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Research Article

The Distribution Patterns and Priorities for Conservation of Monocots Crop Wild Relatives (CWRs) of Iran

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Abstract

Crop wild relatives (CWR) are the most important genetic resources to improve and ensure global food security. Following Vavilov studies on CWRs, Iran is categorized in the higher ranks of conservation priorities. However, the species in this area are severely exposed to threats, which makes it necessary to protect them. Accordingly, the initial step to their conservation is to create an ecological database. Despite the extensive efforts and valuable publications in the Iranian flora, little attention has been paid to the patterns and diversity centers of CWRs in Iran. The current study analyzed 804 grid cells (20820Km) in the Iranian geographic boundaries. Besides, nothing was recorded from 229 grid cells, though 14 taxa (15.73%) were recorded from one grid cell. In this study, 3911 georeferenced locations of monocots CWRs were reported in Iran that belonged to 331 species, i.e. 80 genera of 16 plant families. Besides, Central Alborz, Eastern Alborz, and northern and central sections of Zagros showed the highest diversity, respectively. Also, *Poaceae* (117), *Amaryllidaceae* (73) and *Asparagaceae* (36) led the highest richness of species. Moreover, the Iranian monocots CWRs were categorized in 9 classes of elevation ranging from 0 m to more than 4000 m, and elevation ranging between 1500 to 2000m and 1000 to 1500m above the sea level with 252 and 235 species as the highest richness among others, respectively. Moreover, the highest diversity in genera and species is distributed mostly between 35° to 38° latitudes. Finally, the high variety of CWRs in Iran emphasizes conservation planning for these genetic resources.

Keywords: CWRs distribution, Food security, Middle East, Species richness

Introduction

Crop wild relatives (CWRs) are the nearest relatives of crops (Maxted et al., 2006), so they play an essential role in the genetic improvement of crops in breeding and the biotechnological programs (Hawkes 1977, 1983) such as resistance to pests and diseases, and improving the quantity and quality of grain and fruit in crops (Dwivedi et al., 2003, Hajjar & Hodgkin 2007, Dwivedi et al., 2008). The increase in the human population (UN 2011) accompanied by the harmful effects of climate change on agricultural products and global food production (Schmidhuber & Tubiello 2007, Lobell et al., 2008, Palm et al., 2010, Maxted et al., 2006, Guarino & Lobell 2011) has led to more attention of global agricultural managers to protect human food security (IPCC 2007 & FAO 2008). Crop wild relatives (CWR) are the most important genetic resources to improve and ensure global food security (FAO 2012). The first scientific study entitled "origin of cultivated plants" was published by De Candolle (1908). However, Vavilov (1926), suggested a basic theory known as the center of origin and the center of diversity of the cultivated plant taxa. Accordingly, he introduced eight centers of origin for the cultivated plants. (Vavilov 1992, Ladizinsky 1998 & Khoury et al., 2016). Additionally, the next generation of basic, as well as key studies in this area, includes reviews of diversity centers, evaluation methods, and conservation and management of these valuable genetic treasures. Hanelt (1986), released a comprehensive database on agricultural and horticultural crops, which is available online. There is also an online database accessible http://mansfeld.ipk-gatersleben.de (Mansfeld 2001). Furthermore, several ecological databases have been provided by Zohary and Hopf (1993), Kell et al. (2005, 2008), for Portugal, Khoury et al. (2013), for the U.S, Maxted et al. (2013), for Europe, Fielder et al. (2015), and Maxted et al. (2015), for the United Kingdom, Zeven and Zhukovsky (1975), and Yohannes (2016), for Ethiopia. Besides, some methodologies on in- situ conservation of CWRs were provided by IPGRI (1985). Maxted et al. (2013), published on conservation of CWR and landraces.

Iran covers a critical zone of the Middle East and some parts of Central Asia as two main centers of cultivated plants (Vavilov, 1992 & Khoury et al., 2016). Also, Iran is categorized in the higher ranks of conservation priorities (Castañeda-Álvarez et al., 2016). Several cultivars of *Triticum* L., *Hordeum* L., *Aegilops* L. (Vavilov 1926 & Zohary 1973) as well as several ornamental cultivated plants (e.g. *Tulipa* L., *Fritillaria* Tourn. ex L., *Gladiolus* L., *Iris* L., and etc.) are derived from Iran (Wendelbo 1977 & Sheasby 2007). However, the mentioned species have severely been threatened, which makes it necessary to protect them. Accordingly, the initial step to their conservation is to prepare an ecological database. Despite extensive efforts and valuable publications in the Iranian flora, little attention has been paid to the patterns and diversity centers of CWRs in Iran. Besides, the compilation of these valuable species has been neglected in botanical studies, so, this study tries to provide as many details as possible to assess the diversity and distribution of the species in order to analyze the conservation status and priorities for CWRs. We aimed to identify and analyze important altitude zones, phytogeographic areas and bioclimatic zones, among others, to establish the gen sanctions, gene micro-reserves, and other In-situ conservation methods of these valuable species.

