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RESEARCH ARTICLE

Setting conservation priorities for crop wild relatives in the Fertile Crescent

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Abstract The aim of this paper is to contribute directly to the systematic, long-term conservation of crop wild relatives (CWR) in the Fertile Crescent by setting conservation priorities to secure and improve CWR conservation in situ and ex situ as a means of underpinning global food security. We established the first priority list of CWR within the Fertile Crescent following several criteria comprising production value (m × p), projected production value (m × p), production area (ha), projected production area (ha), native status, energy supply (kcal/capita/day), protein supply (g/capita/day), fat supply (g/capita/day), occurrence status, gene pool, taxon group, and threat status. An inventory of 220 priority CWR was established for the Fertile Crescent region. We followed twelve prioritisation approaches and assessed 21,080 species. About 4% of the total species (835 species) were identified as CWR that have socio-economic value for the region. These 835 CWR species were prioritised to create the CWR priority list which consisted of 220 species (1% of the total species assessed). The majority of the CWR priority list (185 species) were related to cereal, vegetable, and industrial crops and 35 of them are related to fruits and trees. The CWR priority list includes crop wild relatives of the genera *Aegilops* (20 species), *Lactuca* (11 species), *Avena* (11 species), *Carthamus* (11 species), *Allium* (9 species), *Thinopyrum* (10 species), and *Triticum* (3 species). We present the first inventory of 220 priority CWR for the Fertile Crescent. The inventory helps to improve in situ and ex situ conservation and the genetic diversity of CWR. Both the inventory and the methodology applied in prioritisation can be used in setting national, regional, and global conservation strategies. The recommendations will help the Fertile Crescent meet its targets in conserving CWR diversity as well as making sure that CWR genetic resources are preserved to prevent and tackle global food insecurity.

Keywords Conservation · Prioritisation · Food security · Genetic diversity · Plant genetic resources

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Introduction

Human population is increasing rapidly. It was estimated that the population will reach 11.2 billion by 2100 (UN 2017). That is why there is an urgent need to improve crop varieties so we could produce more food and crops will be able to improve yield, are resistant to insects and diseases, can tolerate abiotic stress such as high temperature and drought (Araus et al. 2008). Crop wild relatives are species of plants that are genetically close to cultivated crops. They are an important source of plant genetic materials that can be used for crop improvements. CWR have genes that made them adapted to various stresses in their natural environments (Maxted et al. 2006). A CWR should be in Gene pool one or Gene pool two for the gene transfer to be done easily (Maxted et al. 2006). CWRs have been used to improve crops resistant to diseases, for example in Australia, a crop wild relative of wheat has been used successfully as a source of a gene which is resistant to cereal cyst nematode. The gene from the CWR was transferred to bread wheat (Appels and Lagudah 1990). CWRs have also been used to improve varieties' resistant to stress, for example, *Hordeum spontaneum* K. Koch and *Triticum dicoccoides* Körn. the CWRs of barley and wheat have genes that can make them tolerate salty soil and drought (Nevo and Chen 2010). Crop wild relatives are threatened in their natural habitat, this is due to urbanization, constructing roads, deforestation, desertification, intensive farming, and erosion of soil and plant genetic resources, pollution of land and water, scarcity of water, overgrazing and the impact of climate change (El-Beltagy 2006; Derneg 2010). Trigo et al. (2010) state that climate change impacted negatively on the vegetation in the Fertile Crescent (Trigo et al. 2010). For all the above-mentioned reasons, there is an urgent need to conserve CWR in the Fertile Crescent and conserve their natural habitats. There are several CWR taxa around the world and the number was estimated to be approximately 50,000–60,000 species worldwide and of these approximately 10,740 of them are a high priority for food security (Maxted and Kell 2009). In the Fertile Crescent region, there is a red list assessment that was done for plants in Jordan. Nearly 40% (1072 species) of the flora in Jordan was red list assessed. The assessment found 106 species of the total species have been listed as threatened nationally with 19 species of them being critically endangered, 54 species being endangered, 33 as vulnerable and one species (*Salvia farinacea*) as regionally extinct (Taifour and El-Ohlah 2014). Authors have used a number of approaches for CWR prioritisation (Maxted et al. 1997; Mitteau and Soupizet 2000; Barazani et al. 2008; Ford-Lloyd et al. 2008; Maxted and Kell 2009; Magos Brehm et al. 2010). Magos Brehm et al. (2010) used nine prioritisation criteria (native status, economic value, ethnobotanical value, global distribution, national distribution, ex situ conservation status, in situ conservation status, legalisation, and threat assessment) and applied them to the Portuguese CWR. Species were listed based on their priority from high to low and the top 50 were identified. Those CWR species that were found to be a high priority were give prioritisation for conservation in Portugal (Magos Brehm et al. 2010). While in the United States, Khoury et al. (2013) used crop production and food supply data from the Food and Agriculture Organisation of the United Nations statistical database (FAOSTAT) giving a US priority list consisting of 821 CWR taxa (Khoury et al. 2013). Fielder et al. (2015) applied five prioritisation criteria: use of the related crop, commercial importance of the associated crop, native status, relatedness degree of the CWR to the crop, and latest change in the population to prioritise 148 CWR taxa (Fielder et al. 2015). Other authors when prioritising CWR taxa have used other combinations of prioritising criteria (Barazani et al. 2008), but related crop value, relative CWR relatedness (indicating potential ease of CWR use in breeding), and threat assessment have been used widely. The Fertile Crescent is a very important centre in the plant genetic resources field as it is a centre of crop domestication. Major crops such as wheat, barley, lentils and chickpeas were first domesticated in the Fertile Crescent thousand years ago, (Zeder 2011). The Fertile Crescent is located in Syria, Iraq, Israel, Palestine, Jordan, Lebanon and Turkey (Fig. 1).

