 7. a. Frequency of the observed species that defined in this study, b. Environmental variable plot for *Ferula* sect. *Merwia*.

Table 2. Preliminary assessments of conservation status of the species of *Ferula* sect. *Merwia*, the extend of occurrence (EOO), the area of occupancy (AOO), red list categories: CR = critically endangered, EN = endangered, VU = vulnerable, LC = least concern, NT = near threatened (IUCN 2019)

Taxon	No. of record	EOO (km^2)	AOO (km^2)	Red list category	Previous assessment*
F. alliacea Boiss.	10	245,869	36	EN	-
F. assa-foetida L.	46	3,177,090	180	EN	EN
F. badrakema Koso-Pol.	25	602,956	100	EN	-
F. behboudiana (Rech.f. & Esfand.) D.F. Chamb.	6	3,639	24	EN	DD
F. blanchei Boiss.	5	18,637	20	EN	-
F. flabelliloba Rech.f. & Aellen	10	68,915	36	EN	VU
F. gabrielii Rech.f.	6	13,151	24	EN	DD
F. gummosa Boiss.	57	661,961	220	EN	LR
F. hirtella Boiss.	37	450,859	148	EN	-
F. karakalensis Korovin	20	351,575	76	EN	-
F. latisecta Rech.f. & Aellen	10	40,479	40	EN	DD
F. lehmannii Boiss.	17	1,086,956	68	EN	-
F. linczevskii Korovin	-	-	8	CR	-
F. litwinowiana Koso-Pol.	10	146,972	16	EN	-
F. lutensis Rech.f.	6	51,966	24	EN	DD
F. myrioloba Rech.f.	-	-	4	CR	-
F. narthex Boiss.	64	574,448	256	EN	-
F. negevensis Zohary	20	1,571	56	EN	-
F. persica Willd.	68	403,707	248	EN	EN
F. pseudalliacea Rech.f.	13	248,959	48	EN	LR
F. racemoso-umbellata (Gilli.) Rech.f.	21	288,119	80	EN	-
F. rubricaulis Boiss.	7	31,088	24	EN	-
F. rutbaensis C.C. Towns.	-	-	8	CR	-
F. sharifii Rech.f. & Esfand.	4	52,802	12	EN	DD
F. stenoloba Rech.f.	9	50,314	32	EN	-
F. szowitsiana DC.	120	2,202,504	448	EN	-
F. trachelocarpa Rech.f.	-	-	4	CR	-
F. undulata Pimenov & J.V. Baranova	7	561	24	EN	-
F. xanthocarpa Rech.f.	3	23	8	CR	-

* Jalili & Jamzad (1999)

Discussion

Different factors such as climate change, habitat loss, overexploitation, pollution and invasive alien species are viewed as the principle threat to global biodiversity in the 21st. century. Climate change will have a significant impact on the suitable distribution area of the species that causes gradual decrease of suitable habitat area (Li *et al*. 2020). The 5th. Assessment Report (AR5) of the international panel on climate change (IPCC) indicated that, the annual mean temperature of the Earth's surface has increased by 0.85 ºC over the past 130 years (1880–2012) which is predicted to increase (0.3–4.8 ºC) by the end of the 21st century (IPCC *et al*. 2013). So climate change, especially global warming not only causes temperature changes in different regions but also changes the distribution pattern of precipitation and finally changing the adaptive threshold of plant growth that lead to shifting the suitable habitat range and migration of species (Mahmoudi Shamsabad *et al*. 2018). However, endemic species are very sensitive to climate change that they may have an extinction risk in future and will need more conservation strategy. For example in order to protect *Ferula xylorhachis* Rech.f. (endemic of NE Iran) from the extinction risk caused by global warming and climate change, it has been suggested to introduce the species to new regions such as Zagros Mts. (Mazangi *et al*. 2016) that the phenomena might influence both the existence of species as well as distribution pattern in congruent with ecosystem. Other factors such as soil quality and soil erosion could have a strong impact on determination of habitat suitability and plant distribution (Mousazade *et al*. 2019) as well as natural and human disturbances, and competition with other species (Qin *et al*. 2017). Nevertheless, invasive plant species may lead to the extinction of those that cannot compete effectively, especially rare native species (Mousavi *et al*. 2020).

Mountains as another factor influence the distribution and diversification of species during the time. Recent studies on endemic vascular plant species of Iran indicated that 74% of all the endemics are restricted to mountain areas and five areas of endemism associated with high mountain ranges in Iranian plateau viz., Azerbaijan plateau, Alborz, Zagros, Khorassan-Kopet Dagh, and Yazd-Kerman Mts. (Noroozi *et al*. 2019). These mountain areas could be important as refugia for *Ferula* species (Figs 5 & 6). Consequently, with increasing pastoralism, urbanization, road construction and ongoing climate change, the risk of biodiversity loss in the Iranian mountains is very high, and these habitats need to be more effectively protected. Climate change in central Asia is already noticeable via glacier melting in the higher elevations that during the twentieth century, the glacier areas of the Tian Shan and Pamir-Alai decreased by 25–35% (Makhmadaliev *et al*. 2003). Through climate change, habitat fragmentation, and degradation that caused by intensive grazing, population growth and unsustainable use of natural resources in Tajikistan, the numbers of endangered and vanishing species motivated to raising particularly in several sub-regions in the S Tajikistanian. In this region, the biggest proportion of threatened (CR + EN + VU) taxa was noted for lowlands and colline belts in S Tajikistan as well as for the high-altitude areas in Alai and plateaus of E Pamir. However, more threatened and extinct taxa have a shorter flowering period than the non-threatened plants that cease to extinct faster. The extinct (RE + EX) species belong mainly to Pluriregional and Irano-Turanian phyto-geographical elements. One of the highly fragile sub-regions that face extinction is the two river valleys of Syr-Daria (Prisyrdarian) and upper Pyandzh that both are intensively used for agriculture (Nowak *et al*. 2020a). However, it seems that, these extinction phenomena, cause to vanishing several species of *Ferula* in this region such as *F. linczevskii*, *F. myrioloba*, *F. xanthoxarpa*, etc. that based on our data it has been not reported any new record during the last two decades (GBIF database). Nowak *et al* (2020b) in the classification of tall-forb vegetation in Pamir-Alai and W Tian Shan Mts. indicated that, from 19 determined communities, only five of them were dominated by large Umbellifers such as different species of *Ferula* that severely are in near threatened (NT) and need to conserve.

