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Setting conservation priorities for Argentina's pseudocereal crop wild relatives

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ABSTRACT

Although the considerable value of crop wild relatives (CWRs) as gene donors is well known, in many crop complexes they are subject to increasing threats from anthropogenic factors. The development of a prioritized inventory of CWR species is an essential step towards the conservation of this vital resource, so in this study, we developed a national inventory of pseudocereal CWR species in Argentina and established *ex situ* and *in situ* conservation priorities. The resulting prioritized inventory consisted of 16 species, almost all of which were underrepresented in national and global *ex situ* gene banks. Similarly, the extant reserve network was found to be insufficient for the preservation of pseudocereal CWRs, especially *Chenopodium* diversity. Three hotspot groups were identified in the Andean region: northern, central and southern. The northern group has the highest conservation priority because it harbours CWR species from the primary and secondary gene pools, but the central and southern groups are also important because they harbour endemic species that are poorly represented in the extant reserve network. Therefore, new priority areas for protection are necessary for their conservation. This study emphasizes that the conservation of pseudocereal CWRs in Argentina must be maximized using a complementary *in situ* and *ex situ* approach.

1. Introduction

Crop wild relatives (CWR) are plant species that are valued for their relatively close relationship to crops. Although CWR species have been identified as vital to food security and environmental sustainability, many are subject to increasing threats from anthropogenic factors such as urbanization, habitat fragmentation, agricultural intensification, and climate change (Maxted and Kell, 2009). Therefore, there is broad interest in the conservation of this group of plants.

The first step in developing a national management plan for CWR conservation is to create a checklist of the CWRs present in a country and then inventory the priority species (Maxted et al., 2007). After filtering the checklist following the incorporation of ancillary information (such as nomenclature, application of the gene pool or taxon group concepts, ecogeography, uses, threats and conservation status), the resulting final inventory is the starting point for the conservation of these important plant resources (Maxted et al., 2007).

At present, several countries have a prioritized inventory of CWR species for major crops (Kell et al., 2015; Khoury et al., 2013; Vincent et al., 2013), but many important crop complexes and political regions still lack such an inventory. Therefore, it is crucial to foster the development of this information because conservation actions are urgently needed to secure these vital resources, which are necessary to sustain food production in the world (Maxted and Kell, 2009; Redden, 2015).

The Andean region in South America is an important centre of the origin, domestication, and dispersion of high-protein pseudocereal crops (Jimenez et al., 2013), which includes species from the genus *Chenopodium* (hereafter referred to as chenopod), known as quinoa (*C. quinoa* Willd.); the semi-domesticated cañahua (*C. pallidicaule* Aellen); and species from the genus *Amaranthus* (hereafter referred to as amaranth), known as kiwicha (*A. caudatus* L.) and chaclión (*A. mantegazzianus* L.). However, only quinoa has gained attention worldwide, and it is now cultivated beyond the Andean frontiers (Murphy and Matanguihan, 2015). Although some of the other species have been shown to have similar nutritional and functional properties or have distinctly adapted to harsh climatic conditions, all have remained as local crops (Jimenez et al., 2013; Vargas et al., 2011).

The genus *Chenopodium* has been included in the recently prioritized Harlan and de Wet Inventory of CWR species, but most of the included species are from the Northern Hemisphere (Vincent et al., 2013). Many native and endemic species from South America have been poorly studied in terms of their relationships with crop species and thus remain as only potential allele donors (Jellen et al., 2011), whereas none of the species of the genus *Amaranthus* have been included in the above

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prioritized inventory, although they were staple crops of ancestral American cultures. Moreover, amaranths remain important agricultural commodities in several Latin American countries, and their drought tolerance and environmental plasticity are attractive traits that could promote their cultivation in areas that are challenging to traditional crops (Brenner et al., 2000).

As part of the Andean centre of domestication, Argentina contains important plant genetic resources for major and local food crops, but only a few of its CWR germplasms of globally important crops, such as potatoes and common beans, have been collected, characterized and evaluated (Galván et al., 2006; Jansky et al., 2013). In addition to the weak inclusion of CWR species in gene banks, the state of their *in situ* conservation has rarely been assessed (Marfil et al., 2015), so a critical evaluation of the conservation status of Argentinean pseudocereal CWRs is needed. In this group, *A. mantegazzianus* (a cultivated species) stands out because it is considered to be the only crop to have been domesticated in the country (Parodi, 2010). In addition, a species in the primary wild quinoa gene pool, *C. hircinum*, is distributed from the northwest to the south-eastern lowlands of the country (Wilson, 1990), and many wild amaranth species are sympatric with wild chenopods. Since Argentina contains species in the primary and secondary chenopod and amaranth gene pools, we believe that the diversity of pseudocereal CWRs in Argentina may contribute to future breeding programmes.