Study Area

This study covers the geographical boundaries of Iran as the most critical section of the Iranian plateau comprised of a total surface area of 1.6 million km2 at 20°-20° N longitude and 44°-64° E latitude.

The studied region, including several mountainous chains, mainly consists of Alborz, Zagros, Kopet Dagh, Makran, and numerous scattered internal mountains. As a natural barrier, Alborz prevents the flow of moisture in the Caspian Sea to the center of the Iranian plateau (Stöcklin, 1974 & Axen et al., 2001). Zagros is the most extensive orographic structure in Iran (Fischer 1968), formed due to multiple and complex tectonic events during the latest Cretaceous and all of the Cenozoic periods (Homke, 2007). Kopet-Dagh comprises "a sequence of Jurassic-Pliocene folded sedimentary rocks" (Navab et al., 2006), which is 700 km long, stretched from the eastern boundaries the Caspian Sea to the northeast of Iran. (Allen et al., 2003). Iran consists of several scattered interior mountains in Central, Southern, and Eastern parts. However, basins and lowlands, coastal, and riverine zones form the other parts of the country, surrounded by the mentioned natural massifs (Fischer, 1968). Also, a substantial altitudinal variation between -27 a.s.l (in Caspian basins) to 5671 m a.s.l (in Damavand as the highest peak in Alborz) leads to heterogenic climatic zones in Iran. The precipitation shows an average of about 250 mm, (about less than 1/3 of the average rainfall in the world: 860 mm) (Shakur et al., 2010). Besides, a diverse range of pedological zones resulted from topography, climate, vegetation, bedrock, time, and human effects have been determined by Dewan & Famouri (1964). Accordingly, these complexities in the ecological structures trigger several evolutionary-ecological zones to speciation and diversity in the plant taxa of the area (Zohary 1976, Davis et al., 1994, Barthlott et al., 1996, 1999 & Kier et al., 2005) (Fig.1).

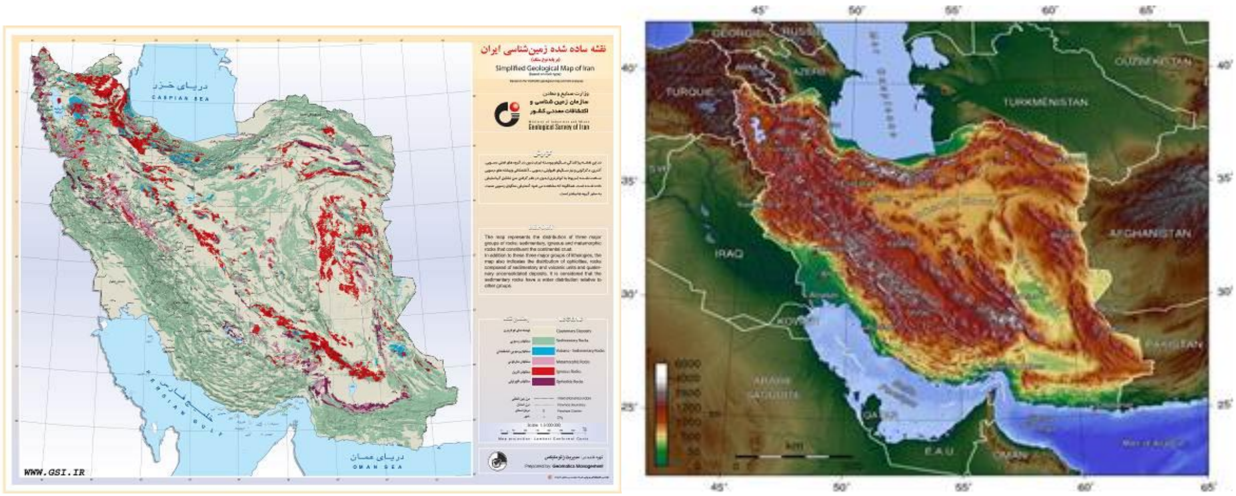

Figure 1: Geomorphological (left) and geological (right) map of Iran (www.ngdir.ir).

