UNIVERSITY OF HOHENHEIM

Conservation of plant genetic resources

3502-470 Plant Genetic Resources

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Tasks of PGR conservation

1. Registration, description, evaluation
2. Collection
3. Conservation
4. Provision, documentation

What are the options for conservation?

What are the options for conservation?

Ex situ conservation

- Seed storage
- in vitro storage
- DNA storage
- Pollen storage
- Field gene bank
- Botanical garden

In situ conservation

- Genetic reservoir
- On farm
- House gardens, fruit orchards

Each method has advantages and disadvantages

Conservation strategies and breeding methods

Feature	Breeding-oriented	Conservation-oriented
Trait	Simple traits (Resistance genes)	Complex, adaptive traits
Breeding method	Introgression of alleles	Composite crosses of diverse genotypes
Selection by	Plant breeders	Nature and farmers (Participative breeding)
Conservation	*ex situ*	*in situ*

Ex situ: Seed storage

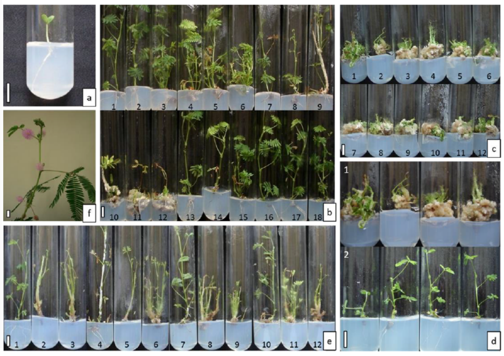
Advantages:

- Efficient and reproducible
- Suited for safe, medium- and long-term storage
- Conservation of the big diversity of individual species

Disadvantages:

- Problems with the storage of recalcitrant seeds
- Evolutionary development, especially with respect to disease and herbivore resistance is frozen
- Genetic diversity can be lost through regeneration
- Limitation on a single species; associated plant species of the same site are not considered

Ex situ: In vitro storage



Bianchetti et al. (2017). An improved protocol for in vitro propagation of the medicinal plant *Mimosa pudica* L. African Journal of Biotechnology, 16(9), 418.

Ex situ: In vitro storage

Advantages:

- Relatively simple long-term storage for recalcitrant, sterile and clonal species
- Simple access to use and evaluation

Disadvantages:

- Risk of somaclonal variation
- Necessity of individual protocols for the maintenance of the tissue culture of most species
- Relatively expensive technology and high costs of maintenance

Ex situ: DNA storage

Advantages:

- Simple, cheap conservation

Disadvantages:

- Regeneration of plants from DNA not yet possible
- Problems with gene isolation, cloning and transfer

Ex situ: Pollen storage

Advantages:

- Simple, cheap conservation

Disadvantages:

- Species-specific protocols for the regeneration of haploid plants as well as for the diploidization are necessary
- Only paternal material is conserved, but mixes of many individuals can be stored

Ex situ: Field gene banks

Advantages:

- Suitable for the storage of recalcitrant species
- Simple access for the characterization and evaluation
- Material can be evaluated during conservation
- Simple access for utilization

Disadvantages:

- Material is exposed to insects, pathogens, vandalism and environmental hazards
- Need for large areas, even with small population sizes
- High costs of maintenance

Ex situ: Botanical garden

Advantages:

- Restricted to wild plants without economical value
- Use as demonstration garden for teaching

Disadvantages:

- Space requirements limit diversity, that can be maintained (frequently only a single individual per species)
- High maintenance costs

In situ: Genetic reservoir

Advantages:

- Dynamic conservation in exchange with changing environment, diseases and pests
- Simple Utilization for evolutionary and genetic studies
- Suitable method for 'recalcitrant' species
- Simple conservation of related wild species
- Possibility to conserve several crop species

Disadvantages:

- Little experience available for management only a limited amount of genetic diversity can be conserved per reservoir
- Material not available for immediate use
- Susceptible for natural and human induced disasters like fire, vandalism, urbanization, pollution, war, etc.
- Requires a very high level of supervision and documentation

In situ: On farm conservation

Advantages:

- Dynamic conservation in the interplay with changing environmental conditions, diseases and pests
- Conservation of traditional landraces of crop species possible
- Enables simple conservation of related wild species and breeding stock.