In this context, we evaluated the diversity of amaranth and chenopod species in Argentina to set conservation priorities. We expected to find a high diversity of pseudocereal CWRs in the northwest of the country, which is part of the Central Andes hotspot (Myers et al., 2000) and the major centre of plant diversity in Argentina (Juárez et al., 2007). As pseudocereals have been largely neglected and underutilized in the economy of this country, we expected to find the pseudocereal CWRs of Argentina to be underrepresented in *ex situ* collections and *in situ* protected areas. Specifically, we address the following questions: (i) What is the taxonomic diversity of the pseudocereal CWRs in Argentina? (ii) What is the degree of relatedness between Argentinean pseudocereal CWR species and cultivated species, and how are they distributed in the country? (iii) What is the current degree of representation of Argentinean pseudocereal CWRs in *ex situ* gene banks and *in situ* protected areas? (iv) Which are the most important established reserves for the conservation of prioritized pseudocereal CWRs? (v) What are the conservation priorities for Argentinean pseudo-cereal CWR?

2. Materials and methods

2.1. Checklist and national inventory of Argentinean pseudocereal CWRs

The Argentinean pseudocereal CWR checklist was developed from the Catálago de Plantas Vasculares del Cono Sur, which contains an updated database of the wild and exotic plant species in Argentina arranged by family and genus (Zuloaga et al., 2008). The checklist was compiled in a standardized format and taxonomically verified following The Plant List (2010).

Next, the national prioritized inventory of the pseudocereal CWRs of Argentina was developed from the checklist by applying the following criteria: 1) the status of each species (whether the taxon is native, endemic or exotic to the country), 2) its relatedness to its respective crop species (after applying the gene pool and taxon group concepts), 3) the *ex situ* and 4) the *in situ* conservation status. We followed these criteria because there were no agricultural statistics available to evaluate the economic value of pseudocereal crop species in Argentina, and none of the pseudocereal CWRs in the country are categorized as threatened by the IUCN. Two species of the genus *Chenopodium* and five of the genus *Amaranthus* are categorized by the IUCN, but they are not found in Argentina.

To apply criterion 1, we obtained information from the Catálago de Plantas Vasculares del Cono Sur (Zuloaga et al., 2008), in which a species is considered native when it is naturally, although not exclusively, distributed in Argentina, while a species is classified as endemic when it is naturally and exclusively distributed in Argentina (political endemism, Cowlling, 2001). According to this criterion, only native and endemic species are considered priorities.

Crop species relatedness (criterion 2) was defined in two ways. First, the gene pool (GP) concept developed by Harlan and de Wet (1971) was applied when information about inter-specific hybridization was available, and in the absence of such information, the taxon group (TG) concept developed by Maxted et al. (2006) was used. As the genus *Chenopodium* is included in the Harlan and de Wet Inventory (available at http://www.cwrdiversity.or), we applied the GP concept to those species from this inventory present in Argentina. For the other *Chenopodium* species, we searched for information about inter-specific hybridization, and when such information was not available, we applied the TG concept following the recent review by Jellen et al. (2011). Conversely, because the genus *Amaranthus* is not included in the Harlan and de Wet Inventory, we applied the GP concept based on the inter-specific hybridization studies reviewed by Brenner et al. (2000) and Trucco and Tranel (2011), and we applied the TG concept based on the taxonomic relationships reported in Mosyakin and Robertson (1996) and Das (2012).The species that were categorized into GP 1b, GP 2, TG 1b, TG 2 or TG 3, *i.e.* those most closely related to existing crop species, were prioritized.

We searched for information about the number of accessions currently maintained by the National Institute of Agricultural Technology (INTA) to evaluate the *ex situ* conservation status (criterion 3) of the species selected according to criteria 1 and 2. This institution has implemented the Germplasm Bank Network (GBN) comprising nine active plant genetic resource banks and eleven collections distributed in different ecological areas across Argentina; the GBN is the only network in the country that contributes to the *ex situ* conservation of crop species and their wild relatives. Additionally, we searched for information in the Royal Botanical Garden at Kew (https://www.kew.org/seedlist/) and the USDA-ARS (https://npgsweb.ars-grin.gov/gringlobal/search.aspx) databases. These institutions maintain collections of wild *Chenopodium* and *Amaranthus* native to the Americas and actively contribute to their *ex situ* conservation (Brenner et al., 2000; Jellen et al., 2011).

The *in situ* conservation status of the species selected according to criteria 1 and 2 was determined by evaluating the degree of representation of those species in the National Protected Areas System of Argentina (NPASA). As no checklist of pseudocereal CWRs in NPASA is available, we obtained this information by overlaying the species distribution maps on a map of the NPASA reserves. We determined the number of reserves in which the priority species are present and the percentage of their geographic distribution that is currently protected.