Material and methods

The primary database on monocot CWRs was provided using 3990 viewpoints from several Iranian and International Herbariums (e.g., HSBU, W, WU, etc.) and a lot of scientific literature on the flora of Iranian habitats. Flora Iranica (Rechinger, 1963-2018) and Flora of Iran (Assadi, 1984-2018) are the main taxonomic references for evaluation. Also, ArcView version 3.2 (ESRI, 2014) and the DIVA-GIS 7.3 were used to make the spatial data layers. The Mansfield Encyclopedia of Agricultural and Horticultural Plants and Crop Wild Relative inventory is considered the primary reference to determine the nearest crop wild relatives (Hanelt 2017, Harlan & Wet 2012). There are two different methodologies (the gene pool and the taxon group concepts) for evaluation, so each evaluation method can be performed based on phylogenetic or taxonomic data around the group. Accordingly, the primary Gene pool concept of the CWR covers the near lineages that readily intercross with the crops. Besides, the CWR (GP2) secondary gene pool concept includes all the biological species that can be crossed with the crop, whereas the hybrids are usually sterile. The tertiary gene pool (GP3) covers those taxa that can be crossed with the crop with difficulty and where usually the gene transfer is only possible using radical techniques. Additionally, the taxon group concepts comprise of taxon group 1b (the crop), taxon group 1b (the same species as a crop), taxon group 2 (the same series or section as crop), taxon group 3 (the same subgenus as crop), taxon Group 4 (the same genus as a crop), and taxon group5 (the different genus to the crop), because the principal database includes a diverse range of CWRs (e.g. medicinal, ornamental, human food, animal forage). Regardless, a checklist of the most important taxa, based on the FAO (2008, 2012), and the national priorities were selected to perform the main analysis. Due to monocot wild relatives' multiplicity, the most important groups, including gene pool one and gene pool two, or taxon groups of 1 and 2 were analyzed for the conservation analyses. However, the distribution patterns have been made based on all species.

The climatic data was based on 45 years (1970–2015) of the Meteorological Organization in Iran. Besides, the bioclimatic zoning was performed based on Rivas-Martínez et al. (1999). The conservation status was assessed based on the IUCN Guidelines at the regional scale (IUCN, 2011), analyzed by Kew GeoCAT (www.Kew.org) (Bachman et al., 2011). In addition, The Area of Occupancy (AOO) and the Extent of Occurrence (EOO) were used to classify the threat ranks.

The distribution localities were marked using the ArcGIS version 10.3 (ESRI, 2014) on the geo-referenced maps (1/106) of Iran, including 0.25° × 0.25° universal transverse Mercator grid cells (except for of 25 km^2 of boundary zones). The index of Species Distribution (SDI) (Selvi 1997, Solymos & Feher 2005) and the rarity index of the taxon (RI) (Williams et al., 1996) were calculated to determine the priorities for conservation. The scoring varied from zero (0) to one (1) in which the higher scores showed higher vulnerability. Besides, the RI=1/Ci, where Ci is the number of grid cells, and l is the number of current species categorized as very rare (VR), rare (R), middle distribution (MD) and widespread (W). The SDI=l-Ci/C, where C is the total number of grid cells. Besides the conservation Value (CV), the RI and SDI of each grid cell were summed up. Thus, the higher scores signify an advanced CV. Moreover, the IPA sites have been based on (Langhamer *et al*. 2007) three criteria: the presence of threatened species and the species richness alongside the threatened habitats. Besides, three criteria, including endangerment, irreplaceability, and discreteness (Langhamer et al., 2007) were used to identify the AZE sites. The species' unique indices were calculated according to the following formula: SSI=∑(1-Ti/T+....), where Ti is the number of geomorphologies, bioclimatic, and phytogeographic units for each species and T represents the total number of studied units in Iran.

Results

The current study analyzed 804 grid cells (20820Km), including the Iranian geographic boundaries. Nothing was recorded from 229 grid cells, though 14 taxa (15.73%) were recorded from one grid cell. 3911 georeferenced locations of the monocots CWRs were reported in Iran that belonged to 331 species, 80 genera of 16 plant families (Fig. 3 and Table 1). Considering the 1164 monocots species (Noroozi *et al.* 2019), the 331 monocots CWRs included 28.5% of Iran's total monocots species (Mehrabian *et al.* 2015). Central Alborz, Eastern Alborz, and northern and central sections of Zagros showed the highest diversity, respectively (Fig. 2). Also, *Poaceae* (117), *Amaryllidaceae* (73) and *Asparagaceae* (36) revealed the highest richness of species (Fig.3).