As organisms survive and reproduce in their habitat and develop their population, therefore, habitat quality can directly affect the distribution and survival rate. In *Ferula* sect. *Merwia*, the prediction map indicated three mountainous regions viz., northern parts of Zagros, Khorassan-Kopet Dagh region, and parts of Pamir-Alay Mts. (Fig. 6) as highest suitable habitats. These regions determined with higher potential in other studies too (Memariani *et al*. 2016a, Memariani *et al*. 2016b, Noroozi *et al*. 2018, Nowak *et al.* 2020b). According to distribution pattern of *Ferula* species in sect. *Merwia*, there are three centers of richness that somehow is similar with predicted hot points (Fig. 5, Red cells). One of the areas is Khorassan-Kopet Dagh floristic province that located in mountainous areas of NE Iran and partly in S Turkmenistan as a transition zone or corridor by connecting different phytogeographical units of the Irano-Turanian region (involving the central Iranian deserts, the Aralo-Caspian (Turanian), central Asian and Afghanistan Mts., and the Hyrcanian province of the Euro-Siberian region) (Memariani *et al*. 2016b). As indicated before, the area might have been isolated in earlier geological times, resulting in allopatric speciation of many related species from surrounding areas and could be a local center of endemism (Kamelin 1970, Memariani *et al*. 2016a, Noroozi *et al*. 2019). This region was exactly corresponded with group 5 elements (Fig. 2, circles in green color) that contains several endemics distributed all over.

Central parts of Afghanistan is another hotspot point of richness for *Merwia* elements in eastern boundary of IT2 that contain endemics scattered mostly at an altitude of 3300 m a.s.l. (e.g., *F. myrioloba* and *F. stenoloba*). This species rich center covers the group six elements (Fig. 2, circles in red color) with mostly Afghani members. Rechinger (1986) based on distribution patterns of large genera such as *Acantholimon* and *Cousinia*, revealed an abrupt discontinuation in species number from the Iran-Afghan mountainous area towards the Turanian lowlands and proposed to exclude the Turanian area (IT3) from the IT region. He established Irano-Turkestanian mountain region extending from central Turkey to Afghanistan including Tian-Shan and Altai Mts. that Sales & Hedge (2013) also confirmed the term Irano-Turkestanian. However, it seems that, Turanian lowland species of *Merwia* could cover the median richness (4–5 species in orange grid cells, Fig. 5), and the number of species from mountain regions to lowlands are decreased as the same report for *Ziziphora clinopodioides* Lam. (Doostmohammadi *et al*. 2018). It is, therefore, supposed the endemic Afghani elements of sect. *Merwia* restricted to mountainous parts of Irano-Turkestanian regions in both Iran and Afghanistan.

The heterogeneity of topography has an influence on species distribution of *Merwia*. Another hotspot is related to Zagros Mts. that with center of Alborz (as a high species richness area with six species, Fig. 5) contain local refugia for *F. gummosa* and *F. persica*. The communities of *F. gummosa* show a disjunctive distribution between Alborz and Zagros Mts. populations and Khorassan-Kopet Dagh populations that, the latter have overlapped distributions with *F. badrakema* communities in NE Iran (Fig. 8).

The Zagros center of diversity is considerable with the elements of group 3 (Fig. 2, circles in black color). This distributional pattern of Ferulas deal with those species scattered in southern parts of Iran such as *F. assa-foetida* and *F. pseudalliacea* that are phyto-geographically most restricted to the southern-most highlands of the Irano-Turanian region in neighboring with Saharo-Sindian region. Since topology and environmental conditions are rather homogenous along the Saharo-Sindian regional zone, the rate of allopatric speciation in this region is low (White & Leonard 1991). Therefore, mountains in south of Iran as well as north of Oman, encompass a rich diversity of plant life and vegetation units that, the major bulk of these highlands in this region are interglacial refugia of Irano-Turanian species that settled within the Saharo-Sindian regional zone (Rechinger & Wendelbo 1985). Doostmohammadi (2018) revealed that, approximately at 1000 m a.s.l., a remarkable change has occurred in flora where many Irano-Turanian species substitute the Saharo-Sindian elements while the lowlands of S Iran representing a Savanna-like formation or the Saharo-Sindian origins. Highland endemics are of the Irano-Turkestanian origin while the endemic species in the lowlands of S Iran are either Turanian vicariants or of the Saharo-Sindian elements that in the case of *Ferula*, the Irano-Turkestanian elements are vicariants in Saharo-Sindian parts of Iran such as *F. assa-foetida* and *F. sharifii*. The only species that represented from Saharo-Sindian region are *F. negevensis*, *F. rutbaensis*, and somehow *F. blanchii* (Table 3) that in the prediction map show a high suitability habitat in Syria and W Iraq (Fig. 6), while *F. rutbaensis* has recorded as a rare species (altitude 200–650 m a.s.l., Townsend 2013) from Saharo-Sindian region (Zohary 1972, Dawood *et al*. 2020). However, those species distributed in lowland deserts of central Iran and NW Afghanistan is a sub-division of the Turanian region. In fact, the Turanian vicariants in S Iran have reached their current locations through this central Iranian sandy bridge.

- Taxonomic treatment with geographic distributions of *Merwia* species

The most important center of endemism of *Ferulinae* is Irano-Turanian region that was first identified by De Candolle (1820) and then by Boissier (1867) as the “Oriental region”. This area is bordered by the Black and Caspian Seas and covers the area of Iran and Turan (C Asia) that have given its name (Djamali *et al*. 2012b). The distribution pattern of *Ferula* species in sect. *Merwia* is compatible with this Oriental region indicated as IT2 sub-region (Fig. 4). The importance of incorporating phylogenetic information is recognized when to establish phytogeographical schemes. Carta *et al*. (2021) incorporate phylogenetic information to understand the relationships among regions with phyto-geographical schemes and propose a new global regionalization. He introduced 16 regions as phytogeographic divisions and one of them as the Mediterraneo-Iranian region is a transition zone resulted from the intergrading of independent evolutionary histories and their taxa more closely related to Holarctic taxa. This region comprise the distribution areas of *Ferula* species which represent a rapid evolutionary radiation and its related species differentiate with limiting morphological features. Here we discuss the species distributions of sect. *Merwia* according to phylogenetic results and three predicted richness centers.