We used species distribution models (SDMs) to estimate the potential geographical distribution of each priority species; species occurrence records were acquired from the Global Biodiversity Information Facility (GBIF, available at http://www.gbif.org/) and CWR Diversity (available at http://www.cwrdiversity.org/). All geographical coordinates were cross-checked for inconsistencies following the methodology proposed by Scheldeman and van Zonneveld (2010). A total of 381 occurrence data points were used to model the potential distributions of all species.

The potential distribution of each species was obtained using Maxent (the Maximum Entropy Algorithm; (Phillips et al., 2006) with a set of environmental variables and species presence records as inputs. Modelling was performed at a resolution of 30 arc-sec (~1 km × 1 km cell size at the equator) (Hijmans et al., 2005), and the environmental inputs included altitude and 19 bioclimatic variables from the WorldClim database (available athttp://www.worldclim.org). We defined species-specific geographical backgrounds using SDMtoolbox v1.1 software (Brown, 2014), in which the estimated background areas of each species were generated using the buffered local adaptive convex-hull tool; each background area was intermediate between its larger buffered minimum convex polygon and its more restrictive radial distance area from all occurrence points. We modelled the potential distribution of each species using an area delimited to South America and imposed a buffer of 200 km and an alpha parameter value of five (Brown, 2014). To reduce the effect of sampling bias, we reduced the degree of overfitting in the models by spatially filtering the occurrence dataset (Boria et al., 2014). We randomly removed the localities that were within 10 km of one another, keeping the highest number of localities.

Potential distributions were modelled separately for two different groups of species. For species with 25 or more occurrence records, their potential distribution was modelled following the methodology proposed by Radosavljevic and Anderson (2014), whereas for species with fewer than 25 occurrence records, we used the methodology of Shcheglovitova and Anderson (2013). Radosavljevic and Anderson (2014) suggest that overfitting can be reduced using masked geographically structured approach (a kind of variation of k-fold cross-validation). Whereas, Shcheglovitova and Anderson (2013), propose using a delete-one jackknife approach for tuning model settings to enhance the distribution prediction for species with few (*e.g.* < a 25) occurrence records. Both methodologies tune two settings that regulate model complexity (feature class and regularization multiplier). Species with fewer than five presence points were mapped using a circular buffer with a 25-km radius around each point (Moray et al., 2014a).

Receiver operating characteristic (ROC) curves and the areas under each curve (AUC) were used to evaluate the accuracy of the Maxent models of the distributions of the target taxa (Phillips et al., 2006). We also calculated the difference between the area under ROC curve of the evaluation data (AUCe) and the calibration data (AUCc) (Radosavljevic and Anderson, 2014). In addition, we calculated the omission rate (OR) using the 10th percentile presence threshold. For species with 25 or more occurrence records, the best models were chosen according to i) a reduced omission rate, ii) the minimum value of the difference between AUCc and AUCe, and iii) the maximum AUCe value (Shcheglovitova and Anderson, 2013). For species with fewer than 25 presence points, the best models were chosen according to i) a low omission rate (calculated based on the minimum training presence) and ii) the maximum AUCe value (Radosavljevic and Anderson, 2014).

2.2. Diversity patterns of Argentinean pseudocereal CWRs

Based on the quality of the available information, we performed two analyses to describe the species richness patterns of the prioritized pseudocereal CWRs in Argentina. First, we described the diversity patterns in political units (*i.e.*, provinces) by building a species presence–absence matrix for each Argentinean province. We followed this approach because each Argentinean province has sovereignty over its own natural resources (articles 41 and 124; National Constitution 1994). In this context, the first step in developing a national management plan for pseudocereal CWRs conservation should identify the provinces with the highest relative value.

In the second analysis, we used distribution maps, obtained with Maxent, to describe the fine-grained species richness patterns by dividing the country into 52,811 53.11-km^2 cells. The cells were hexagonal to minimize edge effects (Nhancale and Smith, 2011). We determined species richness for each cell and then used this information to identify pseudocereal CWR diversity hotspots, which were defined as the 2.5% of cells with the highest species richness (Orme et al., 2005).

2.3. Effectiveness of extant protected areas and identification of new priority areas

We analysed the representativeness of each priority species in NPASA and set the following targets *a priori*: 1) the species should be represented at least once (hereafter referred to as Target 1); 2) the species should be represented at least twice (Target 2); and 3) 10% of the range of each species should be represented (Target 3); we then determined the level of fulfilment for each species. Once we identified the protected species according to Targets 1 and 2, we evaluated which extant protected areas were the most important for the preservation of those species; this will inform future *in situ* conservation actions for the protected species. Using MARXAN reserve design software (Game and Grantham, 2008), we identified these protected areas and selected new priority areas (*i.e.*, cells) that were complementary to NPASA to fulfil the defined targets for all species.

