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In situ and on-farm management of plant genetic resources

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Abstract

For establishing an effective maintaining programme for plant genetic resources (PGR), an integrated system is necessary considering the three principal ways of germplasm management—ex situ, in situ and on-farm. The scientific concept for on-farm conservation is relatively new and desires a special discussion. Differences in conservation and management strategies are defined here with respect to three countries. Germany is used as an example for an industrialized country, relatively poor in landraces. Italy may suit as example for an industrialized country with high diversity in agricultural products and production techniques, and Cuba is an example for a tropical country, scarcely industrialized and extremely rich in PGR. The following categories of countries are defined here: (a) *Category 1*: country e.g. Cuba; (b) *Category 2*: country e.g. Italy; (c) *Category 3*: country e.g. Germany. The definition of specific categories with respect to the different situations of these countries is extremely helpful in valuation of ex situ, in situ and on-farm measures regarding their effectiveness and necessary finances in the context of realization of the requests of the Convention on Biological Diversity to protect the diversity in countries and regions. First of all, management of germplasm including breeding and selection in the hands of the farmers has to be secured. On-farm management is a dynamic approach and the present expectations to this are high and tend to overload this concept. More realistic is an integrated approach considering the respective country and local conditions including farmers' preferences and application of all conservation systems.

Keywords: Agro-biodiversity; Genetic resources; Management practices; Management strategies

1. Introduction

In contrast to the on-farm management of biodiversity itself, the scientific concept for on-farm conservation is relatively new. There have been early proposals, e.g. by Kuckuck (1974), for the conservation of cereal fields together with wild relatives allowing genetic interchange in gene centers. However, only in the eighties of the last century a broader attention was given to on-farm conservation. However, a proposal to conserve fields of *Triticum monococcum* L. and *T. dicoccon* Schrank in Southern Italy (Perrino and Hammer, 1984) received not much attention yet. More

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information was necessary and was provided by stressing the evolutionary importance of introgressions of wild relatives into crops and vice versa, e.g. *Secale* and *Brassica* spp. in Italy), or *Hordeum* spp. in Libya (Hammer et al., 1985; Perrino and Hammer, 1985). The potential of on-farm management of plant genetic resources (PGR) became more and more recognized due to several studies in subtropical and tropical regions (e.g. Esquivel and Hammer, 1988; Altieri, 1989; Brush, 1989). In these centers of diversity genetic erosion is less progressed and on-farm management is practiced in home gardens (Esquivel and Hammer, 1992) or other environments (Brush, 1995).

The management of PGR on-farm became a major issue in the area of PGR conservation for food and agriculture during the last decade. The wording of the Convention on Biological Diversity (CBD) clearly reflects this stating that ex situ conservation is to be considered as a complement of in situ measures (Anonymous, 1993). Actually, the CBD does not use the term on-farm conservation, but according to the reading the CBD considers on-farm conservation as part of in situ conservation. Also the activities of the International Plant Genetic Resources Institute (IPGRI) at Rome are recently much more stressing the in situ and on-farm aspect of conservation of biological diversity for food and agriculture. However, the IPGRI was founded in 1970 to better coordinate international gene bank activities and there was no talk about in situ and on-farm conservation at that time within this organization.

Scientists, political decision-makers and others in industrialized countries discuss a lot about the on-farm sector in particular in developing countries (Engels, 1995). The on-farm sector is very much talked about but one has the impression that it is more a studied object than an active player or participant in the area of PGR conservation.

The purpose of this overview will be to clarify the role of different subjects in a complementary approach to conservation and development of PGR for food and agriculture.

A clarification of the terms ex situ, in situ and on-farm conservation is given in Table 1. Such a clarification seems necessary, since even a legal document like the CBD does not properly distinguish between in situ and on-farm conservation which, however, is important in particular for PGR in food and agriculture.

2. Categories of diversity

There are different categories of biological diversity which have to be considered: (1) infraspecific diversity, sometimes referred as genetic diversity, (2) diversity of species and (3) diversity of ecosystems (Akeroyd, 1996; Wilkes, 1989). To protect diversity of these different categories effectively different strategies have to be chosen. Specified for cultivated plants, wild relatives of cultivated plants and weeds which are the most important categories of plants for plant diversity in agro-ecosystems, Table 2 gives an overview about their efficiency. Such a consideration is artificial since in reality there are many biological and social interactions among the conservation methods and the people involved in them.