- Zagros Mts. hotspot

Western populations of *F. assa-foetida* (as an endemic of S Iran), accompanied here with *F. pseudalliacea* (endemic of WS Iran). However, Chamberlain (1987) indicated that, *F. pseudalliacea* closely allied to *F. assa-foetida* and possibly conspecific but with some characters in leaves softer and larger terminal umbels differentiate from the latter. In figure 3, different accessions of these two species placed in one subclade and their affinity were confirmed. It is clear that, *F. pseudalliacea* apparently has a more western distribution than does *F. assa-foetida* that could be as Zagrossian elements (Fig. 8). *Ferula rubricaulis* is another species grouped with the former two species that distributed in Zagros Mts. with overlapped distribution area. So far, we could not access to gain any sequence data from this species but clustering distance analysis confirmed its position among Zagrossian elements. *Ferula behboudiana* as endemic of W Iran, was reported with close affinity to *F. lutensis* in accordance with broad leaf lobs (Chamberlain 1987) but geographically are far from each other and probably they are vicariates (Fig. 8). Based on clustering distance analysis, *F. behboudiana* has affinity with afore-mentioned Zagrossian elements.

According to recent investigations, several genera of *Apiaceae* such as *Prangos* Lindl., *Ferula*, and *Leutea* Pimenov have scattered in subalpine communities in the SE of Caucasus in Iran part (2000–3000 m a.s.l.). These tall herbaceous plants of *Apiaceae* introduced for subalpine region of Alborz and Azerbaijan Mts. (Noroozi 2014). *Ferula szowitsiana* and *F. persica* have a potential to inhabit in subalpine regions in Alborz and Zagros Mts. (based on occurrence points, Fig. 8). White & Leonard (1991) illustrate a separator line between Anatoly and NW Iran with another parts of Irano-Turanian region that particularly corresponded with the distribution area of *F. szowitsiana* which its distribution pattern shows two groups in this species (western elements in IT2 and elements of eastern and central parts of IT2 accompanied by several elements in ES, Fig. 8). Pesmen (1972) indicated that, this species occurred in dry stony slopes, salty steppe, at an altitude of 800–2150 m a.s.l., mainly inner Anatolia, Armenia (Aras valley), Iran, and central Asia as an Irano-Turanian element. There are variable species in its density of indumentum, and the shape and size of mericarps. This pattern of distribution has indicated in another species of *Ferula* i.e. *F. persica* with disjunction distributions in Caucasus area and Alborz-Zagros Mts. (Fig. 8). Therefore, these disjunctive distributions need more investigations to resolve the species position.

- Khorassan-Kopet Dagh hotspot

This hotspot contains many different species that illustrate as follows: The species *F. gabriellii* as endemic of central Iran and Kavir deserts along with *F. hirtella*, and *F. lutensis* that are endemics of SE Iran can be considered as a geographical group. *Ferula gabrielii* is characterized by distinctively small fruits with probably only two commissural vittae and by stiff deflexed-hairy inflorescence branches, which the “assafoetida” gum is apparently collected from it (Chamberlain & Rechinger 1987). Mozaffarian (2007) indicated *F. alliacea* Boiss. with a little different description compared with Boissier (1872), was differentiated by rectangular to oval or linear leaf lobs. Boissier (1872) introduced *F. alliacea* from three locations viz., E Iran, Jandagh-Yazd (Buhse! specimen), near Shahrud-Neyshabour-Mashhad, and Kerman (Buhse! specimen) in altitudes of 900–2100 m a.s.l., a herb much the same appearance as *F. assa-foetida,* growing only to a height from 70 to 120 cm, the diameter of the crown of the root seldom attaining more than 5 cm, and it also contains “assafoetida” gum.

Rechinger (1987) determined the confused place for *F. alliacea* and indicated the Boissier's specimens are related to another species of *Ferula* such as: *F. gabrielii* was determined for Buhse specimen from Yazd, specimen collected from Neyshabour was referred to *F. flabelliloba*, and the sample of Kerman to *F. assa-foetida*. According to phylogenetic ITS tree, *F. alliacea* has not a definite position that needs more molecular markers to investigate such as cpDNA for determining the correct place (Fig. 3). Nevertheless, its distribution pattern shows two separate communities in the north and southern parts of east of IT2 (Fig. 8) that confirm the phylogenetic results.

Two closely allied species from NE Iran, namely, *F. flabelliloba* endemic of E Iran with a distribution in Khorassan province and *F. karakalensis* that despite their molecular proximity are morphologically differentiated (Chamberlain & Rechinger 1987) and have a same pattern in distribution. *Ferula karakalensis* as a member of Kopet-Dagh is an endemic in north and central parts of Iran, Kopet-Dagh and NW Afghanistan (Fig. 8). Although Rechinger indicated that, Kopet-dagh specimen differ from others with fewer-rayed umbels and narrower fruits but closely resemble Korovin's type (Chamberlain & Rechinger 1987) that occurred in stony slopes in lower arid mountain belt in Turkmenistan (Schischkin 1951).

Two close species of *F. badrakema* and *F. gummosa* are located in this richness center that Schischkin (1951) separated them. *Ferula badrakema* as indicator of Turkmenistan region occurred in sandy, herbaceous hills in semi-desert mountain belt in mountain of Turkmenistan (Badkhyz), as well as east and central parts of Iran, while *F. gummosa* occurred in herbaceous slopes in steppe belt in mountain Turkmenistan (Kopet-dagh) and center of Iran. Rechinger (1987) specified *F. gummosa* closely allied to *F. badrakema*. He also indicated that, the specimens of E Khorassan, and Kopet-Dagh of Turkmenistan that cited by Korovin under *F. gummosa*, are probably referable to the more eastern *F. badrakema* that could scattered to NW, E, and NE Afghanistan. Therefore, this close proximity of these species confirm by our identical molecular data (Fig. 3) as conspecific (Panahi *et al*. 2018). Mozaffarian (2007) in Flora of Iran reported *F. badrakema* as synonyms of *F. gummosa* that found in Shahjahan Mt. and also indicated *F. galbaniflua* as *F. gummosa* with distribution in Alborz and central Iranian Mts. We suggest that, both species should be synonymized based on morphological and molecular affinity as supposed by Pimenov & Kljuykov (1996), and the disjunction occurred in distribution pattern of *F. gummosa* should be related to hybrid origin of harvested populations. Based on distributional map of *F. gummosa* (Fig. 8), it is suggested that, this species is separated in two groups viz., those scattered in Alborz and Zagros Mts., and the others, distributed in Khorassan and Kopet-Dagh Mt. Another species as an endemic from E Iran and Kopet-Dagh of Turkmenistan is *F. latisecta* that have the same localities with *F. undulata* (Chamberlain & Rechinger 1987). Rechinger (1987) synonymized *F. undulata* under *F. latisecta* due to undulate leaves, size of leaf lobes, and size of umbels that their distributional patterns and phylogenetic results confirm their affinity (Figs 3 & 8).