Disadvantages:

- Susceptible to changes in agricultural practice.
- Requires the conservation of traditional agricultural systems and possibly the payment of subsidies.
- Little experience for management available;
- Only a limited extent of genetic diversity can be conserved per farm so that several farms are necessary in different regions to ensure sufficient conservation
- Possible mix-up with participatory plant breeding strategies.

In situ: Home gardens, fruit orchards

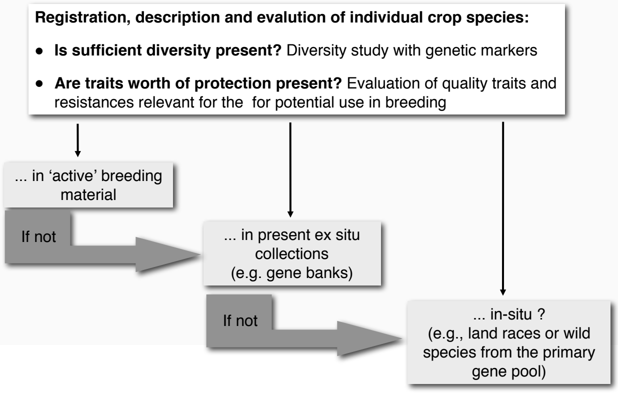
Advantages:

- Dynamic conservation in the interplay with changing environmental conditions, diseases and pests
- Allows the conservation of traditional landraces of rare crops, fruits vegetables and medicinal plants, spices, fruit trees.
- Enables the simple conservation of related wild species and breeding stock.

Disadvantages:

- Susceptible to changes in horticultural practice
- Little experience available for management requires the conservation of traditional agricultural practice and possibly the payment of subsidies.

A possible strategy for PGR management



See global strategies e.g. at
`https://www.croptrust.org/resources/`

The state of ex situ collections i

2nd FAO Report (2010) on the state of world's genetic resources for food and agriculture:

1,750 individual gene banks worldwide

130 hold more than 10,000 acessions each

There are substantial collections in the 2,500 botanical gardens

Genebanks are on all continents, but there are relatively fewer in Africa

The CGIAR collections are among the largest ones

Currently there are about 7.4 million accessions

Only 1.9 - 2.2 million are distinct (about 25-30% of the total)

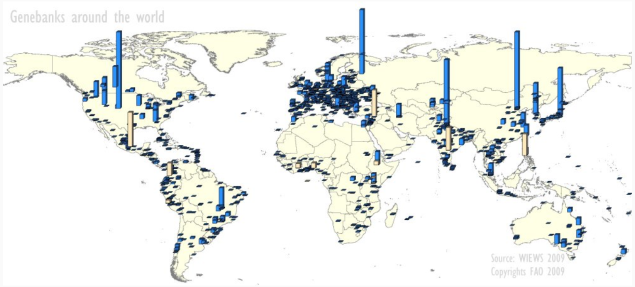
The state of ex situ collections ii

Of the most important crops, 4.6 million accessions are stored

National gene banks harbor 6.6 million accessions

45% of national collections are only in seven countries, increased concentration into fewer countries

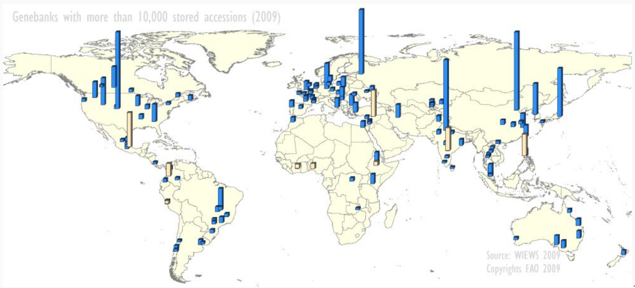
Geographic distribution of genebanks



Source: FAO 2010

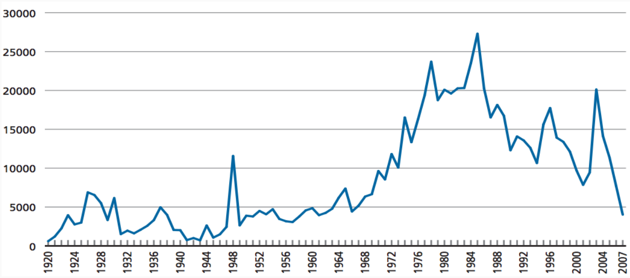
Geographic distribution of genebanks

Genebanks with more then 10,000 accessions:



Source: FAO 2010

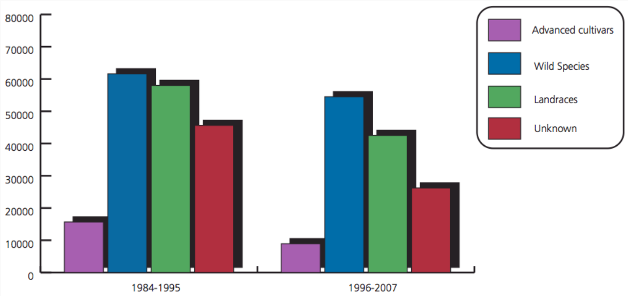
Collection activities in the past



Source: FAO 2010

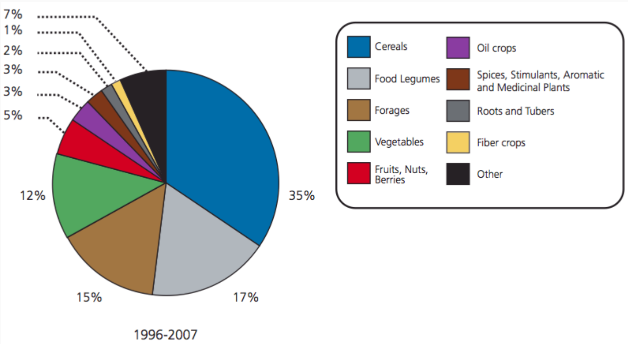
Number of accessions collected each year since 1920 and stored in selected genebanks, including those of the CGIAR centres. Source: FAO 2010.

Types of accessions collected



Source: FAO 2010

Types of crops collected



Source: FAO 2010

Collection sizes for major crops

Genus (crop)	Total world accessions	Major holders rank			
		1	%	2	%
Triticum (wheat)	856 168	CIMMYT	13	NSGC (USA029)	7
Oryza (rice)	773 948	IRRI	14	NBPGR (IND001)	11
Hordeum (barley)	466 531	PGRC (CAN004)	9	NSGC (USA029)	6
Zea (mays)	327 932	CIMMYT	8	BPGV-DRAEDM (PRT001)	7
Phaseolus (bean)	261 963	CIAT	14	W6 (USA022)	6
Sorghum (sorghum)	235 688	ICRISAT	16	S9 (USA016)	15
Glycine (soybean)	229 944	ICGR-CAAS (CHN001)	14	SOY (USA033)	9
Avena (oat)	130 653	PGRC (CAN004)	21	NSGC (USA029)	16
Arachis (groundnut)	128 435	ICRISAT	12	NBPGR (IND001)	10
Gossypium (cotton)	104 780	UzRICBSP (UZB036)	11	COT (USA049)	9
Cicer (chickpea)	98 313	ICRISAT	20	NBPGR (IND001)	15
Solanum (potato)	98 285	INRA-RENNES (FRA179)	11	VIR (RUS001)	9
Pisum (pea)	94 001	ATFCC (AUS039)	8	VIR (RUS001)	7
Medicago (medicago)	91 922	AMGRC (AUS006)	30	UzRICBSP (UZB036)	11
Lycopersicon (tomato)	83 720	AVRDC	9	NE9 (USA003)	8
Trifolium (clover)	74 158	WARDA (AUS137)	15	AGRESEARCH (NZL001)	9
Hevea (rubber)	73 656	MRB (MYS111)	81	RRII (IND031)	6
Capsicum (capsicum)	73 518	AVRDC	11	S9 (USA016)	6
Prunus (prunus)	69 497	VIR (RUS001)	9	UNMIHT (USA276)	9
Pennisetum (pearl millet)	65 447	ICRISAT	33	CNPMS (BRA001)	11
Vigna (cowpea)	65 323	IITA	24	S9 (USA016)	12
Malus (apple)	59 922	GEN (USA167)	12	VIR (RUS001)	6
Vitis (grape)	59 607	INRA/ENSA-M (FRA139)	9	JKI (DEU098)	6
Lens (lentil)	58 405	ICARDA	19	NBPGR (IND001)	17
Vicia (faba bean)	43 695	ICARDA	21	ICGR-CAAS (CHN001)	10
Saccharum (sugar cane)	41 128	CTC (BRA189)	12	INICA (CUB041)	9
Aegilops (wheat)	40 926	ICCI-TELAVUN (ISR003)	22	ICARDA	9
Cucurbita (cucurbita)	39 583	VIR (RUS001)	15	CATIE	7
Helianthus (sunflower)	39 380	IFVCNS (SRB002)	14	NC7 (USA020)	9
x Triticosecale (wheat)	37 440	CIMMYT	46	VIR (RUS001)	5
Ipomoea (sweet potato)	35 478	CIP	18	NIAS (JPN003)	16
Festuca (fescue)	33 008	IHAR (POL003)	14	NIAS (JPN003)	13

