REVIEW

Plant genetic resources for food and agriculture in Chile: Progress in conservation, characterization and uses

Pedro León-Lobos[1*], Erika Salazar[1], Rodrigo Díaz[2], Patricio Hinrichsen[1], Carlos Muñoz[3], and Fernando Ortega[4]

[1]Instituto de Investigaciones Agropecuarias, INIA La Platina, Av. Santa Rosa 11.610, Santiago, Chile.
[*]Corresponding author (pleon@inia.cl).
[2]Instituto de Investigaciones Agropecuarias, INIA Quilamapu, Av. Vicente Méndez 515, Chillán, Chile.
[3]Universidad de Chile, Facultad de Ciencias Agronómicas, Av. Santa Rosa 11.315, Santiago, Chile.
[4]Instituto de Investigaciones Agropecuarias, INIA Carillanca, km 10, Camino Cajón-Vilcún, Temuco, Chile.

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ABSTRACT

Chile is part of one of the centers of crop origin identified by Vavilov, e.g., for strawberries and potatoes. It is also a center of diversification of other crop species such as maize, beans and quinoa. It is one of the biodiversity hotspots of the world and several native species have potential for domestication. All of these types of species are considered Plant Genetic Resources for Food and Agriculture (PGRFA). However, the rich plant genetic diversity present in Chile is being lost, mostly due to human activity. Therefore, *ex situ* and *in situ* conservation of this diversity are of critical importance. In this review we show the achievements in PGRFA conservation activities in the last 15 yr and in plant breeding for the last 60 yr in this country. Several gene banks exist, administrated by different institutions, with over 48 000 accessions preserved, mostly cereals (65%) and grain legumes (23%). Significant advances were achieved between 2006 and 2020 in the conservation, regeneration, characterization and documentation of PGRFA, but work is still needed to complete a fully operable data base for all collections. Over 16 000 accessions of Chilean origin are also kept in gene banks abroad. Plant breeding programs of several agriculturally important crops have made an outstanding contribution to Chilean agriculture and food security, with more than 375 commercial cultivars developed. More effort needs to be made to strengthen *ex situ* conservation and the sustainable use of PGRFA under coordinated actions, guided by a national strategy on genetic resources, if significant contributions are to be made in response to climate change.

Key words: Landraces, phytogenetic resources, plant germplasm.

INTRODUCTION

Plant genetic resources for food and agriculture (PGRFA) represent the largest proportion of the biological diversity on which humankind has relied for its existence (Pilling et al., 2020). They include commercial and obsolete cultivars, genetic stocks, breeding lines, landraces and their crop wild relatives. Crop wild relatives (CWR) are wild plant species that are genetically related to cultivated crops (Maxted et al., 2006), while landraces are variable, identifiable populations, lacking ‘formal’ crop improvement, characterized by specific adaptation to the environmental conditions of the area of cultivation and by a close association with traditional uses, knowledge, habits, dialects and celebrations of the people who developed and continue to grow them (Negri et al., 2008). Landraces and CWR are a critical source of genes that allow crops to adapt to the ever-changing environmental conditions to overcome the constraints caused by pests, diseases and abiotic stresses. Together with breeding material, they are essential for sustainable agricultural production and food security in a scenario of climate change (Ceccarelli, 2012).

However, many PGRFA are endangered or already extinct in their natural habitats or where they were cultivated. Genetic erosion has dangerously reduced crop gene pools and increased crop vulnerability to climate change or the advent of new pests and diseases (Leroy et al., 2018). The decrease in land availability due to soil salinization, increase in land waterlogging, intensive livestock production and the increasing growth of invasive species, among other factors, are the main threats to wild genetic resources (Esquinas-Alcázar, 2005).