- Central Afghanistan hotspot

The hotspot contain Afghani elements of sect. *Merwia* that several of them introduced before. Based on the collected data, *F. lehmanii* shows two disjunctive distribution patterns: those scattered in IT3 in Turcomania, Kara Kum and Kyzyl-Kum deserts (Fig. 2, circles in yellow color), and those populations accompanied by Afghani's species in central Afghanistan (Fig. 8). In the Flora Iranica, *F. lehmanii* has a general distribution from east and central parts of Afghanistan, Pakistan and also Kazakhstan, Kara Kum, and Kyzyl-Kum. Rechinger (1987) mentioned that, the specimens from Afghanistan and Pakistan differ from Russian type in their more densely and finely puberulent leaves but surprisingly did not differentiate them. Schischkin (1951) only reported *F. lehmannii* as an endemic of sandy-clayey deserts in central Asia (Aralo-Caspian, Kara-Kum, Kyzyl-Kum). Phylogenetically, *F. lehmannii* is closely allied to *F. litwiniwiana* (Fig. 3) which the latter reported as endemic in sands of Kara-Kum, Kyzyl-Kum, and Balkh. (W. Bet-Pak-Dala) in central Asia (Schischkin 1951). However, Boissier (1872) indicated that, *F. lehmannii* has occurred in saline deserts of Kyzyl-Kum in N Turkmenistan and mentioned the Stock's specimen collected from Baluchistan (Gurghina) had only similarity in flowers, hence he described this species as an Aralo-Caspian element despite the reported specimen from Pakistan. After precise consideration of several collected herbarium specimens from Afghanistan that reported by Rechinger, it reveals that, they were misidentified as *F. hedgeana* Pimenov & Kljuykov which are scattered in Afghanistan. However, the range of altitude for distribution of *F. lehmanii* as a desert element (from 70 m to upper) is in contrast with Rechinger's records (2000–3000 m a.s.l. in mountainous area). The correct distribution area for this species should, therefore, be considered according to Schischkin's opinion (distribution area is only in IT3).

Ferula narthex is generally distributed both in Afghanistan as well as Pakistan, and clearly is a common species in eastern parts of Afghanistan with close affinity to *F. jaeschkeana*, but distinguished by its more obscurely toothed or entire, longer leaf segments (Chamberlain & Rechinger 1987). *Ferula jaeschkeana* appears to have more eastern distribution (in Pakistan, India boreo-occidentalis) than *F. narthex* does. Schischkin (1951) reported *F. jaeschkeana* from subalpine and shrubby belt in Tian-Shan, Pamir-Alai Mts., and Afghanistan as an element of Indo-Himalayan. Therefore, several records at GBIF that reported from China and India, could not be *F. narthex* and probably were misidentified, hence we excluded them from the data matrix. Based on inferred phylogenetic tree, the position of *F. narthex* is ambiguous and Panahi *et al*. (2018) determined it in basal position of *Merwia* that needs more investigation for grouping with *Merwia* elements.

Table 3. Number of occurrences of each *Ferula* species in the four phytogeographical regions (ES: Euro-Siberian, IT: Irano-Turanian, M: Mediterranean, SS: Saharo-Sindian) plus those distributions indicated in AC (Central Asia)

Taxon	IT				SS	M	ES	AC	Chorotype
	I	II	III	IV					
F. alliacea		10							IT2
F. assa-foetida		27	7		12				IT2
F. badrakema		21	3				1		IT2
F. behboudiana					6				IT2
F. blanchei	3				1	1			IT1
F. flabelliloba		10							IT2
F. gabrielii		6							IT2
F. gummosa		53					4		IT2
F. hirtella		37							IT2
F. karakalensis		13	2				5		IT2
F. latisecta		10							IT2
F. lehmannii		7	9		1				IT3
F. linczevskii			2						IT3
F. litwinowiana			10						IT3
F. lutensis		5			1				IT2
F. myrioloba		2							IT2
F. narthex		43	1	3	2			15	IT2-AC
F. negevensis					20				SS
F. persica		43	1				24		IT2-ES
F. pseudalliacea		11			2				IT2
F. racemosoumbellata		18			3				IT2
F. rubricaulis		7							IT2
F. rutbaensis					2				SS
F. sharifii		1			3				IT2
F. stenoloba		9							IT2
F. szowitsiana		100	2		1		17		IT2-ES
F. trachelocarpa		1							IT2
F. undulata		7							IT2
F. xanthocarpa		3							IT2