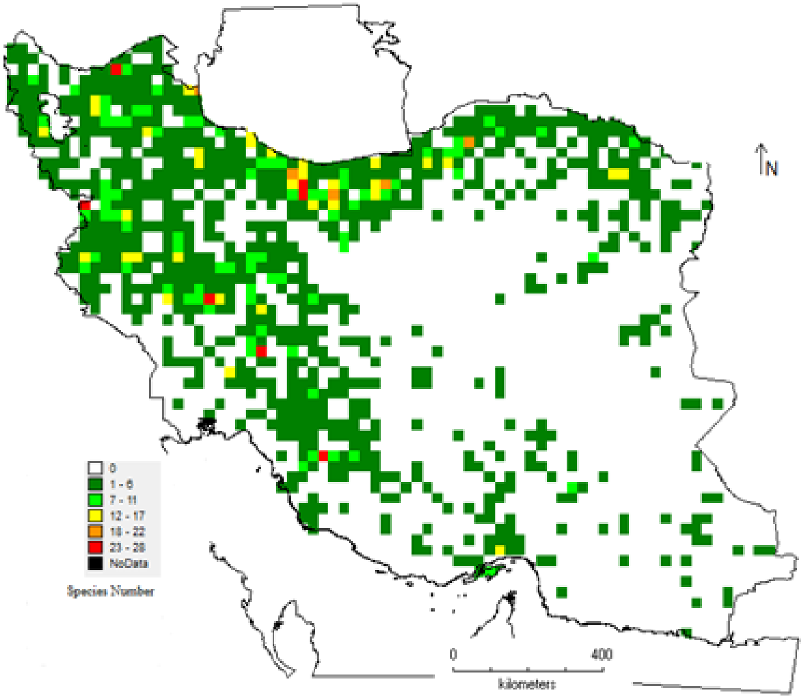

Figure 2: The species richness map of the monocots CWRs in Iran

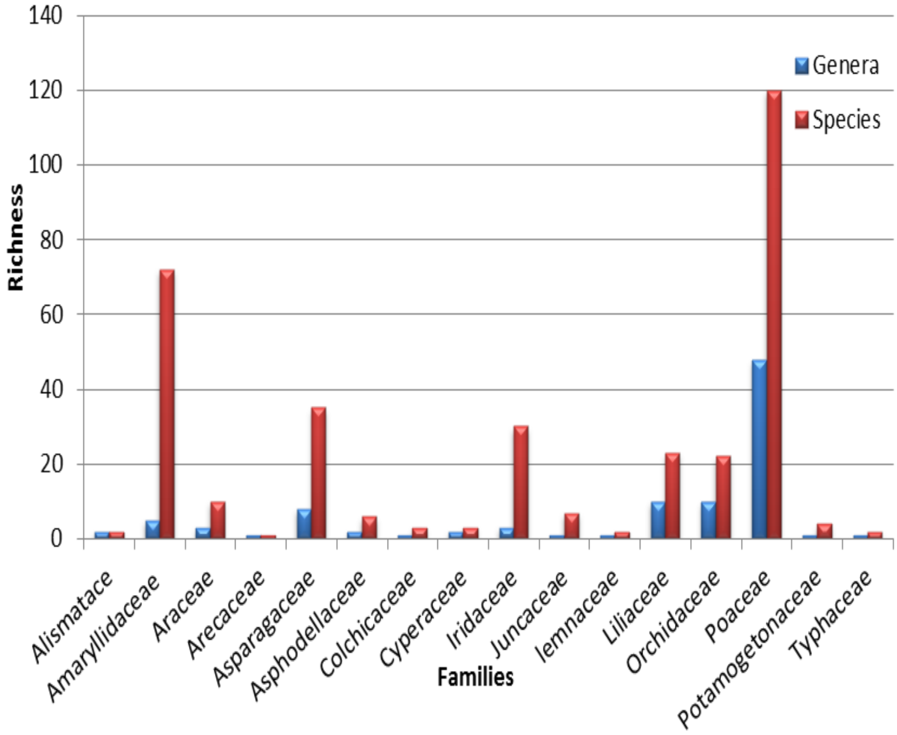

Figure 3: The species and genera CWRs richness of monocots families in Iran

The Iranian monocots CWRs were distributed in 9 classes of elevation ranging from 0 m to more than 4000 m; tow elevational rang 1500 to 2000m and 1000 to 1500m above the sea level with 252 and 235 species passing the highest richness among others respectively (Fig. 4). Moreover, the highest diversity in the context of genera and species is distributed mostly between 35° to 36°

and 37° to 38° to latitudes with 72 and 65 species respectively (Fig. 5).