The PGRFA can be preserved *in situ* in the wild and on farms, and *ex situ* in germplasm banks (Engelmann and Engels, 2002). *Ex situ* conservation is an effective system for maintaining and safeguarding both crops and their wild relatives (Engelmann and Engels, 2002). The development of new cultivars depends to a large extent on breeders and farmers having access to genetic diversity with perspectives for greater and more reliable yields, resistance to pests and diseases, tolerance to abiotic stresses and for producing new and better-quality products (FAO, 2010). Because pests and diseases evolve over time, breeders continually need new and diverse germplasm from outside the utilized gene pool to find specific tolerance or resistance genes to maintain or improve crop yields (Duvick, 1986). In a world of changing climate, expanding human population, shifting pests and diseases, ever-increasing resource scarcity and financial and social turmoil, the sustainable use of plant genetic resources has never been more important to sustain an agriculture to feed the world under an unpredictable and changeable climate (FAO, 2010; 2015a).

Chile is considered an important region for some plant genetic resources. It is a sub-center of origin of various important crops (Vavilov et al., 1992) such as strawberries (*Fragaria chiloensis* (L.) Mill.) and potatoes (*Solanum tuberosum* L. subsp. *tuberosum*). It is a secondary center of diversity for other crops like quinoa (*Chenopodium quinoa* Willd.), maize (*Zea mays* L.), and beans (*Phaseolus vulgaris* L.) An important part of the Chilean flora has potential to become the source of new crops, genes or bioproducts (Díaz-Forestier et al., 2019). The north-central and southern areas of Chile are considered as one of the world hotspots for biodiversity conservation priorities (Myers et al., 2000) due to the high level of endemism (46%; Rodríguez et al., 2018), which means that some plant genetic resources are unique to Chile and therefore strategically important.

In the late 20th and early 21th century, Chile made the first important effort to preserve and use its PGRFA, through building germplasm banks (Suzuki, 1994), improving existing breeding programs and creating new ones (Seguel et al., 2008; Muñoz, 2010).

In the present article we reviewed and analyzed *ex situ* conservation of PGRFA in Chile, focusing on available facilities, species under conservation, characterization efforts and the use that is being made of the conserved germplasm. In this review we refer only to PGRFA, which consist of the diversity of seeds and planting materials of traditional varieties and modern cultivars, crop wild relatives and other wild plant species that are used as food and feed for domestic animals. We have excluded PGR used in forestry and as ornamentals. We also analyze the current constraints for improving both the conservation and sustainable use of PGRFA in Chile, and analyze how Chile is complying with the international treaties regulating this matter.

CHILEAN CONSERVATION FACILITIES

Modern activities with PGRFA started in Chile in the early 1960s, when the Instituto de Investigaciones Agropecuarias of Chile (INIA) was founded and put in charge of various plant breeding programs, previously developed by the Ministry of Agriculture, with the objective of producing new cultivars with better yields and well adapted to local conditions. As it is well known, plant breeders collect, exchange and use PGRFA in the breeding process of the species of interest, but access to genetic material was quite limited. Also, the country did not have either the facilities or the knowledge to preserve PGRFA systematically and safely for breeding work. Consequently, national and representative collections of PGRFA did not exist.

A national survey conducted in 2004-2005 reported a total of 89 units with some kind of facility for PGR conservation in Chile which were administrated by 19 different institutions, mainly universities and research institutes, operating mainly working seed banks, field or greenhouse collections and *in vitro* conservation facilities (Salazar et al., 2006). A second survey conducted in 2015 in Chile, to follow-up the implementation of the Second Global Plan of Action for Plant Genetic Resources for Food and Agriculture (FAO, 2012), found 28 units with some facilities for *ex situ* germplasm conservation, under the administration of only four Chilean institutions (Table 1).

Table 1. Plant germplasm banks in Chile and their characteristics, according to a survey conducted in 2015 in response to the implementation of the Second World Action Plan of Plant Genetic Resources for Food and Agriculture, FAO.

Institution	Conservation capacities	Characteristics
Instituto de Investigaciones Agropecuarias (INIA)	1 Base seed bank 3 Active seed banks 20 Short-term seed chambers 1 In vitro active bank 2 Field gene banks	-18 ºC, 15% eq. RH, hermetic storage; dry chamber. -5 ºC, 40%-45% eq. RH; dry chamber 10 ºC, 40%-45% eq. RH; dry chamber
Universidad Austral de Chile (UACH)	1 Base seed bank 1 Active seed bank 1 Short-term seed chamber 1 Field gene bank	-18 ºC, hermetic storage
Servicio Agrícola y Ganadero (SAG)	1 Base seed bank	-18 ºC, hermetic storage
Centro de Estudios Avanzados en Fruticultura (CEAF)	Field gene bank	

Source: León-Lobos et al. (2018).

