

# Principles of plant genetic resources conservation: Some aspects for a national programme

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## ABSTRACT

Since the dawn of agriculture, plant germplasm has been continually dwindling. The erosion of crop germplasm was accelerated by recent progress in plant breeding. Farmers' adoption of high-yielding and early-maturing varieties of maize, cowpea, and cassava (to mention only three examples in Ghana) has reduced the genetic base of these staple food crops. Increases in land use and climatic changes are also threatening agricultural biodiversity. Droughts and accompanying bushfires, changes in agricultural practices as well as ethnic conflicts are threatening the agricultural biodiversity in many parts of the world. Conservation of genetic resources and reinstatement of genetic diversity in the major food crops are imperative to feeding our ever-growing population. This paper reviews the spectrum of genetic resources, the usefulness of different segments, conservation targets, and strategies for conserving and using the irreplaceable crop germplasm. Some aspects of Ghana's Plant Genetic Resources Programme, which hitherto had not been given prominence, are highlighted to generate interest and support. The significance of ethnobotanical studies and the need to incorporate such studies in future germplasm collecting missions are also highlighted.

## RÉSUMÉ

AKROMAH, R.: *Principes de la conservation de ressources génétiques de plante: Quelques aspects pour un programme national.* Depuis l'aube de l'agriculture, le germplasm se diminuait continuellement. L'érosion de germplasm des cultures était précipitée par le progrès récent de la reproduction de plante. L'adoption des variétés de rendement élevé et de la maturation tôt de maïs, de dolique et de manioc (pour citer seulement trois exemples au Ghana) par les cultivateurs a réduit la base génétique de ces cultures alimentaires de base. L'augmentation d'utilisation de terrain et les changements climatiques aussi menacent la biodiversité agricole. La sécheresse et le feu de brousse qui l'accompagne, les changements dans les pratiques agricoles ainsi que les conflits ethniques menacent la biodiversité agricole dans la plupart du monde. La conservation des ressources génétiques existantes et la réintégration de la diversité génétique dans les cultures alimentaires majeures sont urgentes pour l'alimentation de la population qui va croissante. Cet article réexamine le spectre des ressources génétiques, l'utilité des différents segments, les objectifs de conservation, et les stratégies de conserver et d'utiliser le germplasm de culture irremplaçable. Quelques aspects du Programme des Ressources Génétiques de Plante du Ghana, qui, jusqu'ici, n'ont pas été accordé la prééminence, sont mises en lumière en vue d'engendrer l'intérêt et le support. L'importance d'études ethnobotaniques et le besoin d'incorporer telles études dans les missions futures d'accueillir le germplasm, sont également mis en lumière.

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## Introduction

A widely quoted definition of conservation is "the management of human use of the biosphere (that is, all living things) such that it may yield the greatest sustainable benefit to present generations while maintaining its potential to meet the needs and aspirations of future generations" (IUCN-

UNEP-WWF, 1980). Thus, conservation includes preservation, sustainable use, enhancement, and restoration. As a means of development, maintenance of the ecosystems in the interest of human economies should be integrated with sound management (Prescott-Allen & Prescott-Allen, 1982).

For edible dry matter, the 12 major food crops are wheat, maize, rice, barley, potato, soybean, sugarcane, sorghum, sweet potato, oat, millet, and cassava (Harlan & Starks, 1980). All these crops originated from wild species by undergoing domestication, selection, dispersal, mutation, hybridization, and differentiation-selection cycles. Introgression has undoubtedly played an important role in the evolutionary pathway of several major cereal crops and enriched their gene pools (Harlan, 1961, 1965, 1975, 1976; Chang, 1976a, 1976b). Despite the "Green Revolution" in wheat and rice, the significant increases in food production have barely kept pace with the increases in human population, and mainly because of high population rates and regional ethnic conflicts, the per capita food production in the developing countries has lagged behind demand since the early 1970s.

The prospects of quantum jumps in food production in the future seem less promising than those of several decades ago, because much of the arable lands in monsoonal Asia, for example, has been developed and used. Undeveloped, but potentially usable land, is found only in Brazil and parts of Africa. The use of marginal lands will destroy the ecosystems by deforestation or damage. Future growth in food production will depend on further improvement in crop yield per unit of land and more efficient farming systems to produce more food per hectare per year. Production costs and the use of agricultural chemicals that are deleterious to the environment should be reduced by making efforts to reinstate disease and pest resistance into the genetic backgrounds of the major food crops.