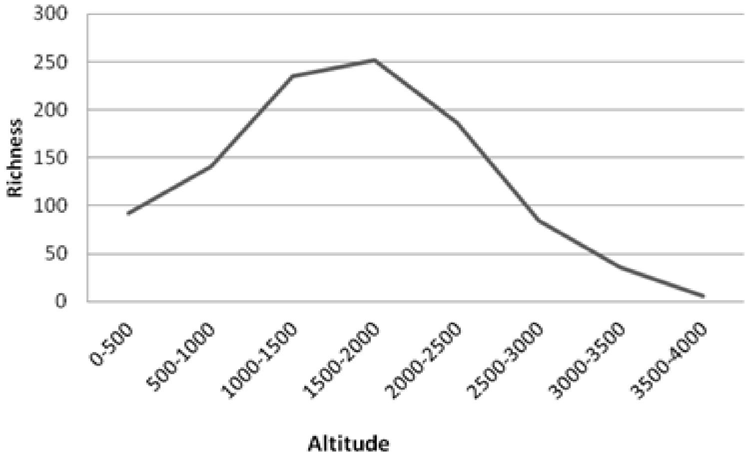

Figure 4: The richness of the monocots CWRs in the highland strip in Iran

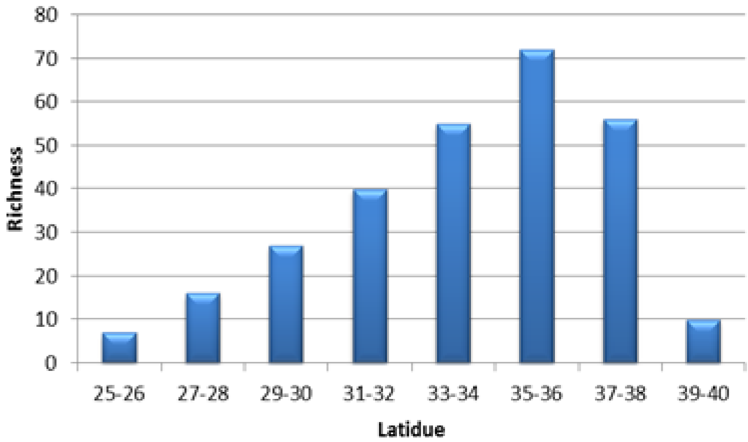

Figure 5: The monocots CWRs richness in different latitudes in Iran.

Based on bioclimatic zonation, 213 species were distributed in mediterranean pluviseasonal-continental (Mpc), 66 in mediterranean xeric-continental (Mxc), 33 in mediterranean desertic-continental (Mdc), 32 in mediterranean pluviseasonal-oceanic (Mpo), and 41 in other bioclimatic units (mediterranean pluviseasonal-oceanic, tropical xeric and tropical desertic) (Table 1). Acording to geological structures, 117 species appeared in sedimentary, 50 in quaternary, 44 in igneous and 32 appeared in other geological formations (Table 1). Furthermore, 127 species appeared in Zagros mountans, 74 in Azerbayjan mountans, 60 in Alborz mountans and 110 appeared in other geomorphological units (Table 1). Kurdistan-Zagros with 172 species, Atropatenian 177, N-Khorasan 80, Fars-Kerman 44, Hyrcanian 80, Centeral-Iran 103, Fars-Kerman 44, Nubo-sindian 14, and N-bluchestan three species, all have constituted the phyto-geographical units of the Iranian monocots (Table 1 and Fig. 5).
The most important taxa were selected in terms of economic and nutritional values (Wiersema and León 2016), including four families, 27 genera, and 90 species (Table 2). Among them, 18 species can be used as food, 68 species can be used as forage and others as medicine, ornament, etc. In

this regard, *Poaceae* (5 and 62) and *Amaryllidaceae* (7) species are the most important ones to use as food and forage (Table 2). Conservation status of the food and forage monocots CWRs, according to IUCN criteria, were included as CR (21), EN (8), and VU (5). However, the other NT (1) and LC (56) composed other categories in the studied taxa (Fig.7). Finally, *Poaceae* and *Amaryllidaceae* have the highest degree of threat (EN and CR) (Table 1). Accordingly, those taxa which were present in 1-5, 6-15, 16-30, and more than 30 grid cells were considered as VR (46: 51%), R (20: 22 %), MD (15: 16%) and W (10: 11%), respectively. Moreover, *Poaceae* (32) and *Amaryllidaceae* (6) covered the highest percentage of very rare and rare taxa, respectively (Fig. 8).

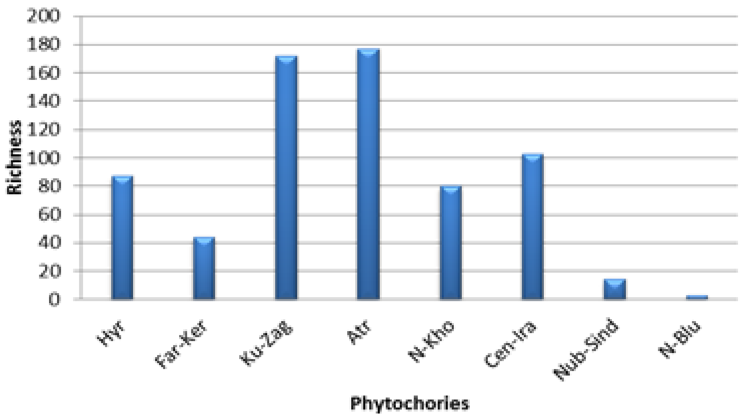

Figure 6: The richness of the monocots CWRs in diverse phytochorions in Iran.