At present, only three base seed banks are recognized for long-term conservation. One is administrated by INIA, located in Elqui Valley (30º02'12.4" S; 70°41'30.6" W), with capacity for safe preservation of over 70 000 accessions (León-Lobos et al., 2018) in standard conditions for long-term conservation (FAO, 2014). The second base bank is located at the Universidad Austral in Valdivia, focusing mainly on potato, vegetables and wild species (Salazar et al., 2006). The third is a seed bank established by the Agriculture and Livestock Service (Servicio Agrícola y Ganadero, SAG) in Punta Arenas, Magallanes y Antártica Chilena Region. Only the banks of INIA have a public inventory and access system to plant genetic material that follows an institutional policy. Chilean regulations for access to genetic resources and the system of INIA were reviewed by Püschel (2019).

There are also six active seed banks for medium-term conservation. Five of them are administrated by INIA to preserve PGRFA with international standards (FAO, 2014); the other is at the Universidad Austral. In 2015, an in vitro and field potato germplasm bank was established by INIA in Osorno (40º31'12.4" S; 73°04'00" W). According to the 2015 survey there are other three field collections, one is the potato collection maintained by the Austral University and the others are the grape, *Prunus* spp. and olive collections at INIA and the Centro de Estudios Avanzados en Fruticultura (Table 1). Some private companies and universities have germplasm collections, particularly for fruit crops (Salazar et al., 2006) but were not reported in the 2015 survey. Due to their strategic relevance, they need to be highlighted and included in the formal PGR conservation system.

MAIN PGRFA CONSERVED IN CHILE

The first inventory of PGRFA conserved in Chile was reported by Salazar et al. (2006), with 67 313 accessions; 55 536 (82.5%) of them were considered PGRFA for comparative purposes in that review. Consequently, aromatic, forestry, medicinal, industrial and native seed accessions were removed from the total accession list of Salazar et al. (2006). In a later inventory (2015), 48 017 accessions of PGRFA were reported (Table 2). This reduction from the 2006 inventory is mainly a consequence of ordering the collections (elimination of duplicates and non-relevant genetic resources), initially administrated by plant breeders; also, several institutions that reported in 2006 did not report in 2015. According to updated inventory, cereals (mainly wheat) represent the most important crop collection, with 31 397 accessions representing 65.4% of all accessions conserved in *ex situ* facilities in Chile, followed by grain legumes (beans, peas, chickpeas and lentils) with 23.2%. The other crop groups have comparatively low representation in germplasm collections (Table 2).

Considering that the INIA collection represents 98% of the total Chilean PGRFA and annually conducts an inventory of its collection, it is a good source of data to analyze progress on PGRFA management in the last 15 yr in Chile. In this period a PGRFA collection at INIA was reduced by nearly 17% (8 849 accessions) because redundancy and non-viable accessions were discarded, mainly of the wheat, vegetable and forage collections (Table 3). Over 67% of the total resulting collection are unique accessions; many of them (≈ 50%) are duplicated in the base bank of INIA as backup. This is an important achievement because in 2006 only 10% of the unique accession were also backed up as base collections. The total new PGRFA accessions held as base collection increased from 3 199 to 14 843 entries (Table 3).

Table 2. Plant genetic resources for food and agriculture conserved in gene banks in Chile. Instituto de Investigaciones Agropecuarias (INIA), Centro de Estudios Avanzados en Fruticultura (CEAF), Servicio Agrícola y Ganadero (SAG), and Universidad Austral de Chile (UACH).