The Fertile Crescent is in the Mediterranean basin region which is a major region that is known for its great plants' diversity. It has between 25,000 and 30,000 plant species (Heywood 2003). Vavilov, (1926) located Crop Origin centres in the world where crops originated and the Fertile Crescent contains two Vavilov centres (Vavilov 1926). Willcox (2012) stated that early farming started in Southwest Asia (the Fertile Crescent today). Willcox (2012) also specified that nine major crops were domesticated in this region including einkorn, emmer, barley, lentil, pea, chickpea, bitter vetch, broad bean, flax (Willcox 2012).

It was estimated that 390,900 vascular plants are known to human (Kew 2016). The number of vascular plants in Turkey is 9753 taxa (Guner et al. 2012). In

Fig. 1 A map showing the location of the Fertile Crescent

Syria, vascular plants amounted for 3500 plants (Post 1933). Zohary (1966, 1986) illustrates that the number of vascular plants in Israel and Palestine is 2700 taxa. Taifour and El-Oqlah (2017) recently updated the vascular plants list in Jordan and now it is 2600 taxa (Taifour and El-Oqlah 2017). Lebanon has 2606 vascular plants (Mouterde 1970). Iraq has 3220 vascular plants (Ghazanfar and McDaniel 2015). The number of vascular plants in the Fertile Crescent equals 21,080 species (Ghazanfar and McDaniel 2015). Vincent et al. (2013) states that the Fertile Crescent is one of the regions with the highest concentration of CWR per unit area globally. Lebanon, Israel, Greece, Portugal, Azerbaijan, Bulgaria, Syria, Italy, Spain, and Turkey are areas with the top CWR concentration per unit, four of them found in the Fertile Crescent (Lebanon, Israel, Syria, and Turkey) (Vincent et al. 2013). Castaneda-Alvarez et al. (2016) also emphasised that the Mediterranean is one of the richest regions in the world for CWR, with 84 global priority taxa in every 25 km^2. Such findings confirm that the Fertile Crescent, as part of the Mediterranean basin, is a hotspot for crop diversity (Castaneda-Alvarez et al. 2016). The Fertile Crescent is possibly the most important centre for ensuring global food security, yet few studies that have been undertaken on CWR genetic erosion in the region (Keisa et al. 2008) indicate that local CWR diversity is being rapidly eroded, and combined with the likely adverse impact of climate change, there is a need to apply contemporary genetic and GIS techniques as an aid to the development of a regional CWR conservation strategy for the Fertile Crescent and so help in safeguarding global food security. This paper addresses the creation of a CWR checklist, prioritisation, and the creation of a CWR inventory as a first step towards developing a CWR conservation and use strategy for the region.