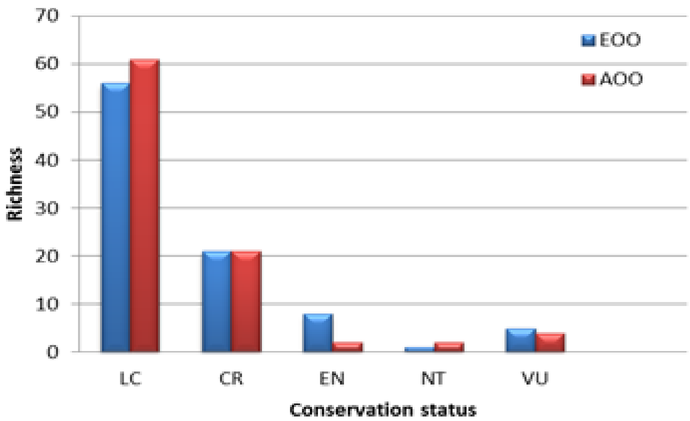

Figure 7: Conservation status of the selected food and forage monocots CWRs in Iran.

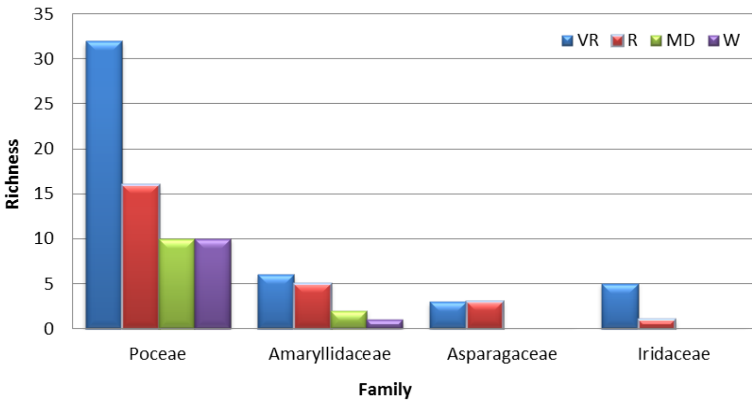

Figure 8: Rarity status of the selected monocots CWRs in Iran.

Discussion

Iran host a diverse range of ecological zones (Takhtajan, 1986) resulted from the climatologic heterogeneities (Frey & Probst 1986), complicated orography (Zohary, 1973) and diverse edaphic zone (Hedge & Wendelbo, 1978) that created the endemic center of the Irano-Turanian region (Leonard, 1991) and a global center of diversity for plants (Davis et al., 1994, Barthlott 1996,1999 & Kier et al., 2005). On the basis of Vavilov theory, about 15% of the cultivated plants (Vavilov 1992, Hummer & hancok 2015) and a vital origin center of temperate CWRs originated from Iran (Harlan 1992, Zohary & Hopf 1993). Also, Iran and Anatolian plateaus cover more than 200 valuable crop wild relatives that are classified as the highest level of priorities for conservation (Vincent et al., 2013). As a scientific rule, areas with high floristic richness have a high diversity of CWRs (IBC, 2012), so setting up the conservation plans ensures the country's biodiversity's sustainability. The main target for setting up an in-situ conservation zone is to guarantee that the highest volume of the genetic diversity of conservation priorities comprised of habitat-based species. The most important criteria for selecting preference for CWRs mainly include economic importance, the genetic potential to improve crops, threat status, conservation status, distribution range, and specific criteria for each taxon (FAO, 2012). The richness is the main criterion for prioritizing the conservation (Kier & Barthlott, 2001, & Huang et al., 2012), so the zones with the highest diversity of monocot CWRs are in Central Alborz, Central Zagros, and NW geomorphologic zone of Iran. It should be noted that Alborz has been known as an important center speciation zone to the Iran-Anatoly center of endemism (Rechinger, 1986 & Mahmoodi et al., 2013). Alborz is known as the main center of Iran endemic trees and shrubs (Mehrabian et al. 2020) and Iran's endemic monocots (Mehrabian et al. 2015). and the diversity center of eudicot CWRs Besides, the Central Zagros is known as another main center of endemic vascular plants in Iran (Hedge & Wendelbo, 1978) that is confirmed by Sayadi & Mehrabian (2016, 2017), Mehrabian et al. (2015), and Mehrabian et al., (2020). The area covers a central zone of SW Asia as one of the most important centers of diversity and the origin of cultivated plants in the world (Vavilov, 1926). The elevation zone of 1500-2000 ma.s.l, showing the highest richness of CWRs as a priority zone for conservation, follows the endemism zone of Iranian plant endemism (Mehrabian et al., 2015 & Mehrabian et al., 2020). The global strategy for crop wild relative conservation and use regional and global level qualifies areas for genetic reservoirs to include a minimal number of CWRs (global = 100, regional = 25 and national = 5) for the establishment of active CWR genetic reserves (CEPE 2001). Accordingly, 6 zones (grid cells) in Iran are eligible to design genetic reservoirs on the regional scale. However, there are several areas to establish the reservoirs on the national scale. In addition, they are valuable zones for education and research, and a practical methodology can ensure the ecological dynamics of these taxa.