	Salazar et al. (2006)		León-Lobos et al. (2018)	
Collections	Total accessions	%	Total accessions	%
Cereals	33 794	60.9	31 397	65.4
Fruits	836	1.5	1 093	2.3
Vegetables	5 093	9.2	1 151	2.4
Legumes	9 610	17.3	11 149	23.2
Oil seeds	251	0.5	150	0.3
Tubers	1 687	3.0	1 377	2.9
Pseudocereals	313	0.6	575	1.2
Forage	3 952	7.1	1 125	2.3
Total	55 536		48 017	

Table 3. Numbers and percentages of accessions in the germplasm conservation systems of INIA reported by Salazar et al. (2006) and INIA inventory in December 2020 preserved as active and base collections (INIA, 2021). Crop Wild Relatives, wild food plants and native forage plants included. Other native were excluded.

	Total accessions in		Total not duplicated in		Active collections in		Base collections in		New accessions in base bank at
Crops	2006	2020	2006	2020	2006	2020	2006	2020	2020
Cereals	33 793	28 560		17 155	32 256	17 138	1273	11 422	10 149
Fruits	395	826		826	690	676	187	150	
Vegetables	5 080	1 172		891	2 376	891	54	281	227
Legumes	9 550	1 1106		8 475	9 768	8 556	532	2 550	2 018
Oil seeds	240	150		150		150	241	-	241
Tubers		689		689		689		-	-
Pseudocereals	162	565		440	85	125	77	440	363
Forage	3 822	1 125		1 125	487	1 125	835	-	835
Condiment					15				
Total	53 042	44 193	-	29 751	45 677	29 350	3 199	14 843	13 833
%				67.3		64.3	10.8	49.9	93.2

This table was built using data from the Catalog of Genetic Resourses (INIA, 2021).

CHILEAN PGRFA CONSERVED OVERSEAS

According to GENESYS Global Portal on Plant Genetic Resources, in June 2021 there were 16 191 Chilean PGRFA accessions preserved overseas (Table 4). These are in 40 different countries, which correspond to 31.7% of the number of accessions kept in germplasm banks in Chile (Table 3). The germplasm banks of the NPGRS at the USDA-Agricultural Research Service (USDA-ARS) and the international seed bank run by CGIAR (formerly the Consultative Group for International Agricultural Research, Montpellier, France) hold 41.5% and 22.5% of the Chilean accessions, respectively (Table 4). Consequently, international gene banks have had a large role in building up and safeguarding duplicates of Chilean PGRFA, particularly species like maize (CIMMYT, 1988) and beans (Paredes et al., 2010).

Over 15% of the Chilean accessions kept in overseas gene banks are landraces collected in Chile (Table 5), which highlights the key role of local and indigenous farmers in preserving the genetic diversity of some crops. Additionally, 31.7% of the accessions kept abroad are breeding and research material (Table 5), which shows the commitment of national breeding programs and their breeders to international collaboration for broadening the genetic base of their programs (Salhuana et al., 1997; IICA, 2010). National breeding programs are highly dependent on the introduction of genetic resources every year, because most of our crops and fruit trees are not originally from Chile, requiring genetic variation from abroad. Despite the large germplasm collections existing in the country and the international collaboration in germplasm exchange already mentioned, Chile, like all other countries, still depends on foreign germplasm to sustain its agriculture and food security (Khoury et al., 2016).

Table 4. Chilean germplasm accessions of plant genetic resources held in national and international gene banks overseas. Source: GENESYS (2021).

Country	Institutions	Accessions	%	Main crop species conserved
USA	National Plant Germplasm System, Agriculture Research Service, U.S. Department of Agriculture (NPGP USDA-ARS)	6 723	41.5	Maize, wheat, lentil, tomato crop wild relatives (CWR), potato, barley CWR, beans, chickpea, rice, others
UK	Royal Botanic Gardens Kew (MSBP Kew), John Innes Centre	1 992	12.3	Natives, wheat
Mexico	International Wheat and Maize Improvement Center (CIMMYT)	1 691	10.4	Maize, wheat
Lebanon	International Centre for Agricultural Research in Dry Areas (ICARDA)	988	6.1	Lentil, pea, chickpea, wheat, barley, forages
Australia	Australian Grains Genebank (AGG)	874	5.4	Lentil, wheat, barley, tomato, chickpea, rice, other
Russia	N.I. Vavilov Research Institute of Plant Industry	766	4.7	Wheat, maize, rice, oat, lentil, amaranth, sunflowers
Colombia	International Center for Tropical Agriculture (CIAT)	602	3.7	Beans
Germany	Leibniz Institute of Plant Genetics and Crop Plant Research (IPK)	761	4.7	Potato, wheat, beans, barley, potato and tomato CWR
India	International Crop Research Institute for the Semi-Arid Tropics (ICRISAT)	186	1.1	Chickpea, groundnut
Spain	INIA, UVP, EELM-SCIC,	222	1.4	Barley CWR, tomato CWR, garlic, cherimoya
Peru	International Potato Center (CIP)	180	1.1	Potato, oca, sweet potato
Other		1 206	7.4	
Total accessions		16 191		