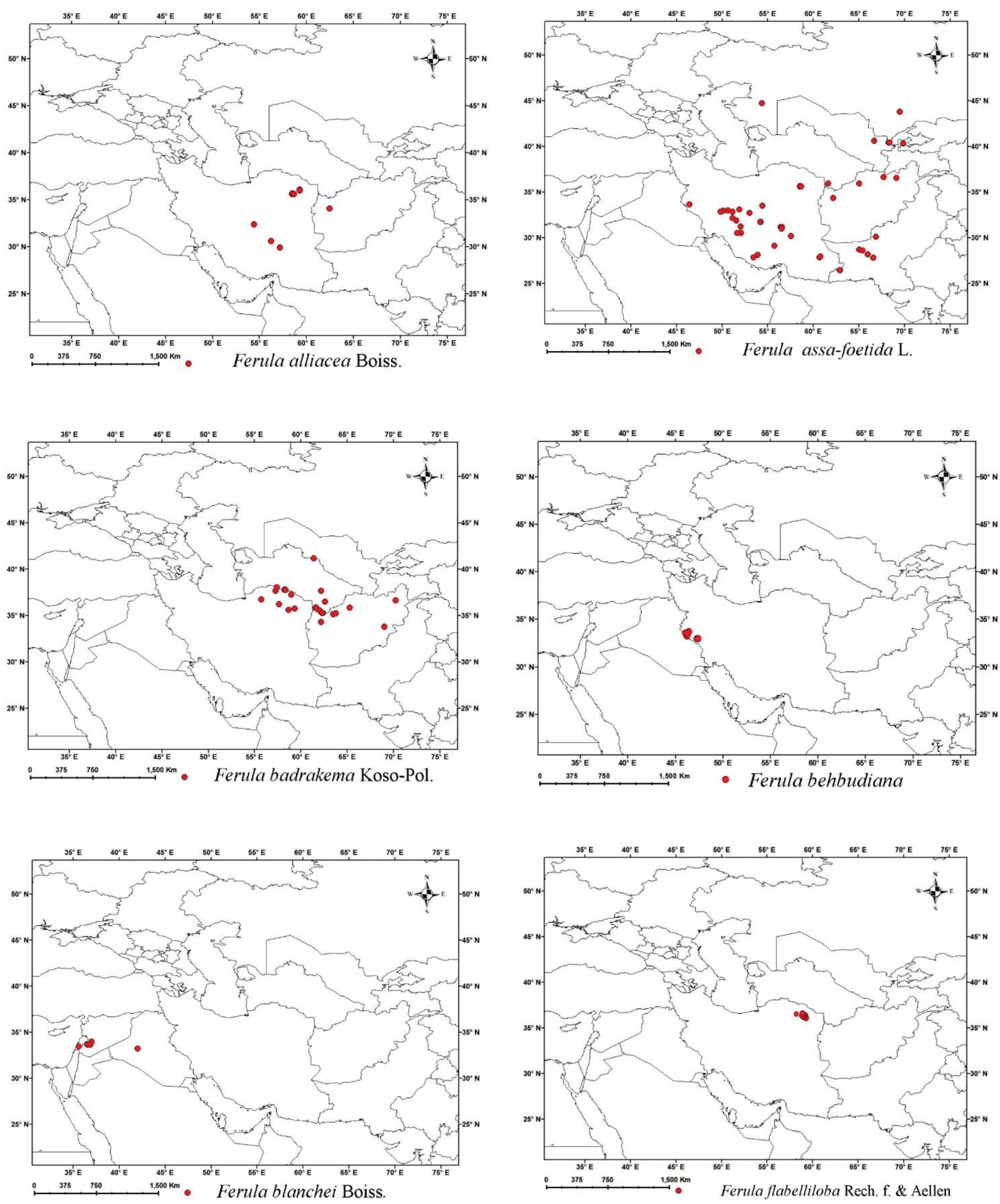

Fig. 8. Distribution maps of *Merwia* elements (arranged alphabetically as in table 1).

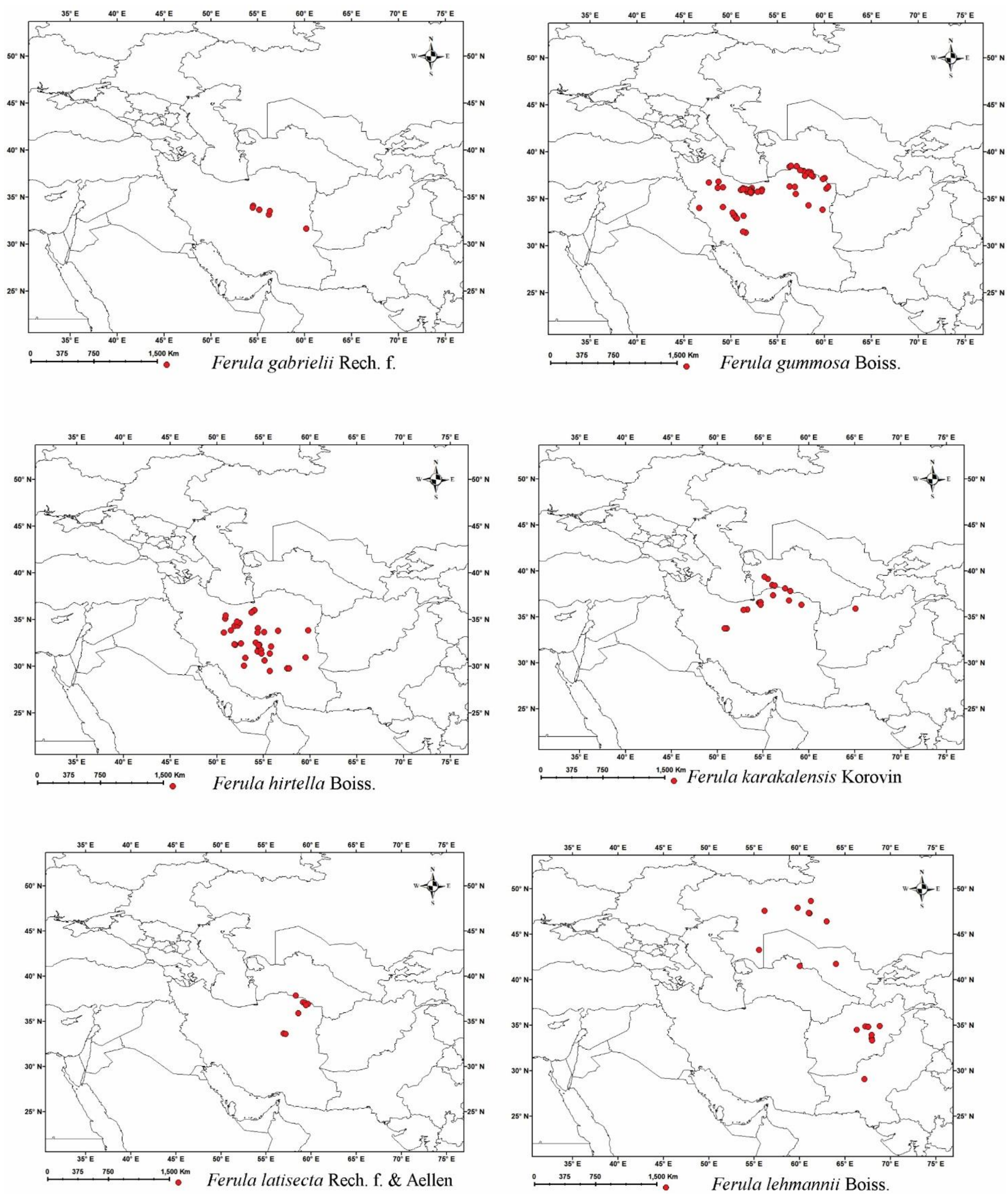

Fig. 8. Continued.