3. Results

3.1. Checklist and national prioritized inventory of Argentinean pseudocereal CWRs

The checklist of Argentinean pseudocereal CWRs included 42 species and four subspecies. The genus *Amaranthus* was represented by 24 species and two subspecies and *Chenopodium* by 18 species and two subspecies, and there were four endemic species of *Amaranthus* and five of *Chenopodium*. At present, eight non-native species of *Amaranthus* and five of *Chenopodium* have been registered.

In *Amaranthus*, eight species (33.33%) showed a close relationship with amaranth crops, and four of them were native or endemic species. The endemic species *A. powelli* and the non-native species *A. hybridus* and *A. retroflexus* belong to the primary gene pool (this includes cultivated species and wild populations with no major reproductive barriers). All species of the genus *Chenopodium* in Argentina were closely related to chenopod crops (Table 1), and two species, *C. hircinum* and *C. quinoa* var. *melanospermun*, belong to the primary gene pool. According to criteria 1 and 2, the national prioritized inventory includes 16 species and two subspecies of pseudocereal CWRs (Table 1), of which 18.75% (3 species) belong to the genus *Amaranthus*, and the remaining 81.25% (13 species) belong to *Chenopodium* (Table 1).

Only *C. quinoa* var. *melanospermun* was represented in the INTA gene bank. In USDA gene bank, only one Argentinean pseudocereal CWR (*Amaranthus asplundii*) was included, whereas four species (*A. powellii*, *A. spinosus*, *C. frigidum* and *C. petiolare*) were maintained in the Royal Botanical Garden gene bank (Table 2). No Argentinean pseudocereal CWRs accessions were found in the international gene bank collections.

All amaranth species were represented in NPASA with *A. asplundii* and *A. powelli* having the highest level of representation, and the greatest percentage of the geographic distribution of these species was also protected in NPASA, although it did not exceed 6%. In *Chenopodium*, six species were not protected by NPASA. *Chenopodium hircinum* and *C. scabricaule* presented high levels of representativeness in NPASA, and *C. frigidum* and *C. ruiz-lealii* showed a protected geographic distribution percentage of more than 10% (Table 2).

3.2. Diversity patterns

The pseudocereal CWR species were distributed in 22 of the 23 provinces of Argentina, with an average of 3.39 ± 1.99 species per province. The provinces of Mendoza (8 species), San Juan (7), Jujuy (6) and Salta (6) registered the highest prioritized pseudocereal CWR species richness.

Mean species richness per cell was 1.81 ± 1.08 with a maximum of 6 and a minimum of zero species (Fig. 1a), and it was 1.81 ± 1.07 with a maximum of 6 and a minimum of 1 species when the cells with at least one species were analysed. The species richness hotspots were grouped into the northern, central and southern zones of the Andean region of Argentina (Fig. 1b). Two of these groups (the northern and central) were in the Central Andean Puna, Central Andean Dry Puna, Southern Andean Steppe, Southern Andean Yungas, High Monte and Dray Chaco

Table 1
Checklist of Argentinean pseudocereal wild relatives. The status of each species (native, endemic and non-native species) and the relatedness degree with pseudocereal crops (RDPC; gene pool or taxon group criterion) are indicated. GP: gene pool, TG: Taxon group. The numbers (from 1 to 4) indicate the relatedness degree.