Source: FAO 2010

Disadvantage of ex situ storage

Natural and other hazards: Maracuja Genebank in Taray/Peru severely

damaged by flood Photo: Karl Schmid

Lack of coevolution in ex situ conservation

Infection with leaf blight pathogen (Helminthosporium)

Photo: Walter Schmidt, KWS SAAT AG

Disadvantages of ex situ storage

Lack of funds for modern air conditioning: Quinoa Genebank of the National University of the Altiplano in Camacani/Peru

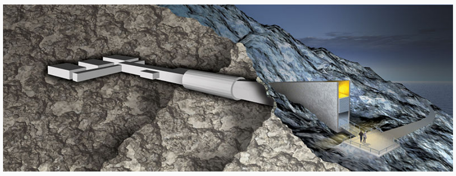
Photo: Karl Schmid

Maintaining gene banks: The Crop Trust

- ”The Global Crop Diversity Trust was established in October 2004 as an independent organization under international law.” `www.croptrust.org`
- Donors: FAO, plant breeding companies, states, research institutes, charity foundations `https://www.croptrust.org/about-us/donors/`
- Collections supported by the crop trust `https://cdn.croptrust.org/wp/wp-content/uploads/2017/02/CGIAR_lay2-2.pdf`

Cropt Trust supports: The global seed vault in Svalbard i

Svalbard
Global Seed Vault



Cropt Trust supports: The global seed vault in Svalbard ii

- Secure seed bank on the Norwegian island of Spitsbergen
- Mission: Preserve seeds in underground facility to provide insurance against loss of seeds in case of major catastrophies
- Funded by the Norwegian government, and other donors (e.g. via Crop Trust)
- Duplicates from other gene banks are stored at low temperatures (once retrieved: ICARDA backup (Syria), 2015)
- Secure? Thawing of the permafrost in 2018 shows vulnerability (while actions to cope with this were undertaken)

Examples of Conservation strategies

- Plant genetic resources conservation strategy for banana https://cdn.croptrust.org/wp/wp-content/uploads/2017/06/Musa_Strategy_2016.pdf
- Annual Crop Trust report 2017 https://cdn.croptrust.org/wp/wp-content/uploads/2018/05/2017_CropTrust_ANNUAL-REPORT.pdf

in situ conservation

in situ conservation

Definitions according to the German Ministry of Agriculture (2000)

in situ conservation

Conservation of plant species (domesticated varieties or varieties created by plant breeding) in the environment, in which they developed their particular characteristics

on farm conservation

Maintenance, cultivation and development of PGR (mostly land races and traditional varieties) on agricultural farms.

Why *in situ* conservation?