Methods

To create the CWR Checklist, the PGR forum was used. It is an online database designed to facilitate CWR conservation and CWR use for Euro-Mediterranean countries. The catalogue was built with a set of available databases including Euro + Med PlantBase (http://www.euromed.org.uk/), Mansfeld's World Database of Agricultural and Horticultural Crops (Hanelt and IPK 2001; http://Mansfeld.ipk-gatersleben.de/Mansfeld/), with forestry genera from the enumeration of cultivated forest plant species (Schultze-Motel 1966), and ornamental genera from the Community Plant Variety Office (http://cpvo.

Table 1 Groups for the production value (in 1000 USD)

Group	Range (in 1000 USD)	Points
G0	Below 1	0
G1	1–2554	1
G2	4765–27,146	2
G3	27,170–52,983	3
G4	54,696–103,121	4
G5	105,340–149,290	5
G6	164,134–235,667	6
G7	236,222–378,381	7
G8	392,493–668,148	8
G9	689,250–3,951,780	9
G10	4,903,859	10

europa.eu/en) and Schippmann et al. (2002) (Maxted et al. 2007). Cwrdiversity also was used, it is an online database for information on CWR (Vincent et al. 2012) (http://www.cwrdiversity.org). The regional plant checklist consists of a widely accessible working set of known plant species with accepted Latin names. The introduced plant species were excluded; but the near-endemic species were included in order to obtain a complete and comprehensive regional species checklist of the native species. The checklist went through thorough evaluation as there were lots of duplications and synonyms. Species names were checked thoroughly against many sources. Mansfeld, Zeven and de Wet (1982) were used to get a more comprehensive list. After checklist approval, prioritisation started. The regional plant checklist was prioritised following several criteria comprising production value (m × p), projected production value (m × p), production area (ha), projected production area (ha), native status, energy supply (kcal/capita/day), protein supply (g/capita/day), fat supply (g/capita/day), occurrence status, gene pool, taxon group, and threat status. The production value of crops was taken from FAOSTAT (2016) which is a database that shows production for 20 most important agricultural commodities for each country around the world. FAOSTAT (2016) database allow users to compare

Table 2 Selection criteria, groups, and point scale used for the prioritisation

Criteria/group	Points										
	0	1	2	3	4	5	6	7	8	9	10
Production value (M × P)*	G0	G1**	G2	G3	G4	G5	G6	G7	G8	G9	G10
Projected production value (M × P)*	G0	G1**	G2	G3	G4	G5	G6	G7	G8	G9	G10
Production area (has)*	G0	G1**	G2	G3	G4	G5	G6	G7	G8	G9	G10
Projected production area (has)*	G0	G1**	G2	G3	G4	G5	G6	G7	G8	G9	G10
Native status*		Non-nat									Nat
Energy supply (kcal/capita/day)*	G0	G1**	G2	G3	G4	G5	G6	G7	G8	G9	G10
Protein supply (g/capita/day)*	G0	G1			G2				G3		
Fat supply (g/capita/day)*	G0	G1			G2				G3		
Occurrence status	Inv				Int						Nat
Gene pool level		GP3				GP2					GP1
Taxon group level		TG4			TG3			TG2			TG1
Threat status IUCN	EW		DD	LC		NT	VU		EN		CR

* Values of the related crop; ** G0–G10: categories for the corresponding criterion values (Int $1000) in 2011 values in 2014 values in 2014

Inv invasive, *Int* introduced, *Nat* native, *GP* gene pool, *TG* taxon group, *LC* least concerned, *NT* near threatened, *VU* vulnerable, *EN* endangered, *CR* critically endangered production and yield for certain food crop for several countries. The economic value of crops in the Fertile Crescent has been taken from the CROP-FAOSTAT unit (http://faostat.fao.org/default.aspx?PageID=567#ancor). As shown in Table 1, points were allocated to CWR according to their production value (in 1000 USD).

The CWR species are ranked from closely related to more remote ones as follows: primary gene pool (GP1), secondary gene pool (GP2), and tertiary gene pool (GP3). The database was accessed to check the gene pools of CWR species that occur in the Fertile Crescent. The International Union for Conservation of Nature (IUCN) (http://www.iucnredlist.org/) has notable information aimed at assessing the risk of extinction to species. The IUCN Red List is designed and managed by the IUCN Global Species Programme and the Species Survival Commission (SSC). It is established upon specific criteria to assist in knowledge of the conservation status of species globally. Selection criteria, groups, and point scale used for the prioritisation are summarised in Table 2.