#### **Genetic erosion of crop germplasm**

Among the natural resources, the germplasm or genetic resources of crop plants have been sharply depleted in both the number of crop species and the genetic diversity expressed by the number of genetic variation within a species since the beginning of scientific plant breeding (NAS, 1972; Frankel, 1973, 1974; Harlan, 1975). The

genetic base of the major food crops was sharply reduced when farmers, consumers, processors, and governments demanded genetic uniformity among the new varieties. The rapid spread of improved varieties has intensified the displacement of the traditional unimproved cultivars (land races) and accelerated their extinction. The trend towards greater uniformity has increased the potential genetic vulnerability of the major crops to epidemics of diseases and pests. The broad genetic base required for further improvement continues to shrink simultaneously. Paradoxically, and as Hawkes (1983) rightly put it, genetic erosion is a by-product of successful plant breeding. In this regard, genetic conservation programmes are measures to safeguard the seemingly less attractive germplasm which plant breeders may return to for genes that could restore hope in times of disease or pest outbreak.

Under the aegis of the Consultative Group for International Agricultural Research (CGIAR) and through the direct initiatives of the International Agricultural Research Institutes, a sizeable amount of the genetic resources of the major food crops, namely wheat, maize, rice, cassava, yams, cowpea, groundnut, pigeon pea, sorghum, millet, banana, and plantain have been assembled for long-term conservation and use. The European Union, the USA, the Nordic countries, Russia, and many of the East European countries have also made great efforts in conserving their plant genetic resources. Unfortunately, the countries of the 'gene-rich' south have not paid much attention to their dwindling genetic resources. It is important that these countries do their best to conserve the genetic resources of their indigenous food crops that face the greatest threat of genetic erosion due to the spread of new improved varieties and environmental degradation.

#### **Need to conserve genetic resources for future needs**

Plant breeders have been drawing heavily on reservoirs of genetic variation for the impressive progress made in the past five decades.

Mutations, spontaneous and induced, have provided additional, though small, gene to the pool. Future plant breeding will depend on a continuing and expanding supply of genetic resources. The urgent task facing all users of crop germplasm is rescuing and preserving the dwindling resources to meet the following imminent needs:

1. To minimize damage by major diseases and pests.
2. To control new pests or new biotypes of a pest.
3. To tolerate adverse environments, i.e. drought, adverse soil factors, excess water, extreme temperatures, and pollutants.
4. To extend cropping into new areas.
5. To improve physical and nutritive quality.
6. To increase physiological efficiency in dry matter and grain production.

Measures should also be taken to safeguard germplasm already assembled for conservation and facing the threat of genetic erosion through loss or neglect (IBPGR, 1983). Genetic erosion is an irreversible process. National programmes should, therefore, be strengthened to conserve and make full use of the available germplasm. There should be collaboration on national and international levels so that free exchanges are assured to enable crop scientists to adequately evaluate and use the gene pools. Cooperative and multidisciplinary efforts are also needed to provide security for the conserved stocks, either as *in situ* or *ex situ* collections. Thus, major portions of the crop germplasm may be conserved for use by the present and future generations of humankind. The preservation of genetic diversity is a matter of insurance and investment for sustaining and improving future food resources. It is also an issue of moral principle to deter the extinction of useful plant species (IUCN-UNEP-WWF, 1980).

#### History of biological conservation

Until the dawn of the Neolithic era, sometimes referred to as the Neolithic Revolution, man

depended entirely on his immediate environment for food, which consisted of plants and animals in the wild, obtained by hunting, trapping, fishing, and gathering. Within the radius of their travel on foot, the early hunters maintained a kind of equilibrium among the human population, the sources of food available from wildlife, and the surrounding environment. As rudimentary agriculture began to grow in several cradles of agriculture about 10,000 years ago, the late hunters settled on sites where the domestication of plants and animals was compatible with the surrounding environment. The settled life pattern led to the formation of communities. This socio-political change brought about a new awareness of the variable environment, which determined the abundance or scarcity of food. Because populations grew faster in a settled life pattern than in a nomadic style, population pressure led to the recognition of the need to conserve biological resources so that a sustainable food supply within the community could be ensured.

The 'rubbish heap' hypothesis of Anderson (1969) suggests that ecological weeds which colonized the disturbed areas around human dwellings were gathered and eventually cultivated. Some of the ecological weeds were probably those which had been gathered, and from which seeds and other propagules had been discarded, thus reinforcing the intimate relationship between man and those plants. Soon after, human migration also took on a greater dimension to cope with the dwindling food sources. Soil conservation measures then became some of the more recent outgrowths of biological conservation ethics. Man's awareness of the need to maintain a balanced biotic environment to ensure a sustained supply of food, fibre, and other necessities signalled the advent of a higher state of civilization.