Moreover, "Alliance for Zero Extinction (AZE) sites cover the total population of one or more species listed as Endangered or Critically Endangered on the IUCN Red List of Threatened Species". Some AZE sites are located within the protected areas. However, there is no management plan to protect them within these areas. Some of the mentioned sites can be protected by establishing the plant micro-reserves (Gómez-Campo 1981, Laguna et al. 2004). Besides, the sites hosting at least 95% of the known population of CR or EN taxa have been classified as the Alliance for Zero Extinction (AZE) (Langhammer et al., 2007). Eragrostis pilosa (L.) P.Beauv., Phleum phleoides (L.) H.Karst., Saccharum bengalense Retz. , and Secale segetale (Zhuk.) Roshev. are the most important species in the richest part (orange grid cell) of the CR group, and *Allium oschaninii* O.Fedtsch., *Festuca rubra* L, and *Phleum alpinum* L. are the most important species in the richest part in the EN group. (Table 1, Fig. 9). Some AZEs occurred along the boundaries of the protected areas, where there are no suitable ecological conditions for viability or efficient actions for their conservation. According to the complementary site selection assay, from 14 proposed areas, seven were placed out of the protected areas (NBSAP2, 2016) that should be added to these areas in the future. The red and orange grid cells area, with 12-14 and 9-12 species respectively, are worth to protect food and forage CWRs. Some could be protected by establishing plant micro-reserves (Gómez-Campo, 1981 & Laguna et al., 2004) (Fig. 10) Moreover, 14 species with RI of 1 had a high conservation value, which included 15.38% of the total species. More, 22 species, constituting 24.17% of the whole species, exhibited a high level of species special index suggesting that their habitat should be conserved (Table 1).

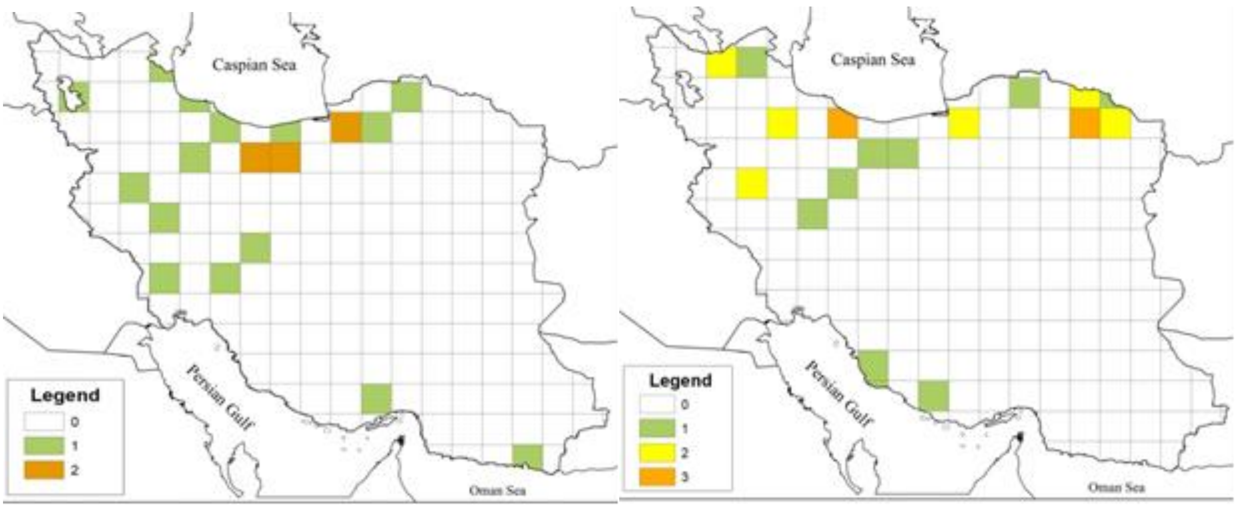

Figure 9. The monocots CWRs distribution in Iran (left) is critically endangered (CR) (right) endangered (EN). The maps were prepared in a 1° × 1° grid cell. (except for 100 Km^2 of boundary zones).