A simple ranking system (SRS) was used and each CWR was given a score accordingly. Each group is allocated a number of points based on the importance or implication of the level/status of the group. For example, invasive taxa get 0 point and native get points; introduced get 4 points. The number and range of the categories are from G0 to G10 and are determined according to the occurrence status. Ten groups were created and linked to the production value (from G0 to G10). G0 means the CWR has no commercial value at all and G10 has 10 points. The higher the production value of the crop, the more points it scores. Ten groups were established to represent the production value, (Table 2); each category gets a number of points. In this case the larger the production value, the more points the taxa get. Once the points were allocated to all the groups for each criteria, the next step was to apply these methods to each CWR species in the regional checklist and relate the matching points. The final points for a species is the total score of all the criteria listed. Species that got the highest score are the top priority; then the inventory was formed of the first 220 species on the list. The inventory was sent to ICARDA for approval as the ICARDA is one of the leading centers in conserving plant genetic diversity in the region. The species in the inventory were evaluated and confirmed that they represent the most important CWR in the region.

Results

The total number of taxa in the Fertile Crescent is 21,080 taxa and 835 taxa are CWR that are related to

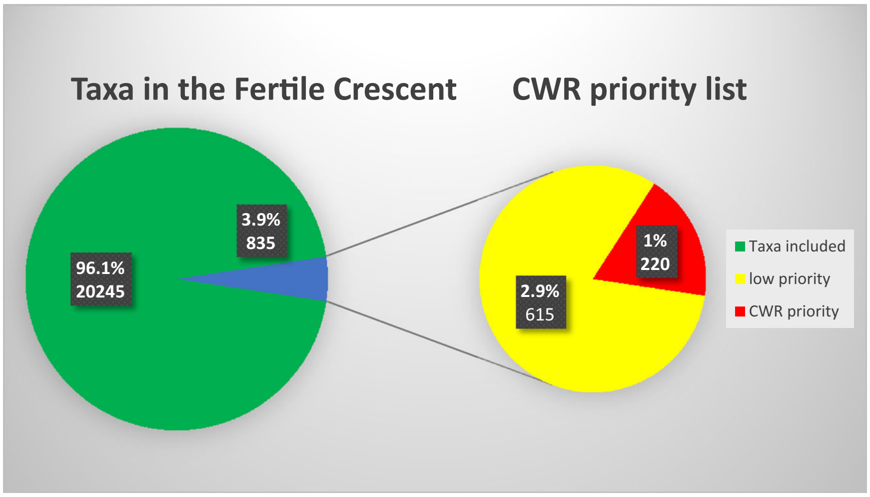

Fig. 2 The organisation of the taxa in the CWR checklist and the CWR inventory

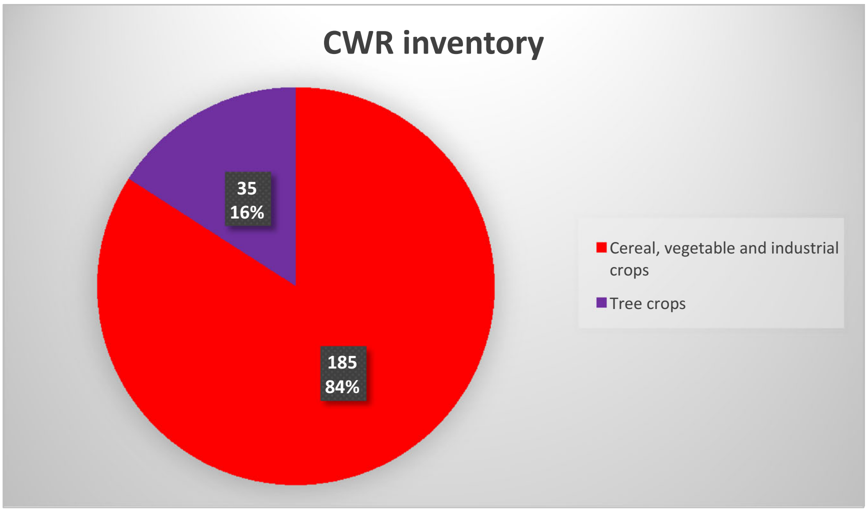

Fig. 3 CWR inventory

crops which have socio-economic value in the region. The 835 taxa of the Fertile Crescent went through prioritisation processes. The first 220 species based on the twelve prioritisation criteria. The remaining 615 are excluded from the list as they are of lower priority. The CWR priority list contains CWR taxa and relates to cereal, vegetable, and industrial crops and 35 taxa are relates to fruits and trees. Figure 2 shows the organisation of the taxa in the CWR checklist and the CWR inventory.