This table was built using data from the Global Portal on Plant Genetic Resources (GENESYS 2021).
Holding institutions in Spain are: Centro Nacional de Recursos Fitogenéticos (INIA España); Universidad Politécnica de Valencia (UVP); Consejo Superior de Investigaciones Científicas. Estación Experimental La Mayora (EELM-SCIC).

Table 5. Types of Chilean germplasm held in international and national gene banks overseas.

Type of germplasm	Accession number	%
Traditional cultivars/Landraces	2 453	15.2
Breeder lines	2 437	15.1
Advanced/Improved cultivars	2 235	13.8
Breeding/Research material	392	2.4
Clonal selection	68	0.4
Natural	1 792	11.1
Wild	1 429	8.8
Semi-natural/sown	48	0.3
Semi-natural/wild	25	0.2
Other	37	21.8
Not specified	1 776	11.0
Total	16 191	

This table was built using information from the Global Portal on Plant Genetic Resources (GENESYS, 2021).
It is quite possible that some accessions are duplicated in gene banks in different countries, so overestimation of the accessions cannot be discarded.

CHARACTERIZATION, REGENERATION AND DOCUMENTATION OF PGRFA

Characterization, regeneration and documentation are routine activities of gene bank operations (FAO, 2014). They are essential for ensuring the quality and quantity of the material conserved. Lack of related information such as passport and characterization data is one of the main problems affecting accessions preserved in gene banks elsewhere, and Chile is not an exception. Salazar et al. (2006) did not report information on the number of accessions with passport and characterization data and documentation. In those years the only PGRFA collections well documented with agronomic characterization were maize (Paratori and Sbárbaro, 1990), beans (Bascur and Tay, 2005) and Chilean guava (Rodríguez, 2000) preserved by INIA. Partial characterization had been done for collections as lentils (Paredes et al., 2006), rice (Castillo and Alvarado, 2002), chili peppers (Pertuzé et al., 2016) and wild strawberry (Maureira et al., 1996; del Pozo and Lavin, 2015).

The 2020 updated INIA PGRFA inventory showed a substantial increase in the percentage of accession agronomically characterized (68.8%) respect to early reports (Salazar et al., 2006). Also, a 66.7% of the unique accessions kept by this institution have passport data, and 60.8% are documented in an online database (Table 6). Passport and characterization data for 18 142 accessions are kept online at the INIA Grin Global Data Base (INIA, 2021). The latter is a substantial achievement compared to the previous situation in 2006.

According to Salazar et al. (2006), only 7% of the accessions held in gene banks have some molecular characterization. This figure increased just to 12.0% in 2020 due to efforts on molecular characterization of some cereals, fruit and tuber collections (Table 6), particularly for Chilean potatoes, wild strawberry, Chilean guava and grape collections (Table 7). Although some species like maize, wheat, tomato, beans and quinoa have a few accessions characterized using molecular tools (Table 7), a lot of work needs to be done for complete genetic characterization of most Chilean PGR collections. The genetic characterization has been mostly based on the development and use of simple sequence repeat (SSR)-type markers (the gold standard for population genetic collection indexing, cultivar fingerprinting and other genetic studies). Examples are the newly developed SSRs for maqui berry (*Aristotelia chilensis* (Molina) Stuntz; Cona et al., 2020) and for other

Table 6. Numbers and percentages of accessions in the germplasm conservation systems of INIA held as base and active collections of INIA according to the December 2020 inventory with passport data, agronomic characterization, molecular characterization and data base documentation.