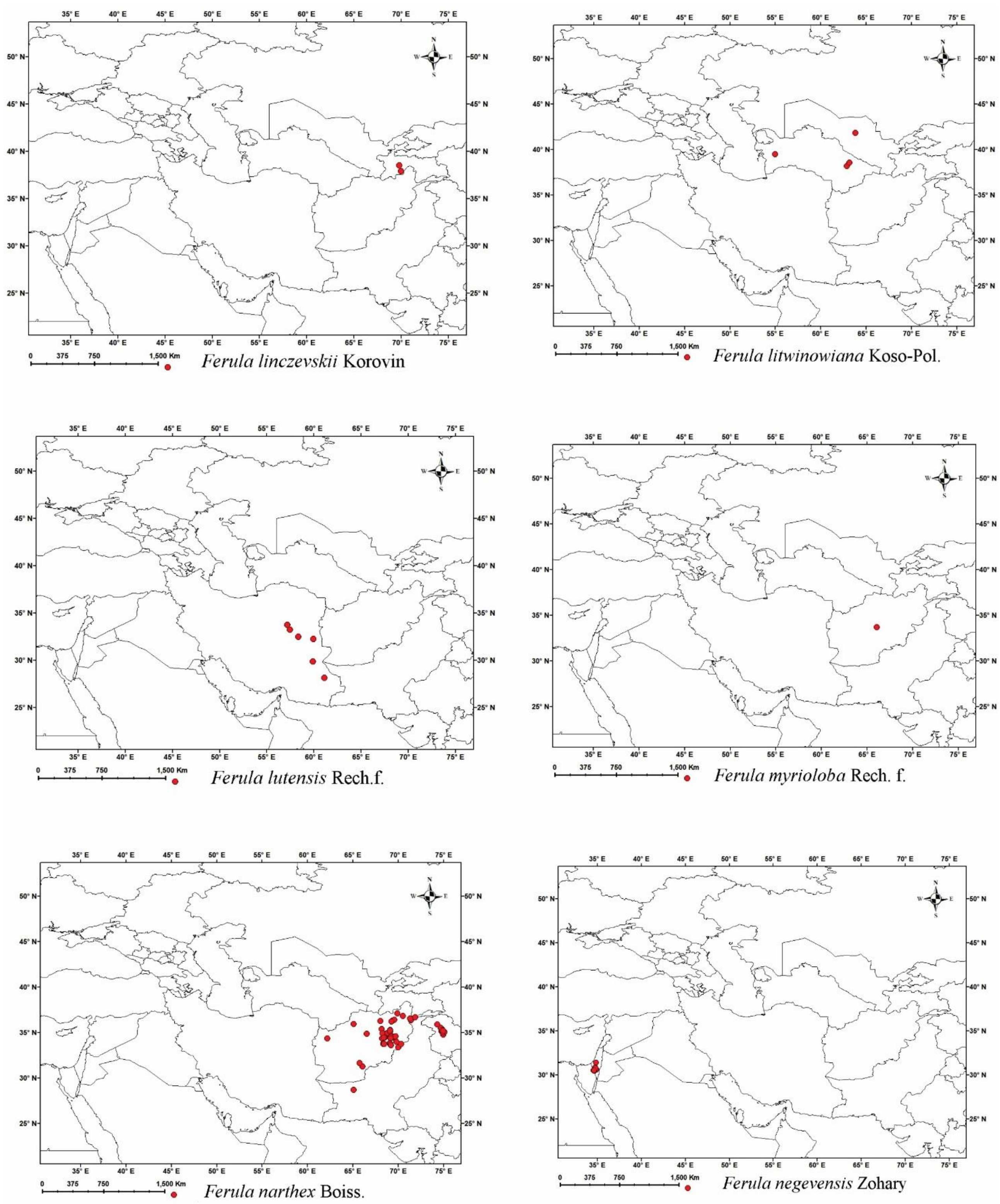

Fig. 8. Continued.

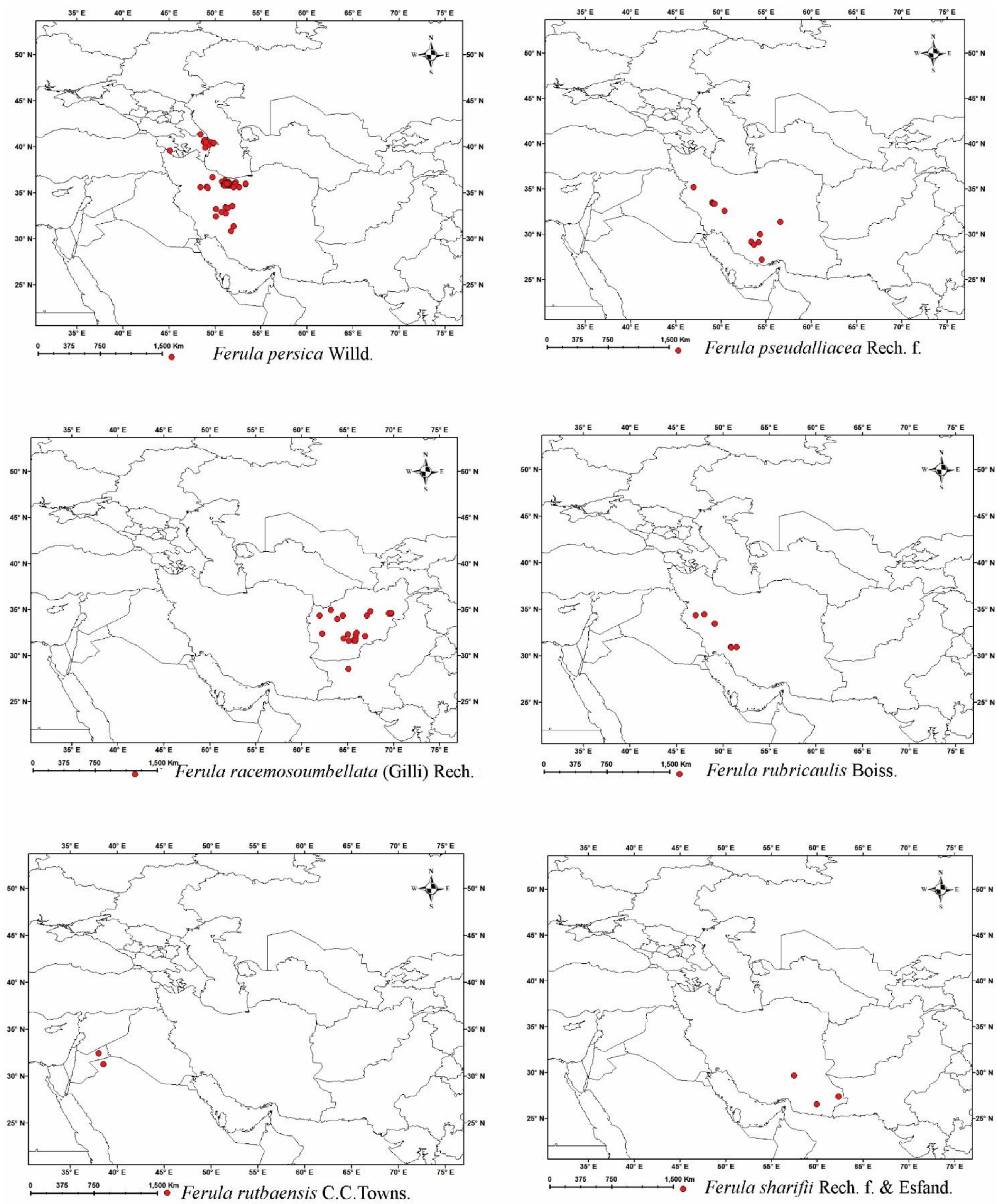

Fig. 8. Continued.