CWR related to cereals, vegetables and industrial crops accounted for 84% of the CWR inventory. CWR related to trees accounted for 16% of the CWR inventory (Fig. 3).

Figure 4 shows the number of taxa per genus included in the priority list.

Figure 5 shows the number of CWR taxa per genus listed in the tree wild relatives' priority list.

Table 3 represents the Number of families, genera, and taxa per general crop use for the CWR included in the inventory.

Discussion

The purpose of this study is to enhance the conservation of CWR in the Fertile Crescent by creating a CWR checklist for the region, setting prioritisation methods, and creating a CWR inventory. They are acceptable results as the number of CWR taxa in the checklist is consistent with the number of taxa in the countries of the Fertile Crescent proposed by by Ghazanfar and McDaniel (2015). The approach used in prioritisation which is species-based approach followed a similar approach as Maxted et al. (1997), Magos Brehm et al. (2010), Khoury et al. (2013) and Fielder et al. (2015), where the focus was on species rather than habitat-based prioritisation. The knowledge generated will enable policy makers to implement effective protocols for conservation and sustainable management of such critical plant genetic resources. CWRs play an essential role in the current and upcoming food security strategies; they are a potential source of diversity for domesticated species. CWRs have contributed to improved cultivation by introducing resistant genes against many insect and plant diseases. In addition, they provide improved tolerance to salinity, drought, and extreme temperatures. There is a broad diversity of crops and their wild relatives throughout the Fertile Crescent. For the above-mentioned reasons, this study aims to analyse the diversity of wild relatives of the most significant crops in the Fertile Crescent as a keystone for implementing a regional conservation strategy for such genetic resources. The study will help generate and apply a CWR conservation strategy for the region. Recommendations for further research is to undertake a gap analysis and to generate and apply a CWR conservation strategy for the region. This will