From a standpoint of a user of PGR, in situ activities are sometimes judged very critical and the general picture for conservation activities is also very negative referring to Shands (1991): ‘genetic resources conservation has been less than completely satisfactory over time as a result of weak or poorly funded ex situ collections while in situ efforts have been virtually nil.’

3. Examples from different countries

3.1. Germany

In Germany about 90% of the original diversity of landraces is lost (Hammer, 1998). For some crops traditional landraces continue to exist, e.g. fruit trees, medicinal and aromatic plants, local vegetables, grasses and other fodder plants. In the cereals, a severe decline can be observed similar to that in Finland where landraces of oats have been reported to be 100% in 1902, 34.4% in 1922, 7.5% in 1935–1939, 1.5% 1950, and 0.2% in 1955 (Ahokas and Manninen, 2000).

Germany, on the other hand has a strong gene bank system which can give input for on-farm

Table 1
Comparison of ex situ, in situ and on-farm conservation or management of genetic resources of animals and plants on-farm regarding different criteria (changed, after Gladis, 2000)

Criteria	Ex situ	In situ	On-farm
Taxa focussed on	Cultivated species with their infraspecific taxa; wild species of potential use	Wild species with their infraspecific taxa; main interest to hemerophobes (not adapted to cultivation)	Cultivated species, accompanied taxa and hemerophilous relatives (adapted to cultivation)
Intention (purposes)	Conservation and investigation (protection, utilisation, exchange, presentation, evaluation, breeding, reintroduction programs)	Maintenance (evolutionary adaptation, protection, population biology, monitoring, potential utilisation)	Management (utilisation, mainly diversification of products; maintenance and development of PGR, studies on domestication, extensivation in agriculture and protection of human environment)
Methods	Keeping individuals or minimum populations outside their natural habitat in an artificial environment, mainly without parasites, predators (special case: in vitro)	Protecting vital populations and their native environment under native conditions and native selection pressure (with increasing human influence)	Keeping domesticated animal and plant populations, protecting whole ecosystems under farming including grassland conditions and selection by farmers and consumers
Limitations	Personal interests, missing collecting strategies (what?) and sampling concepts (how and how much?), finances, space for storage and reference collections, scientific capacity, low level of knowledge regarding optimum and pessimum living conditions, biology, ecology, behaviour, etc., limited access (quantity of samples, regeneration technique and frequency), missing data on traditional preparation, application or use, genetic shift and drift	Expanding human population with irreversible influence on native environment including protected areas	Reduced number of experienced farmers (increasing specialisation, intensified and industrialized agriculture); the utilised biodiversity is reduced to few high yielding and near related plant varieties and animal races, required by modern marketing systems and industry; fast changes in land use and management
Institutions and people involved	Gene banks, Botanical and Zoological Gardens, special collections, research stations, breeder's collections, amateurs and professionals, a decreasing number of specialists	Protected areas, National Parks, Biosphere Reserves, specialists in research, amateurs and professionals	Farms, gardens, grassland, forests, Biosphere Reserves including ruderal areas, specialists in research and breeding, farmers, hunters, consumers
Experience	500 years	10 000 years	10 000 years unintentionally + 10 years intentionally
Networking	Global and regional exchange of material and material related data, internationalisation of breeding work; specialisation of collections (new)	Purpose-dependent networks exist or networks are under construction. Their aim is harmonisation of activities	Regional networking, co-operation with ex situ collections should be established; land use within protected areas depends from applied techniques (e.g. in biosphere reserves, see the UNESCO-program MAB)
Security	It is unknown, which technique is the best, which characters and data, what material will be of value in future; participants on networks have to accept agreements and regulations		

Table 1 (*Continued*)

Criteria	Ex situ	In situ	On-farm
Remarks	The quality of data and each kind of information on collected material like names, origin, characters... should never be confused with the material itself. The decision about true or false doublets e.g. needs more basic studies		

activities and strengthening new on-farm facilities (Gladis, 1994; Hammer, 1994).