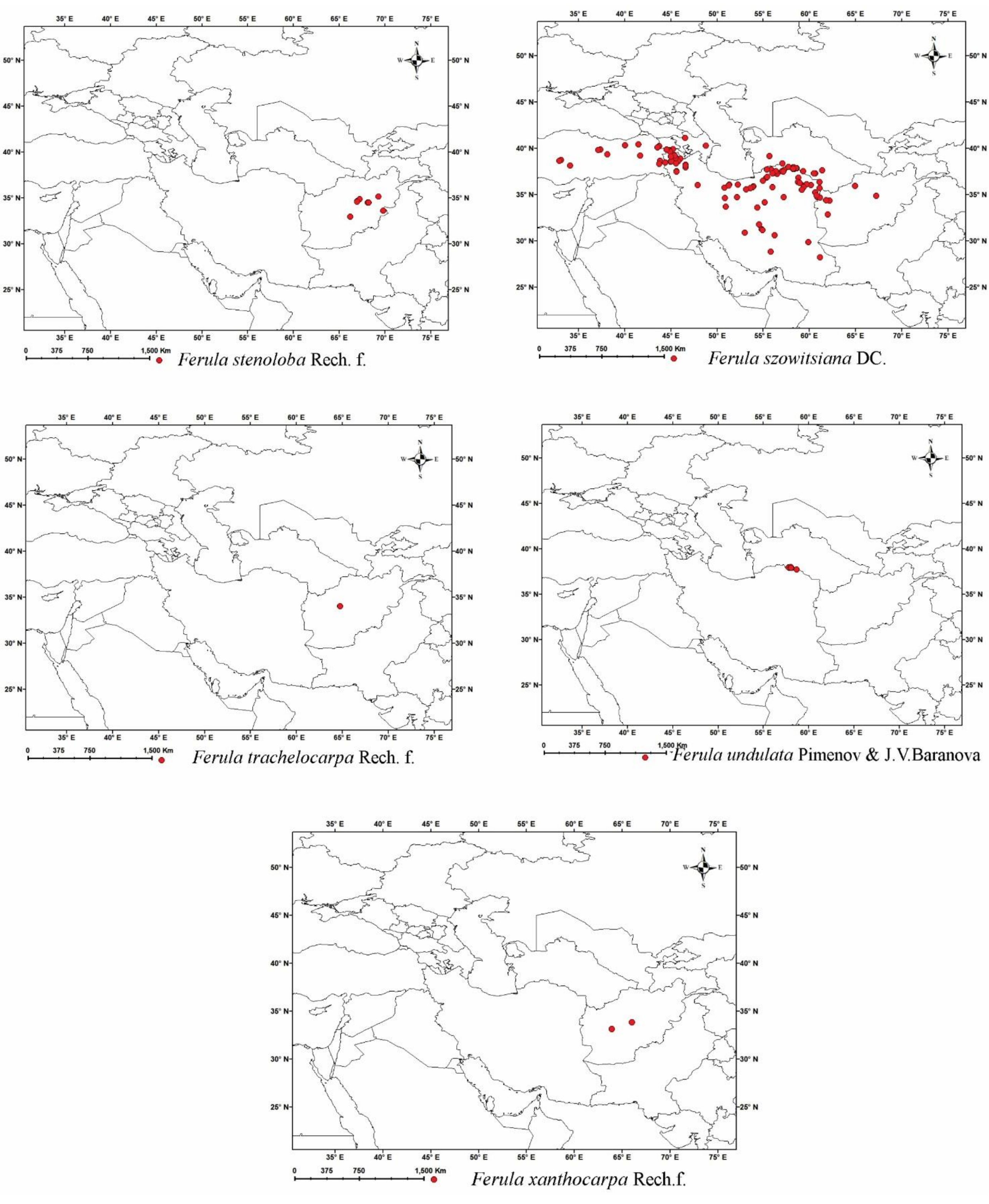

Fig. 8. Continued.

Appendix 1. Accessions of *Merwia* section of *Ferula* examined in this study with respective GenBank accessions numbers for ITS region (asterisk for the sequences that recently earned and have not submitted in GB yet)

Taxon	Accession No.	Voucher and reference No.	ITS
F. alliacea Boiss.	2050	Iran: Khorasan-e Razavi prov.: Neyshabour to Kashmar at 70 km, 11 Jun. 1981, Mozaffarian & Assadi 35506 (TARI)	KP701406
	9839	Iran: Khorasan prov.: Mountains of Bezgh and Ataeeh villages, 12 Apr. 2012, Iranshahi 12613 (FUMH)	*
F. assa-foetida L.	0148	Iran: Isfahan prov.: Semirom, Vanak range, Dalankuh Mts., 16 May 2001, Parishani 14017 (HUI)	KJ660765
	0359	Iran: Fars prov.: 65 km from Lar to Jahrom, 1 Apr. 1974, Davis & Bokhari D.56275 [identification confirmed by D.F. Chamberlain] (E)	KJ660764
	2051	Iran: Kerman prov.: Kianshahr to Zarand, Kianshahr at 2 km, 4 May 2008, Kanani & Gholipour 1253 (MPH)	KP701407
	0433	Iran: Isfahan prov.: Naein, Chopanan, 4 May 1990, Ghaedi 7524 (SFAHAN)	KJ660766
	9806	Iran: Chaharmahal & Bakhtiari prov.: Tang-e Sayyad protected area, from Bostanshir and Abshorshor, 5 Jun. 2009, 2245 m, Mozaffarian 97203 (TARI)	*
	9807	Iran: Hormozgan prov., Bastak, Kuh-e Parzy, 10 May 1996, 1800 m, Moradi 78261 (TARI)	*
F. badrakema Koso-Pol.	0162	Turkmenistan: Badkhyz, near Kepele cordon, 12 May 1976, Botschantzev 696 (LE)	DQ379388
F. behboudiana (Rech.f. & Esfand.) D.F. Chamb.	0423	Iran: Kermanshah prov.: Reno, 25 Apr. 1967, Kashkouli 12934E (W 18008)	KJ660767
F. blanchei Boiss.	0343	Iraq: Western desert, 162 km E from Rutba to Ramadi, 28 May 1957, Rechinger 12839 (E 00175645)	KJ660768
F. flabelliloba Rech.f. & Aellen	0076	Iran: Khorasan-e Razavi prov.: Mashhad, Golmakan and Esjil, Kuh-e Binalud, 10 Jun. 2004, Mozaffarian 87053 (TARI)	KJ660777
F. gabrielii Rech.f.	0429	Iran: Yazd prov.: Jandaq-Biyabanak, S Dasht-e Kavir, Apr. 1933, Gabriel 98 (W 1936-6800)	KJ660779
F. gummosa Boiss.	0150	Iran: Isfahan prov.: near Semirom, 24 May 1984, Aryavand & Sahebi 10083 (HUI)	KJ660787
	0158	Turkmenistan: Nukhur Mts., 24 Apr. 1913, Samokish s.n. (LE)	DQ379407
	0149	Iran: Isfahan prov.; Khansar, Darband-e Layjand village, 15 Jun. 1992, Feyzi 8893 (SFAHAN)	KJ660786
	9802	Iran: Khorasan prov.: Esferayen, Shahjahan Mts. Region, rocky, soily Tourkan Mt. from deep gorge close to Noushirvan village, 8 Jun. 1984, 1400–2500 m, Mozaffarian 48590 (TARI)	*
	9803	Iran: Tehran prov.: 13 km from Firouzkuh to Semnan (XV3), 9 Jun. 1981, 2000 m, Assadi & Mozaffarian 35283 (TARI)	*
F. hirtella Boiss.	2053	Iran: Yazd prov.: Before Bahabad, 4 May 2008, Kanani & Gholipour 1270 (MPH)	KP701409
	0191	Iran: Isfahan prov.: Naein, Jandagh village, 4 May 1993, Feyzi 9316 (SFAHAN)	KJ660820
	9829	Iran: Kerman prov.: 28 km a Rayen from main road Kerman-Bam, 27 May 2019, 2371 m, Panahi 107141 (TARI)	*