- Important characteristics of PGR can only be maintained in the environment in which they were developed.
- New PGR are constantly being generated in agroecosystems
- Security copies of gene bank collections are necessary
- Agroecosystems in the centers of biological diversity and evolution are natural laboratories for agricultural research.
- The Convention on Biological Diversity demands activities for *in situ* conservation

Why *in situ* conservation?

Goal of in situ conservation with respect to plant breeding:

... *what the breeder needs in the interest of long-term adaptability is a continually replenished store of locally adapted variability.*

– Simmonds 1962

Methods of *in situ* conservation

- Genetic reserves
- Dynamic Genepools/Management ('Evolutionsramsche')
- On farm conservation
- Home gardens

Genetic reserves

- Genetic reserves are spatially separated reservoirs in which wild plants grow in a natural and protected environment, where they can persist for generations and evolve further.
- Genetic reserves are suitable for the in situ conservation of related wild plants from the primary and secondry gene pool of crop species.
- PGR in genetic reservoirs should be constantly monitored for their level of genetic diversity

(Maxted et al. 1977)

Apple tree forests in Kazakhstan

Zhongar-Alatau State National Nature Park established in 2010 (356,022

ha) flickr

Dynamic gene pools

- **Bulk populations**: artificially created crossed populations from a diversity of existing varieties.
- **No selection:** Grown at many sites without (artificial) selection under real conditions and can therefore adopt locally across generations (Evolutionsramsche)
- **Pre-breeding and germplasm enhancement:** Conserve and make available locally adapted variability for plant breeding
- **Genetic base broadening:** in the narrow sense, they are not conservation strategies, but methods to increase variability of usable genetic variation for plant breeding.

Creation of dynamic gene pools

1. Create a starting population by multiple mutual crosses of many different lines or populations.
2. Characterize phenotype and genotypes of the starting population to recognize changes.
3. Representative subsets of the cross are grown at many sites for many generations (> 10) to achieve local adaptation.
4. The crosses develop only with mild selection under local growth conditions (Let nature do the work!)
5. Representative seed samples of each generation and at all sites are centrally collected and stored.
6. Phenotypic and genotypic changes in the crosses are monitored and documented in predefined intervals.

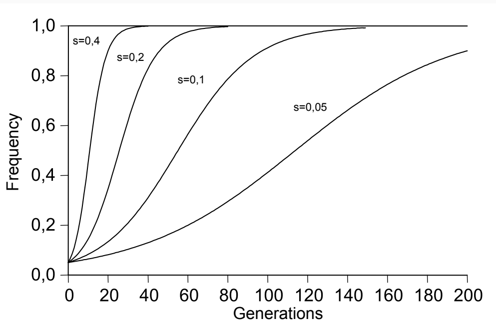
Population genetics of bulk populations: Outcrossers

- Rye, corn, rape seed
- Creation of starting population by simple random mating
- Natural selection acts on individual genes, therefore slow
- Introgressions have a big effect → Isolation is necessary
- Established heterotic groups need to be treated separated, for example the Petkus and Carsten Pools in rye

KWS Lochow

Population genetics of bulk populations

Change of frequency, *p*, of a favourable allele with different selection coefficients, *s*. Assumption: $p_0 = 0.05$, intermediate inheritance, random mating, no genetic drift.



Geiger 2004

Population genetics of bulk populations

Self-fertilizing crops

- Wheat, barley, lentils
- Laborious creation of starting population because of manual crosses
- Natural selection acts on genotypes, therefore fast
- Changes in few generations recognizable
- Low probability of introgression

Examples of bulk populations

Composite crosses

- in Davis, CA (Harlan and Martini 1929 and 1938)
- 28 Lines (15 USA, 13 Europe) were fully crossed $\rightarrow$ 378 crosses
- Grown at different locations without selection until today.