Genus	Species	Species authority	Status	RDPC
Amaranthus	*albus*	L.	Non-native	TG 4
	asplundii var.*asplundii*	Thell.	Native	TG 2
	asplundii var. *australis*	Hunz.	Endemic	TG 2
	blitoides	S. Watson	Non-native	TG 4
	blitum	L.	Native	TG 4
	cardenasianus	Hunz.	Native	TG 4
	celosioides	Kunth	Non-native	TG 2
	crispus	(Lesp. & Thévenau) A. Terracc.	Native	TG 4
	deflexus	L.	Non-native	TG 3
	dubius	Mart. ex Thell.	Non-native	TG 3
	hybridus subsp. *Hybridus*	L.	Non-native	GP 1b
	hybridus subsp. *Cruentus*	L. Thell.	Non-native	GP 1b
	hunzikeri	N. Bayón	Endemic	TG 4
	kloosianus	Hunz.	Endemic	TG 4
	muricatus	(Gillies ex Moq.) Hieron.	Native	TG 4
	persimilis	Hunz.	Non-native	TG 4
	palmeri	S. Watson	Endemic	TG 4
	pedersenianus	N. Bayón & C. Peláez	Endemic	TG 4
	peruvianus	(Schauer) Standl.	Native	TG 4
	powellii	S. Watson	Native	GP 1b
	retroflexus	L.	Non-native	GP 1b
	rosengurtii	Hunz.	Native	TG 4
	spinosus	L.	Native	TG 3
	standleyanus	Parodi ex Covas	Native	TG 4
	viridis	L.	Native	TG 4
	vulgatissimus	Speg.	Native	TG 4
Chenopodium	*album*	L.	Non-native	TG 2
	antarcticum	(Hook.f.) Hook.f.	Native	TG 3
	carnosulum	Moq.	Non-native	TG 2
	cordobense	Aellen	Endemic	TG 2
	dessicatum	A.Nelson	Non-native	TG 2
	frigidum	Phil.	Native	TG 3
	giganteum	D.Don	Non-native	TG 2
	hircinum subsp. *catamarcensis*	Aellen	Native	GP 1b
	hircinum subsp. *hircinum*	Schrad.	Native	GP 1b
	obscurum	Aellen	Endemic	TG 3
	papulosum	Moq.	Native	TG 2
	parodii	Aellen	Endemic	TG 3
	petiolare	Kunth	Native	TG 2
	philippianum	Aellen	Native	GP 2
	pilcomayense	Aellen	Native	TG 2
	quinoa var. *melanospermun*	Hunz.	Native	GP 1b
	ruiz-lealii	Aellen	Endemic	TG 3
	scabricaule	Speg.	Endemic	TG 3
	vulvaria	L.	Non-native	TG 2

ecoregions, whereas the southern group was in the Patagonian Steppe, Magellanic Subpolar Forest, Valdivian Temperate Forest and Rock and Ice ecoregions.

3.3. Effectiveness of extant protected areas and priority areas

Under Target 1, NPASA conserved 62.5% of the prioritized pseudocereal CWR species: three amaranths and seven chenopods. The level of representativeness according to Target 2 was similar to that obtained for target 1, but only *C. frigidum* and *C. ruiz-lealii* met Target 3. All NPASA protected areas preserved at least one chenopod species, while only 69.23% of these areas protected at least one amaranth species. The highest species richness (six species) was registered in El Leoncito National Park followed by Perito Moreno, Los Glaciares, Patagonia, San Guillermo, Los Cardones y Campo de los Alisos National Parks, and the MARXAN analysis showed that El Leoncito and Los Cardones National Parks and Formosa Natural Reserve were the most important extant protected areas needed to preserve 100% of the protected species according to Target 1. El Leoncito and Río Picomayo National Parks, Laguna de los Pozuelos Natural Monument, and Formosa Natural Reserve were the most important extant protected areas for meeting Target 2.

Table 2
Ex situ and *in situ* conservation status of the Argentinean prioritized pseudocereal wild relatives. For *in situ* conservation status, the number of reserves in which the species occur, and the percentage of geographic range (GR) covered in NPASA (National Protected Areas System of Argentina) are showed. For *ex situ* conservation status, the number of accessions in INTA (Instituto Nacional de Tecnología Agropecuaria), USDA (United States Department of Agriculture Agricultural Research Service) and KBG (Kew Botanical Garden) is indicated.

Genus	Species	Reserves	% of GR	INTA	USDA	KBG
Amaranthus	*asplundii*	20	5.58	0	4	0
	powellii	23	3.51	0	0	4
	spinosus	4	0.89	0	0	10
Chenopodium	*antarcticum*	0	–	0	0	0
	cordobense	0	–	0	0	0
	frigidum	3	10.82	0	0	1
	hircinum	37	0.81	0	0	0
	obscurum	0	–	0	0	0
	papulosum	0	–	0	0	0
	parodii	0	–	0	0	0
	petiolare	9	3.68	0	0	1
	philippianum	0	–	0	0	0
	pilcomayense	2	2.26	0	0	0
	quinoa var. *melanospermun*	2	2.28	9	0	0
	ruiz-lealii	1	15.01	0	0	0
	scabricaule	15	4.68	0	0	0

Only six cells were needed to maximize the protection of pseudocereal CWR diversity under Target 1 (Fig. 2A), and the number of new priority areas increased by approximately two-fold (13 cells) for Target 2 (Fig. 2B). For Target 3, a total of 4564 cells were needed to maximize the protection of Argentinean pseudocereal diversity (Fig. 2C). The new priority areas for Targets 1 and 2 were in the provinces of Córdoba, La Pampa, Mendoza, Neuquén, Chubut, and Santa Cruz, whereas the new priority areas for Target 3 were distributed throughout Argentina, except for the province of Tierra del Fuego.