		Accessions with					
Crops	Total non-duplicated	Passport data		Agronomic characterization		Data base documentation	
	Nr	Nr	%	Nr	%	Nr	%
Cereals	17 155	10 887	63.5	14 571	84.9	11 820	68.9
Fruits	826	506	61.3	191	23.1	383	46.4
Vegetables	891	570	64.0	403	45.2	389	43.7
Grain Legumes	8 475	5 010	59.1	4 234	50.0	4 138	48.8
Oil seeds	150	1	0.7	-	-	-	0.0
Tubers	689	689	100.0	454	65.9	689	100.0
Pseudocereals	440	440	100.0	354	80.5	440	100.0
Forage	1 125	890	79.1	342	30.4	283	25.2
Total	29 751	18 993	63.8	20 549	69.1	18 142	61.0

This table was built using data from the online Catalogue of Genetic Resources (INIA, 2021).

Table 7. Numbers and percentages of crop accessions with molecular characterization preserved in the INIA-Chile gene bank network.

Crop group	Crop	Non-duplicated accessions	Genotyped accessions	%	Reference
Cereals	*Triticum aestivum*	12 390	1 360	11.0	Zerené et al. (2000); Hinrichsen et al. (2002); Zúñiga et al. (2004)
	Zea mays	1 487	97	6.5	Salazar et al. (2017)
	Oryza sativa	2 007	249	12.4	Aguirre et al. (2005); Becerra et al. (2015; 2017)
Fruits	*Vitis vinifera*	289	289	100.0	Narváez et al. (2000; 2001); Hinrichsen et al. (2001); Moncada et al. (2006); Moncada and Hinrichsen (2007); Milla-Tapia et al. (2013); González et al. (2016)
	Fragaria chiloensis	186	216	100.0	Hinrichsen et al. (1999); Becerra et al. (2001; 2005); Carrasco et al. (2007)
	Ugni molinae	122	100	82.0	Seguel et al. (2000)
Vegetables	*Allium sativum*	281	200	71.2	Paredes et al. (2008)
	Solanum lycopersicum	170	32	18.8	Donoso (2017)
Legumes	*Phaseolus vulgaris*	1 389	237	17.1	Johns et al. (1997); Becerra et al. (2010; 2011)
	Lens culinaris	1 834	91	5.0	Rodríguez et al. (1999)
Tubers	*Solanum tuberosum*	689	589	85.5	Mathias et al. (2007); Muñoz et al. (2016)
Pseudocereal	*Chenopodium quinoa*	397	59	14.9	Fuentes et al. (2009)
Forage	*Medicago polymorpha*	143	41	28.7	Paredes et al. (2000; 2002)
Total non-duplicated accessions		29 751	3 560	12.0	

berries in process of domestication, such as Patagonian barberry (*Berberis* spp., Varas et al., 2013). The characterization of materials maintained in collections and of isolated genotypes found in old orchards based on SSRs has been successfully implemented (Rojas et al., 2008; González et al., 2016; Salazar et al., 2017).

By other side, there are several publication reporting characterizations of Chilean germplasm from scientific groups at universities. For example, agronomic characterization for 30 accessions of *F. chiloensis* (Mora et al., 2016; 2019), genetic characterization of 39 accession of native and cultivars of *S. tuberosum* (Solano et al., 2013), *Phaseolus coccineus* L. (Arriagada et al., 2021) and 87 sweet cherry cultivar presents in Chile (Guajardo et al., 2021). However, there are not certainty about the actual status of these and other used in research. It is not clear if these are institutional collections formally established and managed as germplasm bank or just are working collection maintained for scientific purpose. Clearly, there is a need for update a national inventory on plant genetic resources.