Dynamic management of composite populations

- in France, 1984 (Goldringer et al. 2001, 2004)
- 2 $\times 16$ wheat lines (PA, PB) and 62 lines (PS) were generated
- Cultivation of bulk in 7 - 12 regions in large plots without selection

Examples of bulk populations

Composite crosses in Scandinavia

- 1991/1992 (Veteläinen and Nissilä 2001)
- 25 local and 15 exotic lines
- Grown at different locations in North- and South-Scandinavia

Dynamic management of wheat in France

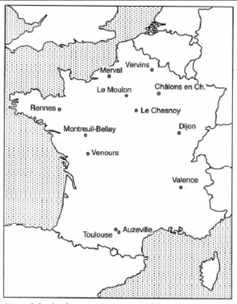


Fig. 13.1. Network for the dynamic management of the wheat genetic resources programme (DGER of the French Agriculture Ministry, INRA, INA-PG and BRG).

Frequency of plants resistant against *Pseudocercosporella* ('Eyespot) after 10 generations of separate cultivation

Starting population: 0.24

Population	Intensive	Extensive
Le Moulon	0.09	0.17
Montreuil	0.08	0.00
Rennes	0.35	0.37
Toulouse	0.11	0.30
Vervins	0.81	0.23

Average (all locations after 10 generations): 0.25

Evolutionary Pool: Sustainable genetic diversity

- An evolutionary pool is a population created from high-performing components (lines, families, varieties)
- Grown for many generations at a site
- May be grown under mild selection by breeder
- Goal: Maintenance and development of diversity useful for plant breeding

(F. W. Schnell 1980)

Bulk populations in Germany i

'Fachbeirat Pflanzengenetische Ressourcen (BeKO)'

→ Advises the Federal Government on the maintenance and use of plant genetic resources. (`https://www.genres.de/fachgremien/fachbeirat-pflanzengenetische-ressourcen`)

Working group "In situ conservation and on-farm management"

Goals:

- Support BeKo in the implementation of priority actions from Chapter 5. 1. of the specific programme according to the priorities defined by BeKo

Bulk populations in Germany ii

- Biological goals for the section on on-farm management:
  - Increase diversity of species and varieties in production and use
  - Fund regional breeding of varieties
  - Create bulk populations → develop modern land races

See also: `https://pgrdeu.genres.de/insitu?lang=en`

On-farm conservation

- Maintenance of traditional varieties or cultivation systems by farmers in traditional agricultural systems Maxted et al. (1997)
- A dynamic method to maintain developmental processes that determine the genetic diversity of crops and their related wild species under cultivation conditions
- Is based on the insight that farmers created and conserved a high diversity of crop species and that this process is ongoing despite the socio-economic and technical changes
- Considers the great importance of evolutionary processes that results from the selection of plant material (e.g., land races) by the farmers. (IPGRI 1998)

On farm conservation: Potatos in the Andes

- Several thousand morphologically different types of potatos of four different levels of ploidy are grown in the andes.
- Farmers in some villages grow up to 50 different types
- Although modern varieties are grown, land races sustain with a stable proportion because of their better taste, better storage ability and because of their role as traditional gifts between farmers
- Mixtures of land races are maintained to serve as the basis for seed amplification for future needs

Brush 1995

On-farm conservation: Andean root tubers

Conservation of Andean root tubers in a dynamic mosaic system

12 families of farmers in a climatically diverse region the the Andes practice the dynamical conservation of 50 potato, 27 Oca, 7 Ullucu (Pappalisa) and 8 Isano landraces of the region (Terrazas and Valdiva 1998)

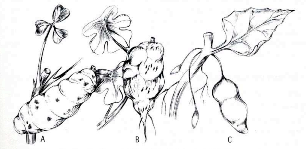


Abb. 49 Sproßknollen der Tropen: **A** Oka *(Oxalis tuberosa)*; **B** Knollige Kapuzinerkresse *(Tropaeolum tuberosum)*; **C** Ulluco *(Ullucus tuberosus)*.