4. Discussion

Based on our results, the prioritized inventory of Argentinean pseudocereal CWRs contains 16 species, which account for 7.3% of the global taxonomic diversity of pseudocereals (220 species from both genera, Fuentes-Bazan et al., 2012; Mosyakin and Robertson, 1996). Most of this taxonomic diversity was principally constituted by species belonging to the primary and secondary gene pools; these groups have a higher priority because of their close relatedness with crop species and the relative feasibility of transferring their useful traits into crop species (Maxted et al., 2006). This finding supports our idea that the pseudocereal CWR diversity in Argentina could potentially contribute to future crop breeding programmes. In this sense, two species native to Argentina have been or are currently being used in breeding programmes. Brenner et al. (2000) reported a successful crossing between the wild non-dehiscent species *Amaranthus powellii* and *A. cruentus* and *A. hypochondriacus* breeding lines in an effort to reduce grain shattering, and populations of *Chenopodium hircinum* from the hottest environments in Argentina are currently being crossed with quinoa to transfer heat stress tolerance at flowering (E.R. Jellen, pers. comm.). In this sense, Argentinean pseudocereal wild relative populations of different ecogeographic regions will be a source of useful traits for breeding programmes, so future studies should focus on a more systematic evaluation of populations from these gene pools. Even though

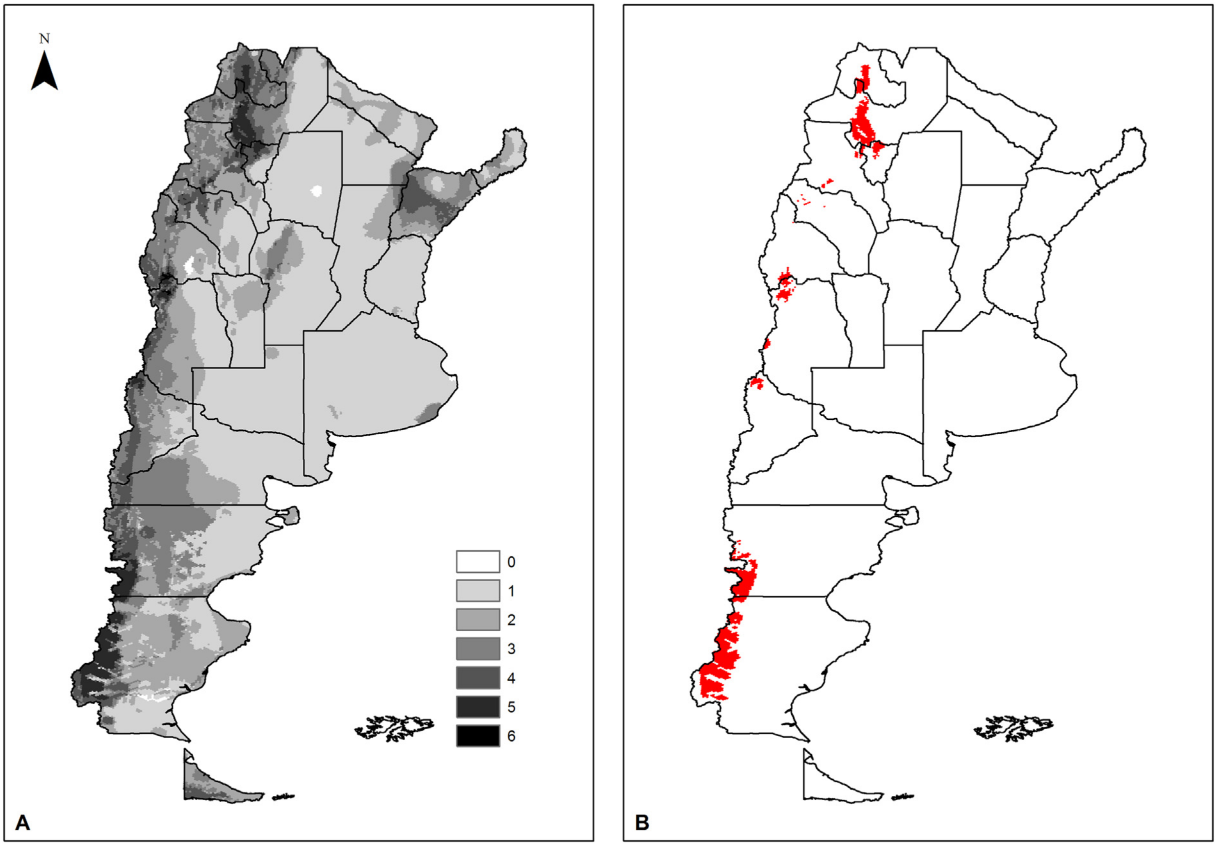

Fig. 1. Species richness of the 16 wild Argentinian pseudocereal relatives in each cell (at a grid-cell resolution of 30 arc-sec) dividing the country.

we did not include a non-native species in our prioritized national inventory of pseudocereal CWRs, future studies should evaluate species in this group since they could be used in breeding programmes, especially for *Amaranthus* crops. For example, *A. hybridus* and *A. retroflexus*, which belong to the primary gene pool, were registered in Argentina. The incorporation of non-native species into conservation programmes will require special consideration since they behave as weeds in crop fields and are invasive in disturbed natural environments (Jarvis et al., 2015).