For Germany, an approach integrating ex situ and on-farm sectors was presented (Hammer, 1996). There have been reported about 50 initiatives actively working in the field of in situ conservation and development of PGR (Blümlein et al., 1995). From all industrialized countries Germany has probably one of the highest degrees of organization within the informal sector engaged in in situ conservation projects.

Comparable to the situations reported for Cuba (Hammer et al., 1992–1994) and Italy (Laghetti et al., 1998), also in Germany immigrants have an increasing influence of the diversity of cultivated plants, mainly in gardens (Gladis, 1999).

With respect to agro-biodiversity, Italy has to be considered as a category 2 country with a low to medium native and agro-biodiversity, mostly secondary, outside a center of diversity. On-farm management on a low level persistent (e.g. fruit trees), mostly Non Governmental Organizations (NGO) and activities of other enthusiasts. Gene banks usually well developed, many Botanical Gardens.

3.2. *Italy*

A comparison between the results of a PGR exploration done in South Italy in 1950 (Maly et al., 1987) and explorations in the 1980s of the same area led to the result that about 75% of the landraces in the area have been lost (Hammer et al., 1996). However, there is still a perspective for the on-farm conservation, particularly for plants in gardens and on small fields, where effective niches are provided for landraces of vegetables, pulses, fruit trees, and aromatic plants. Landraces of cereals are much more eroded which depends, among others, on the availability of local mills.

Nevertheless, about 25% of the landraces are available for on-farm conservation from gene banks. On some of the small islands, e.g. Linosa and Ustica (Hammer et al., 1997, 1999a), specific and infraspecific diversity of crop plants has been better preserved, so that proposals for on-farm conservation have been made. A certain synergism could be developed with the flourishing tourism of

Table 2
Conservation methods and their relative superiority for different categories of diversity scored by their importance for specific groups of diversity (changed, after Hammer, 1998)

Method of conservation	Ex situ (gene banks)	On-farm (agro-ecosystems)	In situ (other ecosystems)
Category of diversity	Developed countries (category 3)		
Infraspecific diversity	C**** R** W***	C*** R** W**	C* R**** W**
Diversity of species	C** R** W***	C*** R** W***	C* R*** W**
Diversity of ecosystems	C* R* W*	C** R*** W****	C* R*** W**

*, no importance; **, low importance; ***, important; ****, very important. *Explanations:* The relative importance of the methods to the specific groups of diversity is indicated by the number of asterisks. C, crop species; R, species of wild relatives of crops; W, weeds.

the islands. Some agricultural products like the famous lentil of Linosa or lentil from Ustica and other indigenous and the several wild endemics of the floras are of great scientific interest. The typical agricultural products and their genuineness and characteristics can be protected and can receive more recognition by new community denominations in Italy. Due to these marks of origin and quality, the income of the farmers of these islands could increase (Hammer et al., 1997).

In central and especially northern parts of Italy the conditions for on-farm conservation are less favorable. During the period of 4 years, only 486 landraces could be collected (Hammer et al., 1999b) in comparison with 1622 landraces obtained in South Italy and Sicily (Hammer et al., 1992). Progress can be observed by increased use and reintroduction of traditional landraces, e.g. from hulled wheat (Vazzana, 1996).

The situation in North Italy is close to that of Germany. Only few landraces are still available for conservation but a lot of new activities are developed by NGO's. As an example 'pro specie rara' should be mentioned, which covers also the mountainous parts of North Italy (Anonymous, 1995).

South Italy belongs to the classical Mediterranean center of diversity already recognized by Vavilov (1926). The evolutionary power of this area has led to specific and infraspecific differentiation of crops. Even recent introgressions between cultivated species and their wild relatives can be observed frequently (Hammer et al., 1999a), increasing the variation of crop plants. Centers of diversity of crop plants have to play a leading role with respect to on-farm management (Brush, 1995), and they actually do, because they only belong to a small part to the 'western' countries with their high genetic erosion.

With respect to agro-biodiversity, Italy has to be considered as a category 2 country with a medium to high biodiversity; within, between or near related to center(s) of diversity. On-farm management on a lower level (about 20%) through agri- and horti-culture. Gene banks medium to well developed.