Ullucus tuberosus: Tubers for sale at market, Silvia, Colombia, Photo: Hugh Wilson

Tropaeolum tuberosum - tubers (left) from a Mexican market and (top) plants under cultivation in flower, Lake Titicaca, Bolivia. Photos: Hugh Wilson

CR Sperling and SR King, 1990

Tuber variation of *Oxalis tuberosa* from market in Pasto, Colombia

CR Sperling and SR King

Oxalis tuberosa with flowers, Chinchero, Peru

Mosaic dynamic system of the Andes

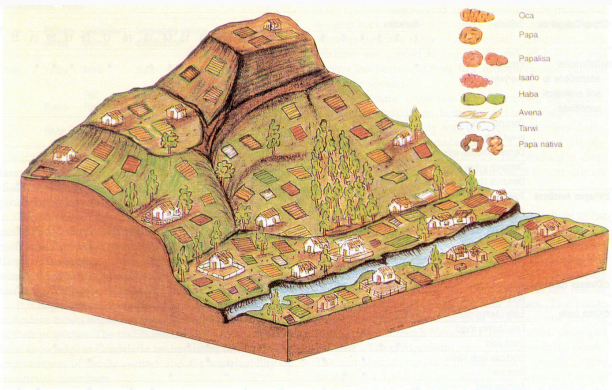


Fig. 4. The 'mosaic dynamic system' consists of the dispersion of Andean tuber diversity, as a country strategy which lessens loss risk, making the survival of local cultivar diversity possible

Terrazas and Valdiva 1998

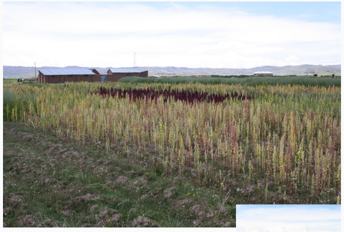
Parque de la Papa

www.parquedelapapa.org

A community-driven *in situ* conservation system

- Location: Titicaca lake, close to Puno, Peru
- Crop: Quinoa
- Number of varieties: Not determined
- Each family is responsible for a set of quinoa varieties

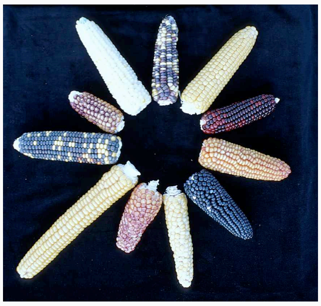
In situ conservation of quinoa



On-farm conservation: Maize in South Mexiko

- Diversity of maize varieties was not reduced since the 1950s but was increased slightly
- Farmers integrate modern varieties in Landraces
- Hybrids are not grown much
- High rate of outcrossing is a reason for the high diversity

(Brush, 1995)



On-farm conservation: Pearl millet in Rajastan

- Farmers grow mostly land races
- Maintenance of diversity and the typical character of landraces is most important
- By this method, land races are conserved and in situ conserved
- Farmers in West Rajasthan have a different strategy than farmers in East Rajasthan

(vom Brocke 2001, PhD Dissertation, Univ. Hohenheim)

Land race

Introgressed land race

Modern land race

Seed management by farmers in India

	West Rajasthan	East Rajasthan
Goal	Minimize production loss and secure seed availability during droughts	Conservation of specific, morphologically different land races, named after their villages of origin
Regional level	Frequent seed exchange between neighboring villages, over long distances All land races of the region are seen as equivalent, missing adaptation or quality traits do not prevent seed exchange	Well-known villages are the basis of local seed markets
Population level	“Conservation” land races includes mixing in of small amounts of modern varieties (Introgression)	Any mixing is avoided to conserve the unique characteristics of land races