The results of this study showed that a low to null percentage of Argentina's pseudocereal CWR species is currently conserved in the country's Germplasm Bank Network (INTA GBN), which is consistent with our hypothesis as pseudocereal crops have only recently received attention. However, this has negatively impacted current *ex situ* conservation efforts. Moreover, information collected from other international gene banks revealed poor representation of the pseudocereal CWR species of Argentina, *i.e.*, there were no accessions from Argentinean populations. Our results suggest that these species are of high priority for future collecting efforts due to the severe gaps in their *ex situ* collections. Recently, Castañeda-Álvarez et al. (2016) indicated that the collection of quinoa should be intensified at a global scale, supporting our results. Furthermore, future studies should evaluate how collections of Argentinean pseudocereal CWRs must be planned, applying methodologies that have been used to plan the germplasm collections for other CWRs (Castañeda-Álvarez et al., 2015; Parra-Quijano et al., 2012; Ramírez-Villegas et al., 2010). We believe that *ex situ* conservation actions should be coordinated by INTA, which is the only national public institution devoted to safeguarding the germplasm of plant genetic resources for food and agriculture in Argentina.

Amaranthus species showed the highest levels of representativeness in NPASA, while *Chenopodium* species exhibited highly variable levels. These results are consistent with those of other evaluations of different groups of organisms in different regions of the world (González-Maya et al., 2015, Rodrigues et al., 2004; Vellak et al., 2009, 2010). According to our analysis, *Chenopodium* species have been the pseudocereal CWRs most affected by the lack of conservation planning in Argentina, and future studies should demonstrate whether our conclusions apply to other native Argentinean CWRs.

Our results showed that major coordination between *ex situ* and *in situ* conservation is necessary (Maxted and Kell, 2009). For example, the three species belonging to the primary gene pool (*A. powelli*, *C. hircinum* and *C. quinoa* var. *melanospermun*) exhibited strong differences in their levels of protection; when they were relatively well represented in NPASA, they had low or no representation in the gene banks or *vice versa*.

The diversity in political centres (*i.e.*, provinces) coincided with the identified cell-based hotspots. The northern and central hotspot groups were located in the most diverse provinces (Mendoza, San Juan, Jujuy and Salta), and the former is included in one of the most important hotspots in South America (Tropical Andes; Myers et al., 2000). In addition, the northwest region of Argentina has been considered to be the centre of Argentinean plant diversity, so it is an extremely important candidate for conservation (Godoy-Bürki et al., 2014; Juárez et al., 2007; Ortega-Baes et al., 2015). Additionally, previous studies have indicated that this region is a main centre of CWR diversity (*e.g.*, potato wild relatives; Hijmans and Spooner, 2001). Therefore, the northern hotspot should be considered one of the most important conservation priorities for pseudocereal CWRs because it harbours wild relative species belonging to the primary and secondary gene pools, namely, potentially useful species for breeding programmes. Although the central and southern hotspot groups were principally composed of wild relative species belonging to TG 3, most were endemic to these zones and poorly represented in NPASA. Consequently, future conservation actions should be established for these species.

Our results showed that NPASA was ineffective at protecting pseudocereal CWR diversity, so extra efforts must be made to maximize