Appendix 1 (contd)

F. karakalensis Korovin	0168	Turkmenistan: Lesser Balkhans, near Akga-Kuima, 22 May 1949, Tarasov 25 (LE)	DQ379409
	9835	Iran: Semnan prov.: Shahrud, Shahvar Mt., above Tash village, 23 Jun. 2019, 2701 m, Panahi 107128 (TARI)	*
F. latisecta Rech.f. & Aellen	2049	Iran: Khorasan-e Razavi prov.: Mashhad, Ghoochan to Toos, Ardakan, Abghad, Talghoor, 26 May 2007, Kanani *et al*. 1198 (MPH)	KP701405
F. lehmannii Boiss.	0120	Kazakhstan: Aktobe region, Bayganin district, near Danguz-tau, 13 Jun. 1956, Yunatov & Kuznetsov s.n. (LE)	DQ379418
F. linczevskii Korovin	0196	Tajikistan: Imam-askari Mt., 3 km W from village Darai-Imam, 4 Jun. 1960, Botschantsev & Egorova 946 (LE)	KJ660755
F. litwinowiana Koso-Pol.	0108	Turkmenistan: near Uzboy, kolkhoz Jigirdekli, 14 May 1953, Rustamov s.n. (LE)	DQ379423
F. myrioloba Rech.f.	0418	Afghanistan: Deh Kundi, Khonak ridge, 1 Jul. 1967, Rechinger 36665 (W 1972-11554)	KJ660799
F. narthex Boiss.	0375	Afghanistan: Khost, Shamol valley, 60–70 km W Khost, Rechinger 35474 (E)	KJ660800
F. negevensis Zohary	0089	Israel: Negev Highlands, Borot Loz, 22 km SW Mizpe Ramon, 20 Apr. 1992, Danin s.n. (B)	KJ660757
F. persica Willd.	0190	Iran: Isfahan prov.: Semirom to Padena, Tang-e Shahid, 9 Jun. 1983, Nowroozi 2833 (SFAHAN)	KJ660807
	9850	Iran: Mazandaran prov.: ca. 50 km SW Chalous, above Delir village, 18 Aug. 1984, 2800 m, Assadi & Mozaffarian 51639 (TARI)	*
	9849	Iran: Tehran prov.: Karaj, Sarvedar, 5 Jun. 1974, 1500 m, Foroughi & Sanii & Amini 12322 (TARI)	*
F. pseudalliacea Rech.f.	0377	Iran: Lorestan prov.: Oshtorankuh, 16–17 Jun. 1974, Renz 48257 (B)	KJ660808
	9808	Iran: Fars prov.: Mian Jangal protected area, Tang-e Ahram, 27 Apr. 2003, 1900–2200 m, Mozaffarian 83627 (TARI)	*
F. racemosoumbellata (Gilli) Rech.f.	0378	Afghanistan: Kandahar prov.: Hill to the W Kandahar, S Argandhab bridge, 7 May 1969, Hedge, Wendelbo & Ekberg W 7627 (E)	KJ660809
F. rutbaensis C.C. Towns.	0341	Jordan: Syrian desert, 205 km from Amman to Rutba, 27 May 1957, Rechinger 12872 (E)	KJ660812
F. sharifii Rech.f. & Esfand.	0411	Iran: Sistan-o-Baluchistan prov.: Tang-e Sorha, 18 Apr. 1949, Sharif 801E (W 1963-4949)	KP701411
F. stenoloba Rech.f.	0382	Afghanistan: Bamian, Band-e Amir, 19 Jul. 1969, Wendelbo & Ekberg 9790 (E)	KJ660819
F. szowitsiana DC.	0135	Turkmenistan: Central Kopet Dag, Prokhladoe, 14 Jun. 1969, Meshtsheriakov s.n. (LE)	DQ379427
	0192	Iran: Isfahan prov.: 110 km E Isfahan versus Naein, Seyfabad village, 6 May 1982, Aryavand & Sahebi 6036 (HUI)	KJ660821
F. trachelocarpa K.H. Rechinger	0605	Afghanistan: 27 Jul. 1962, Rechinger 18891 (W)	KJ660824
F. undulata Pimenov & J.V. Baranova	0127	Turkmenistan: Central Kopet Dag, 35 km S Geok-Tepe, near Novo-Kheirabad, 25 May 1963, Gubanov s.n. (LE)	DQ379456
Ferula xanthocarpa K.H. Rechinger	0604	Afghanistan: Ghorat prov.: N slopes of Kuh-Tscheling-Safed-Daraq Mt. (Pirestan), 2600–2800 m, 31 Jul.–1 Aug. 1962, Rechinger 19104 (E) [syntype]	KJ660828

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