3.3. Cuba

Cuba has not been characterized as a gene center by Vavilov (1926) but later studies have shown that this island owns a high diversity of crop plants (Hammer et al., 1992–1994). Already on the species level the diversity is impressive: 1200 species of crop plants have been found, about 17% of the world crop species. Most of the material was found in gardens with subsistence agriculture. These so-called 'conucos' have been characterized as microcenters for agro-biodiversity. The conditions there allow preservation and evolution of cultivated plants (Esquivel and Hammer, 1988, 1992).

In these gardens most of the PGR (about 70%, with the exception of the important plantation crops) can be maintained under on-farm conditions without additional input from GO's or NGO's. Of course, the situation has to be monitored to avoid present or future losses. A gene bank system has been created in Cuba where samples of the more important crops are stored for security reasons. These gene banks could also do the necessary monitoring of genetic resources work.

As a tropical country, Cuba provides the possibility to grow many different plant species. The high crop species diversity is due to the influence of immigrants from different parts of the world, e.g. Africa, East Asia, Europe (Hammer et al., 1992–1994), who introduced their plant material from the respective origin or occurrence. In this sense, Cuba cannot be seen as a center of origin (or as primary gene center) according to Vavilov (1926), but as a secondary center of diversity, which established during the last 500 years. It shows the relevance of on-farm conservation in countries with poorly developed economy.

With respect to agro-biodiversity, Cuba has to be considered as a category 1 country with a very high biodiversity, primary or secondary; situated in a center of diversity. On-farm management through subsistence agri- and horti-culture. Gene banks developing.

The numbers of cultivated plants and the maintenance systems for PGR in the three countries are shown in Table 3. For forest plants, nongovernmental measures are just in the initial phase (Begemann et al., 2001). The efficiency of conservation methods is largely dependent of the country categories (Table 4).

4. Discussion

Breeders have to define their breeding goals according to the request of the market: they always need genetic resources for reaching higher yield, better quality, faster growth, better tolerance against biotic stress (diseases, pests, competitors) and against abiotic stress factors (climatic conditions, salinity, chemical contamination). Farmers can only grow what breeders offer and thus produce what industry and market desire. Systems of interdependences have always existed, but after the industrialization the markets themselves became more and more uniform.

The management of agro-biodiversity and genetic resources on-farm needs diverse farming methods and diverse social structures, regional relationships. In industrial countries, the traditional structures are lost or reduced and so are the genetic resources. Links to on-farm management programs in other countries and continents are essential for exchange of material and experience. The intended revitalization of on-farm management practices, methods and results needs to be well documented (see Zeven, 1996).

In developing countries this situation is very different. Several projects regarding participatory plant breeding are initiated there. Whether these projects really will help to preserve a wider range of diversity will become obvious in the future (e.g. Sthapit and Joshi, 1998).

Table 3
Numbers of cultivated plants and governmental maintenance systems for PGR in different countries

Germany	350 crop plant species. Different ministries are responsible for managing PGR ex situ and in situ. The co-operation between them as well as between the federal and regional structures has to be improved; on-farm management exists very limited on private basis only. The large gene banks are facing severe reduction of funding and staff. A system of protected areas exists
Italy	550 crop plant species. Proposals for founding special reservations for agro-ecosystems are made several times. A system of gene banks, i.e. seed gene banks and field gene banks exists. IPGRI and FAO headquarters are situated in Rome
Cuba	1200 crop plant species. A gene bank exists but covers a very limited amount of samples and diversity. On-farm activities are not organized but very frequent and important

Table 4
Efficiency of conservation methods in dependence of country categories

Method of conservation	Category 1 (e.g. Cuba)	Category 2 (e.g. Italy)	Category 3 (e.g. Germany)
Infraspecific diversity	E** I**** O****	E*** I*** O***	E**** I** O**
Diversity of species	E** I**** O****	E*** I**** O***	E**** I*** O**
Diversity of ecosystems	E* I**** O****	E* I**** O***	E* I*** O**

*, no importance; **, low importance; ***, important; ****, very important. *Explanations:* The relative importance of the methods to the specific groups of diversity is indicated by the number of asterisks. E, ex situ; I, in situ; O, on-farm.