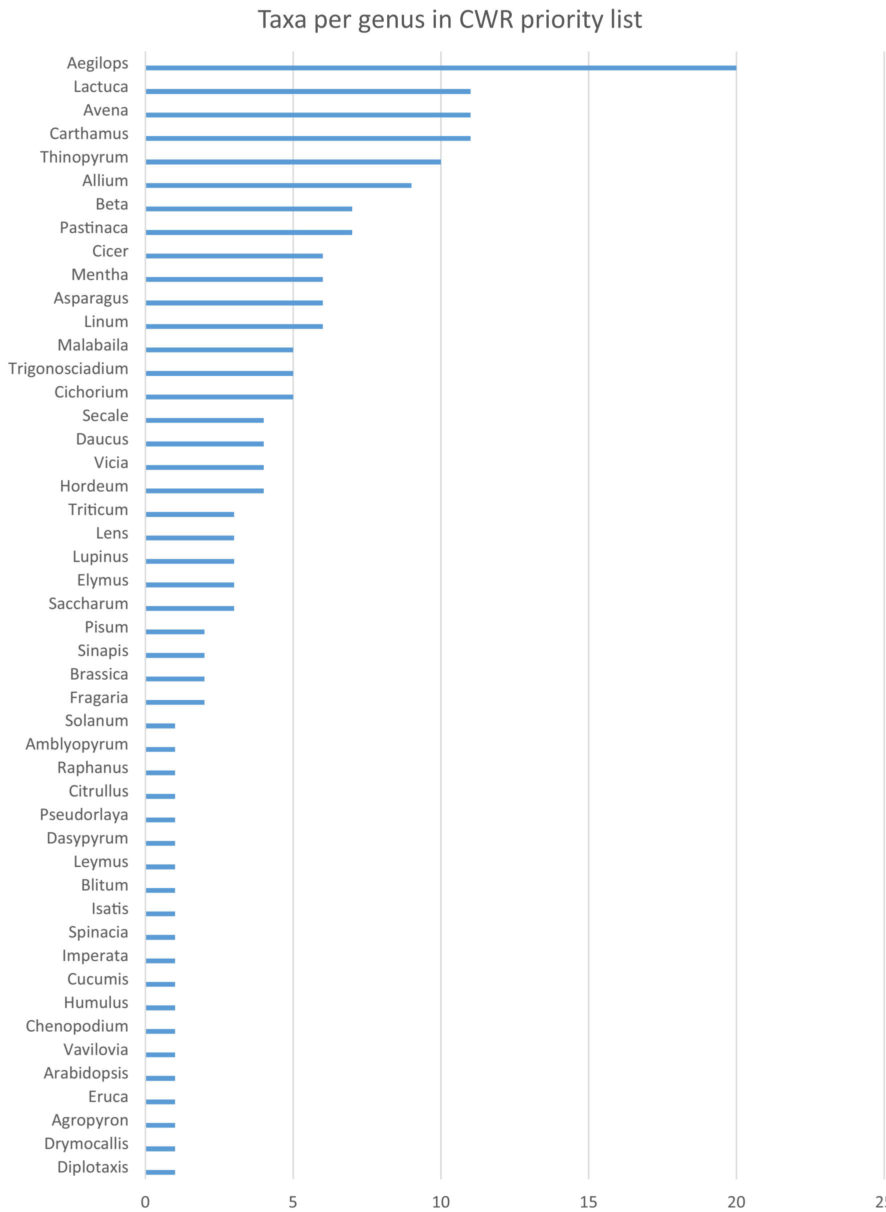

Fig. 4 The number of taxa per genus included in the priority list

help the world stand against climate change and other threats to agriculture biodiversity and food security. The results and conclusions of this study are important as it is the first time somebody has created a CWR checklist, prioritise and create a CWR inventory for the Fertile Crescent. These three elements are the first step toward conservation of genetic resources to help our planet stand against climate change and other threats to agriculture biodiversity and food security.

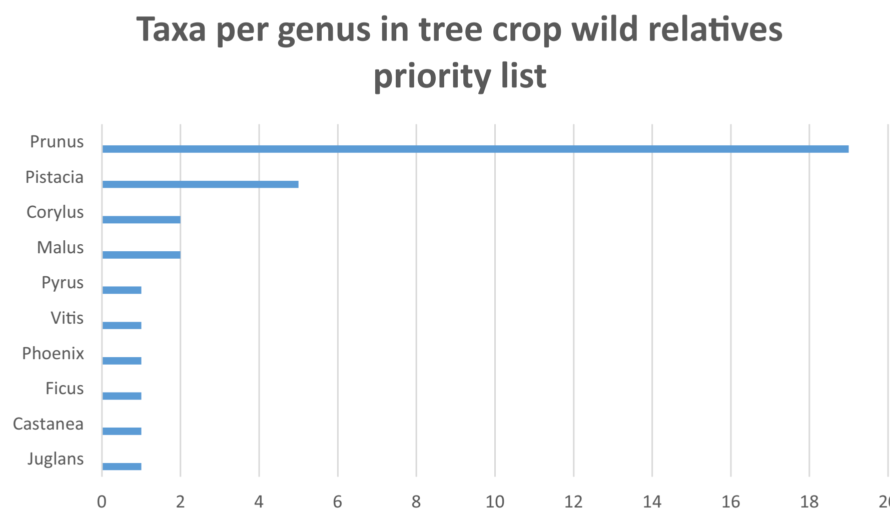

Fig. 5 Number of CWR taxa per genus listed in the tree wild relatives' priority list

Table 3 Number of families, genera, and taxa per general crop use for the CWR included in the inventory

General crop use	Priority list	
	Families	Genera
Cereal	2	6
Forage	1	3
Fruit and nuts	8	18
Industrial	2	3
Legume	1	5
Herb and spice	2	2
Oilseed	2	2
Vegetable	8	15
Total	26	54

Conclusion

We present the first inventory of 220 priority CWR for the Fertile Crescent. The inventory helps to improve the in situ and ex situ conservation and the genetic diversity of CWR. Both the inventory and the methodology applied in prioritisation are applicable and can be used in setting national, regional, and global conservation strategies. The recommendations will help the Fertile Crescent meet its targets in conserving CWR diversity as well as making sure that CWR genetic resources are preserved to prevent and tackle global food insecurity.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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