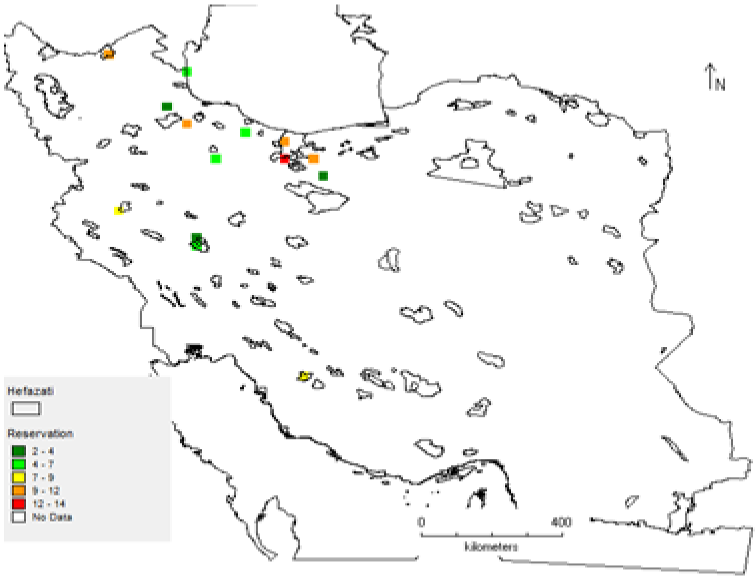

Figure 10. The map of complimentary site selection assay of the selected monocots CWRs in Iran

Also, a wide range of Iranian CWRs is distributed in restricted zones of Iran that are classified as critically endangered on the regional scale, all of which are reported in the global priority list of CWRs presented by FAO (2012). Nonetheles, some of them have a global distribution, but each region has unique genotypes that are severely damaged by anthropogenic pressures (e.g., fire, overgrazing, land- use change, and overharvest) as well as long term drought in Iran, which has led to genetic erosion and the disappearance of these valuable genetic resources.

The following are the most critical CWRs of Iran to support food and have the highest rank of priority for conservation: *Triticum dicoccoides* (Asch. and Graebn.) Schweinf, *T. monoconoccum* subsp. *aegiopoides* (Link) Thell., *T. monoconoccum* subsp. *monococcum* L., *T. turgidum subsp. polonicum* (L.) Thell., *T. aestivum subsp. spelta* (L.) Thell. as Gene pool one to *T. aestivum* L., *Secale segetale* (Zhuk.) Roshev as Gene pool one to *S. cereal* L., *Hordeum spontaneum* K.Koch as Gene pool one to *H. vulgare* L. (Nevo, 1995 & Nevo et al., 1998).

In addition, more than 90 wild species of *Allium* L. are reported in Iran as one of the main diversity centers of the genus in the World (Fritsch & Friesen 2002). Several species of the mentioned genus are used as a flavor and wild vegetables (e.g., *Allium akaka* S.G.Gmel. ex Schult. and Schult.f., *A.assarnse* R.M.Fritsch and Matin, *A. Allium stipitatum* Regel etc.) (Fritsch *et al*., 2006 & Keusgen *et al*, 2006). Besides, there are about 63 endemic species *Allium* in Iran (Akhavan Roofiga et al., 2019). These species can donate valuable traits to edible onions. They can also have the ability to be domesticated to reduce the negative pressures of overharvesting and improve the economy of local communities.

Crocus, as a Eurasian and North African element, was distributed from the Aegean Sea in western Turkey and the Balkans (Eastern Mediterranean to the Irano–Turanian region) (Erol et al., 2012). Wild relatives of *Crocus sativus* L. are useful to saffron improvement as sources of a variety of valuable traits (Khoury *et al.* 2010). Among the wild Iranian *Crocus* sp, *C. pallasii* Goldb., as a CWR, is closely related to *C. sativus* and its candidate parents (Sheidai et al., 2018).

Conclusion

Negative anthropogenic and natural pressures (e.g., climate change, land-use change, overgrazing, overharvest, etc.) have reduced the diversity of the mentioned unique genotypes, resulting in their disappearance and extinction. The high variety of CWRs in Iran emphasizes the importance of conservation planning for these genetic resources. Also, ecological modeling, as an effective method, can evaluate the habitat suitability and simulate their future distribution to conservation management of the valuable species (Hirzel *et al*., 2006 & Vincent et al., 2019).

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