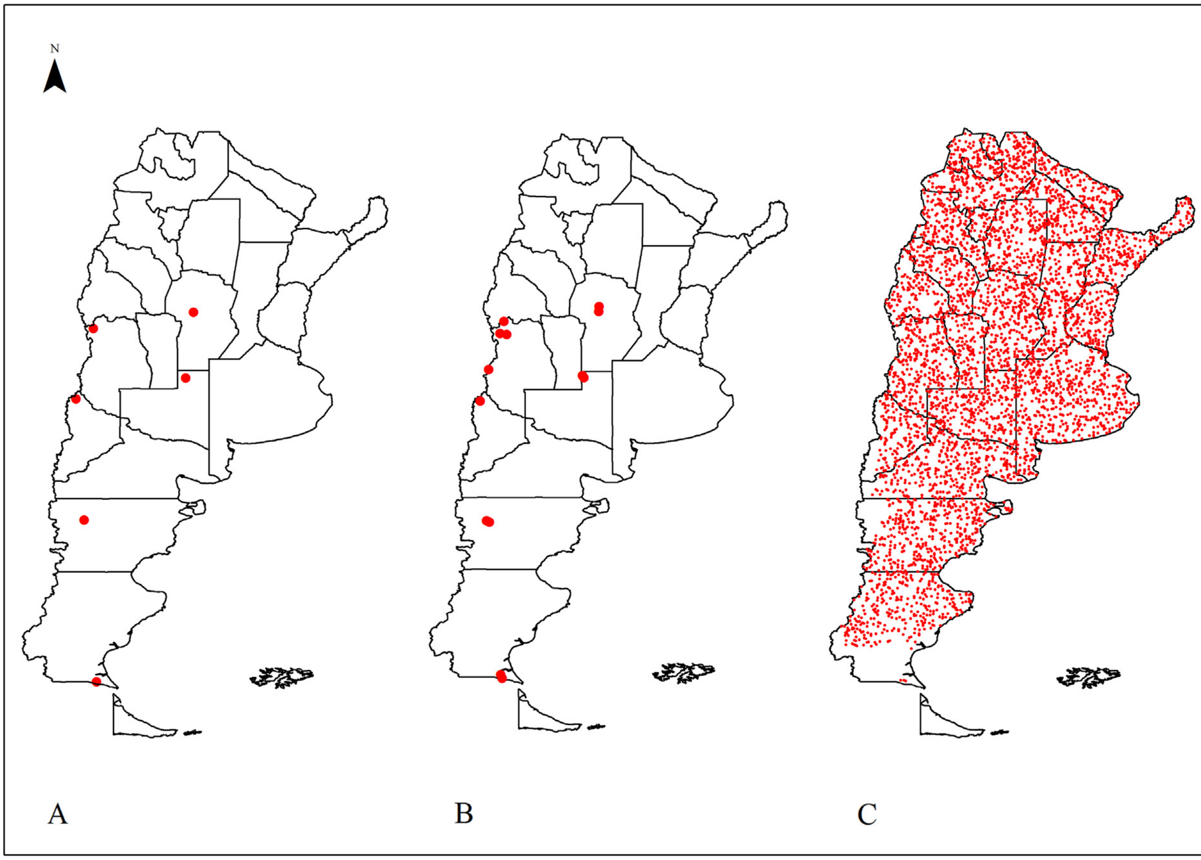

Fig. 2. Priority areas for pseudocereal CWR conservation in Argentina by different targets. A) The species should be represented at least once (Target 1); B) the species should be represented at least twice (Target 2); C) 10% of the range of each species should be represented (Target 3).

the *in situ* conservation of Argentinean pseudocereal CWRs. Since we used distribution maps to determine if the prioritized species were protected, future studies should verify the presence-absence of these species through field surveys. According to our results, a limited number of extant reserves included all of the currently potentially protected diversity for target 1: El Leoncito and Los Cardones National Parks and Formosa Natural Reserve. In these protected areas, conservation actions could be directed towards population management if the presence of priority species is confirmed. These actions should include demographic studies, germplasm collection for *ex situ* conservation, genetic diversity studies, and evaluations of current and future potential threats (*e.g.*, agricultural activities and climate change) in the reserves and in their adjacent areas (Maxted and Kell, 2009). These actions could be coordinated by the Administración de Parques Nacionales, a national public institution that administers and regulates all activities (including scientific ones) performed in NPASA.

To maximize the level of protection of Argentinean pseudocereal CWRs, five new areas (*i.e.*, cells) were needed to fulfil Target 1. As expected, higher targets required a greater number of priority areas, and the number of new areas increased proportionally to the number of species and the increase in the representation of their geographic distributions. Conservation actions in the new areas would mainly benefit non-protected *Chenopodium* species (*C. antarticum*, *C. cordobense*, *C. obscurum*, *C. parodii*, and *C. philippianum*), so further studies should evaluate whether the new priority areas selected to protect pseudocereal CWR diversity also significantly contribute to the conservation of other wild relatives of important crops, such as potatoes, common bean, squash, and chilli peppers. This consideration is relevant because CWR species are a focal group for conservation due to their importance for food security (Maxted et al., 2007; Moray et al., 2014).

5. Conclusions

Overall, our results support the establishment of conservation priorities for this economically important group of plants using a complementary *ex situ* and *in situ* approach. Efforts to collect additional accessions from the priority CWRs of the primary and secondary gene pools would improve the severe gaps in the current gene bank collection of Argentina. In addition, the monitoring and management of Argentinean pseudocereal CWRs in extant protected areas, primarily those identified in the present study would improve their *in situ* protection. However, additional priority areas must be included to maximize the protection of species that are poorly represented in the National Protected Areas System of Argentina.

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