A brief characterization of the people directly or indirectly involved in the conservation of biological diversity can be given as follows.

In industrialized countries, farmers and gardeners are not any more participating in breeding or selection procedures, i.e. they do not actively influence the genetic structure of the plants they grow. The seed supplies for each growing season are usually bought on the market and re-growth of stored seeds from former cultivation became the exception in industrialized countries because of several reasons, e.g. growing of hybrids, phytopathological problems, legislation, etc.

Farmers and gardeners are often not organized and in western countries are actually competing severely against each other. Economically based decisions have replaced all traditional influences on how farming and gardening is practiced and which cultivars to grow. A sense of community between farmers has been replaced by the survival of the economically fittest. A vast amount of knowledge is threatened by extinction in the near future in industrialized countries. The traditional family farm is more and more replaced by larger entities and this change seems to accelerate. Establishing monetary subsides for conserving biological diversity in the on-farm sector has been proposed several times, but whether such subsidies will prohibit genetic erosion can be questioned.

5. Conclusion

Gene banks have to define more clearly what their role will be in a concerted action to reduce genetic erosion (Hammer et al., 1999c). There can be no doubt that scientifically trained gene bank staff, plant breeders, population biologists and other conservation biologists have been the people, who actually draw public attention to the need of increased activities for conservation of biological diversity by in situ and on-farm conservation. Later in time but much more noticed by the public, politically engaged groups and individuals became very active in the area of biodiversity conservation. It is obvious that the biological diversity of cultivated plants can not be understood sufficiently by only approaching the phenomena from one of the many view points: a botanically, genetically, politically, historically, socially or economically. However, thorough approaches by the different disciplines have to be made and the most important task for the future will be to integrate the different aspects and come to show practical and efficient ways for conservation and development of PGR.

Therefore, approaches like participatory plant breeding for selecting cultivars with local adaptations are with very few exceptions, only found in developing countries. Local adaptation can be adaptation to local environmental conditions, but also adaptation to local preferences of consumers or local peculiarities in usage or processing of the harvested material.

In developing countries, the lack of access to technical and chemical means of modern agriculture helps to artificially conserve traditional ways of farming. Political instability can cause very severe sudden changes in the rural societies and this will always include a reduction of biological diversity. So far family tights and strong cultural traditions cause an enforced stability in developing countries, which often means poverty, hard work and the opposite of freedom to the farmers. The burden of hard physical farming work is often on the shoulder of women in these societies. However, this has resulted in the continued preservation of a lot more diversity in agro-ecological systems than in developed countries including their gene banks.

Conservation biologists are the group mostly involved in scientific description and understanding of biological diversity. Botanists and zoologists are inclined to focus on wild species and scientists with an agricultural background, for example breeders, tend to neglect the broader picture of biodiversity because they are subject to strong economic pressures and have to produce scientific results of economic relevance. Plant breeders are probably the agricultural scientists, who have the best understanding for biological diversity issues as far as species of relevance for food and agriculture are considered. Plant breeders have also been the first who recognized the value of PGR and that they are endangered by extinction (Harlan, 1975). Molecular genetics became an important tool for studying the diversity of plants. However, the description of biodiversity is still a scientific challenge. There is no scale for measurement of diversity. Also molecular approaches will not solve this principal problem. The knowledge and recognition of biodiversity in agro-ecosystems is due to the efforts of modern science as it has developed in the last centuries. Alexander von Humboldt is probably the first scientist, who clearly recognized this at the beginning of the 19th century while traveling through many parts of the world. Alphonse De Candolle, Vavilov and others scientifically developed his ideas.

A problem to be faced in the near future will be lack of taxonomists. For efficient communication in particular with people engaged in the on-farm sector it will be essential to strengthen and spread the knowledge of classical taxonomy. Already there exists an amazing confusion about species identification within the scientific community. This has also economic consequences for the field of PGR for food and agriculture (Small, 1993). Gene banks should have tight links to plant taxonomy in order to better understand the issues related to species and infraspecific diversity. By spreading this knowledge gene banks will significantly support in situ activities for conservation of diversity. Also, gene banks should much more actively approach the different on-farm and in situ initiatives existing. This will be an important step to reach complementarity of activities.

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