OPPORTUNITIES FOR CHILEAN PGR- WHAT IS NEEDED TO PROMOTE THEIR USE

Plant breeding program have been playing a strategic role on sustain Chilean agriculture. Since the middle of the 20th century, Chilean breeding programs have released 375 new cultivars, according to the national property registration system (SAG, 2021). This figure includes all commercial cultivars approved, pending approval and obsolete. Of this total, 55.7% are cereals; 16.8% grain legumes, 12.8% fruit crops and 14.7% are miscellaneous cultivars of tubers, mainly potatoes, forage crops, ornamentals and other cultivated species (Table 8).

Plant breeding programs for wheat, barley, oat, and rice released most of the commercial cultivars used by Chilean farmers ever since (Engler and del Pozo, 2013). Yield improvement and pest resistance had been the main focus of the breeding programs in crops in Chile like wheat (Cortázar et al., 1988; Zerené et al., 1997), legumes (Paredes, 1994; Tay et al., 2004; Mera and Galdames, 2007), rice (Cordero-Lara, 2020), and quinoa (Zurita-Silva et al., 2014). In recent years resistance to abiotic stresses (Acuña et al., 2012; Soto-Cerda et al., 2015; del Pozo et al., 2016; Morales et al., 2017) and fruit/seed quality have also been included (Barticevic et al., 2004).

Fruit crop breeding programs are underway by different institutions for table grapes, cherries, peaches and nectarines, plums, apples, blueberries, raspberries (e.g., Infante et al., 2011; Gambardella et al., 2014; García et al., 2020) and some native fruits (Seguel et al., 2009; Vogel et al., 2016), mainly focused on fruit quality and postharvest life. Most programs are using conventional breeding techniques, but also using biotechnological tools as in grape (Barticevic et al., 2004; Peña-Cortés et al., 2005; Hinrichsen et al., 2008; Mejía et al., 2011; Torres et al., 2014), plum (Guajardo et al., 2015; Gainza et al., 2015; Salazar et al., 2020) and peach (Meneses et al., 2016; Miyasaka Almeida et al., 2016) to reduce the time for obtaining new cultivars, making the breeding more precise, cost-effective, and to solve problems that cannot be addressed by conventional breeding (del Pozo et al., 2019).

Table 8. Summary of commercial plant varieties generated in Chile and included in the national property registration system administrated by the Servicio Agrícola y Ganadero (SAG) of Chile. Includes all expired, definitive, pending and provisional commercial crop varieties created and released in Chile.

Type of crop	Nr Crops	Crops	Registered varieties	%
Cereals	9	Wheat, barley, maize, oats, rice, durum wheat, triticale, rye	206	54.9
Legumes	9	Bean, pea, lentil, chickpea, snow pea, white lupine, yellow lupine, blue lupine, Andean lupine	62	16.5
Fruit	15	Grape, peach, avocado tree, plum, raspberry, pear, tangerine, nectarine, apple tree, blackberry, Chilean guava, cherry tree, kiwi, lemon tree, maqui	63	16.8
Tuber	1	Potato	20	5.3
Forage	3	White clover, red clover, bromo, alfalfa	10	2.7
Vegetables		Onion, pumpkin, zucchini	6	1.6
Oil seed	1	Raps, linseed	4	1.1
Pseudocereals	1	Quinoa	3	0.8
Seasoning	1	Oregano	1	0.3
Total	43		375	

This table was built using information from SAG (2021).

Climate change imposes new restrictions for the development of sustainable agriculture in Chile, particularly in the Mediterranean-type climate region of Chile (Roco et al., 2017). Consequently, the adaptation of crops to climatic change has become an urgent challenge that requires some knowledge about how crops respond to these changes (Ceccarelli et al., 2010; Galluzzi et al., 2020). Plant breeding needs to develop new cultivars with enhanced traits better suited to adapt to climate change conditions using both conventional and genomic technologies (del Pozo et al., 2019; Razzaq et al., 2021). To support this effort, Chilean gene banks have and must ensure the provision of the widest possible genetic diversity available for each relevant crop (León-Lobos et al., 2018). Also, it is important to enhance coordination between germplasm manager and breeder aimed to: a) Select accession with high priority to characterization, b) agree traits more useful for breeding purposes, and c) design and conducting germplasm trails to evaluate of high number of traits as possible that allow characterization of a genotype’s performance under different environmental condition (del Pozo et al., 2019).