In situ conservation by state organisations

Maintenance breeding of the land race Blanco de Urubamba in Peru by INIA

In situ conservation by state organisations

Phenotypic selection of cob morphological traits

Home gardens

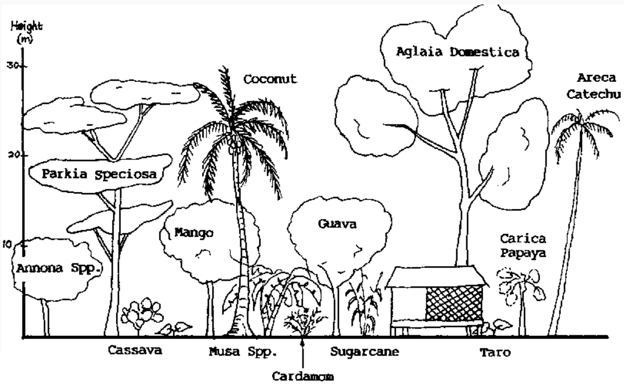
- Conservation of genetic resources in home gardens is a particular form of on farm conservation
- Home gardens have a high species diversity in small areas
- Species in home gardens are predominately vegetables, tubers, spices and medicinal plants (Tomatos, pepper, maniok, cumin, mint, thyme, parsley)
- Fruit orchards close to homes harbor genetic diversity of fruit trees, wood trees and shrubs

Tropical Home Gardens

Tropical Home Gardens

Tropical Home Gardens

Scheme of a tropical home garden in Java, Indonesia



Source: Nair 1988

Ex situ and ∈situ conservation and genetic diversity

Heredity
https://doi.org/10.1038/s41437-021-00423-y

the genetics society

ARTICLE

Genetic diversity and selection signatures in maize landraces compared across 50 years of in situ and ex situ conservation

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Abstract
Genomics-based, longitudinal comparisons between ex situ and in situ agrobiodiversity conservation strategies can contribute to a better understanding of their underlying effects. However, landrace designations, ambiguous common names, and gaps in sampling information complicate the identification of matching ex situ and in situ seed lots. Here we report a 50-year longitudinal comparison of the genetic diversity of a set of 13 accessions from the state of Morelos, Mexico, conserved ex situ since 1967 and retrieved in situ from the same donor families in 2017. We interviewed farmer families who donated in situ landraces to understand their germplasm selection criteria. Samples were genotyped by sequencing, producing 74,739 SNPs. Comparing the two sample groups, we show that ex situ and in situ genome-wide diversity was similar. In situ samples had 3.1% fewer SNPs and lower pairwise genetic distances (F_{st} 0.008–0.113) than ex situ samples (F_{st} 0.031–0.128), but displayed the same heterozygosity. Despite genome-wide similarities across samples, we could identify several loci under selection when comparing in situ and ex situ seed lots, suggesting ongoing evolution in farmer fields. Eight loci in chromosomes 3, 5, 6, and 10 showed evidence of selection in situ that could be related with farmers' selection criteria surveyed with focus groups and interviews at the sampling site in 2017, including wider kernels and larger ear size. Our results have implications for ex situ collection resampling strategies and the in situ conservation of threatened landraces.

Summary i

- Several options are available for managing plant genetic resources.
- The two main approaches for conservation are ex situ and in situ conservation.
- Both ex situ and in situ conservation management can be combined in a single strategy to manage PGR.
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- The two main approaches for conservation are ex situ and in situ conservation.
- Both /ex situ/ and /in situ/ conservation management can be combined in a single strategy to manage PGR.

Summary ii

- Genetic erosion is the loss of genetic diversity because of genetic drift. In ex situ collections, there is a significant amount of loss by genetic drift because of the required rejuvenation.
- Different types of in situ management
- Community-driven and state-funded systems
- in situ conservation strategies originated on all continents
- Main goal: keep plants in their native environment
- Effect on long-term trends on genetic variation is unclear

Review questions i

1. Why are populations with a large effective population size expected to evolve faster than populations with a small effective population size? Why is this relevant in the context of plant genetic resource conservation?
2. What are the key arguments against an /in situ/ and against an /ex situ/ conservation strategy, respectively?
3. What are the key arguments in favor of /in situ/ and /ex situ/ conservation strategy, repsectively?
4. How would it be possible to differentiate between adaptive and nonadaptive traits observed in landraces?

Review questions ii

5. What are the different types of dynamic gene pools?
6. Why is selection in dynamic gene pools slower than in self-fertilizing crops?
7. What are the differences between dynamic gene pools and varieties grown in dynamic gene pools?
8. What are the challenges of a systematic management of genetic resources in dynamic populations on a national level?

References i

Maxted N, Ford-Lloyd B, Hawkes J (1997) Plant genetic conservation: the in situ approach. Springer Us