Strong research orientated is needed for characterize, evaluate and select germplasm tolerant to higher environmental temperature, drought (del Pozo et al., 2019) and salty soils (Isayenkov, 2019). Efforts had been done on some selected germplasm of landraces, cultivars or commercial varieties of tomato (Martínez et al., 2014; Tapia et al., 2015; Martínez et al., 2020; Blanchard-Gros et al., 2021), native potatoes (Lizana et al., 2017; Ávila-Valdés et al., 2020), Chilean beans cultivar (Lizana et al., 2006; Martínez et al., 2007), wheat (Lizana and Calderini, 2013; del Pozo et al., 2016; 2020; Brunel-Saldias et al., 2020; Meier et al., 2022), forage legumes (Acuña et al., 2010; Inostroza et al., 2015; Acuña et al., 2016; Inostroza et al., 2019), quinoa (Ruiz-Carrasco et al., 2011; Morales et al., 2017), grapevine (Bavestrello-Riquelme et al., 2012). However, a pre-breeding orientated characterization and phenotyping well-coordinated initiatives are required characterize wider collections and for accelerating the development of new and improved cultivars better adapted to environmental constrains (Camargo and Lobos, 2016; Zhao et al., 2019).

In general, plant breeding programs in Chile (e.g., Jobet, 2007; Humphries et al., 2021) have been aided by strong international cooperation, especially through the CGIARs, which must be strengthened by being part of the international crop improvement programs and the search for new genes to face climate change. A strong and well-coordinated action between agronomist, germplasm bank curators, breeders, biotechnologists and plant physiologists are needed.

POLICIES FOR COLLECTION, CONSERVATION, CHARACTERIZATION AND USE OF PGRFA IN CHILE

The importance of a coherent national coordinated approach for the collection, conservation, characterization, management and use of PGRFA is widely recognized (FAO, 2010; 2019). All stakeholders should be considered in creating a national policy, including planners, scientists, germplasm curators, breeders, extensionists, farmers’ organizations and indigenous communities (Spillane et al., 1999). Also, representatives from both the public and private sector (profit and non-profit) are essential (FAO, 2015b).

Although Chilean PGRFA stakeholders from the agriculture sector have been properly identified (Salazar et al., 2006), their integration into formal participation instances is lacking. Efforts have been made to set up a national system for PGRFA in Chile, but with limited success (Cubillos et al., 1995; MINAGRI, 2014), mainly due to a lack of appropriate funding, lack of adequate coordination and political commitment in relation to the institutional organization required.

A national strategy on genetic resources is required and should: a) Include PGR for food and agriculture, forestry, animals, aquatic organisms and microorganisms, both wild and domesticated; b) build a participatory process with active involvement of different stakeholders with long term commitment; c) harmonize with other national policies and strategies for other areas such as biodiversity and climate change; d) have a foundational base in international agreements and guidelines, particularly the Global Action Plans on Genetic Resources (FAO, 2012) and technical guidelines (FAO, 2015b), and must also include all elements of the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) (FAO, 2009); and the policies for access and benefit-sharing regulations according to the Convention of Biodiversity (United Nations, 1992).

CONCLUSIONS

Chile has an important number of Plant Genetic Resources (PGR) conserved under *ex situ* conservation methods, particularly of crops important for agriculture and food security. An appreciable fraction of them is duplicated abroad; international germplasm banks have a strategic role in safeguarding the Chilean crop genetic heritage. It is necessary to collect and repatriate those genetic resources, especially if they are not adequately represented in collections, like landraces, local varieties of vegetables, fruits and wild relatives. It is also fundamental to promote and conduct research and activities on agronomic, physiological, biochemical and genetic characterization collections of PGR for Food and Agriculture (PGRFA) to support plant breeding under climate change conditions. Although most PGRFA are conserved at INIA, work is needed to enhance national capabilities in the quality management of PGRFA collections in gene banks of other organizations. Finally, a national functional coordination and strategy on generic resources needs to be in place to safeguard and promote the sustainable use of PGRFA for present and future Chilean agriculture.

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