The domestication of plants resulted in a number of fundamental changes in the plants. Ford-Lloyd & Jackson (1986) observed that during the process of domestication, plants lost their ability to survive as wild plants, as mutations which

enabled man to harvest plants more easily, such as the non-brittle rachis mutations in cereals, or the loss of legume dehiscence in the pulses, arose in plant populations. Hawkes (1969) suggested that the early men must have gathered and consumed brittle and non-brittle forms, but when man began to retain some of the seeds for sowing, selection pressure changed in favour of the non-brittle mutants. The process of harvesting actively favours these mutations, but such plants would be at a considerable advantage in the wild. Other features which have changed through the process of domestication include the suppression of defensive mechanisms (e.g. spininess in yams), the reduction of sexual fertility in vegetatively propagated crops, and a change in habit, including a change from perennial to annual.

#### Dangers of genetic uniformity

The history of world agriculture during the past 150 years is dotted with examples of major epidemics due to diminishing genetic base and point to the importance of maintaining genetic diversity in major crops. The following six examples are worth citing:

1. The famine of the 1840s in Ireland due to the potato late blight (*Phytophthora infestans*) (NAS, 1972).
2. The wheatless days of 1917 in the US due to stem rust epidemics (*Puccinia graminis*) (NAS, 1972).
3. The great Bengal famine of India in 1943 associated with the brown spot disease of rice (*Cochliobolus miyabeanus*) and a typhoon (NAS, 1972).
4. The complete elimination of all oats derived from the variety Victoria in the US, due to the Victoria blight caused by *Cochliobolus victoriae* (NAS, 1972).
5. The southern corn leaf blight epidemic (*Cochliobolus heterostrophus*) of 1970-71 on all US corn hybrids carrying the T-type cytoplasmic male sterility (NAS, 1972).
6. The rapid shift of the rice brown planthopper (*Nilaparvata lugens*) from Biotype 1 to

Biotype 2 during 1974-76, when large areas of the Philippines and Indonesia were planted to a few semidwarf rice (Chang *et al.*, 1979). This cycle was repeated in 1982-83 when IR36 was widely grown in the same areas (Chang, 1984).

These catastrophes were solved only after reinstatement of genetic diversity in the respective crops, and through sequential release of varieties with vertical resistance based on major genes. Recent approaches have relied on horizontal resistance under multi-gene controls that prevent total crop failure during disease outbreak. The potential risks of genetic uniformity leading to the vulnerability of crops are even greater today as farmers continue to grow new varieties from season to season and usually on the same plots. There is the need to introduce genetic diversity into major crops for several reasons:

1. Slow down genetic changes in a major pest or pathogen.
2. Prevent evolution of a minor pest into a major pest.
3. Minimize yield reductions due to unusual climatic changes.
4. Provide the potential for further genetic improvement.

Diversity in itself does not guarantee protection unless that diverse gene pool includes genetic resistance to, or tolerance for, the production problem concerned (Brown, 1983).

#### Land races, wild species, and weed races

Land races are farmer-developed varieties of crop plants that are adapted to local environmental conditions. Wild species are the non-cultivated species that are more or less closely related to a crop species (usually in the same genus). They are not normally used in agriculture but can occur in agro-ecosystems (e.g., as weeds or a component of a pasture or grazing land). The land races and wild species offer the largest potential for use in plant breeding. Land races evolved by natural and human selection under conditions of low-input cultivation, and were adapted to the local

environment where they were cultivated for ages. Land races are characterized by diversification among races; within a race, between sites and populations, and within sites and populations. Their genetic diversity, expressed over space and time, is likely to provide improved protection against climatic extremes and epidemics (Harlan, 1975). Land races can provide high yield potentials to plant breeders, if properly used in crosses, e.g., semidwarfism and photoperiod insensitivity in wheat and rice. However, the main use of land races has been and will remain as donors of desirable genes (Frankel & Soule, 1981).

The CSIR Plant Genetic Resources Centre (PGRC) at Bunso, Ghana, like many other PGR centres elsewhere, has collected many of the land races of the major food crops in Ghana, but the germplasm collections are still deficient in eco-geographic coverage, number, and information on their potentials. Land races also present challenges during field sampling, nomenclature, maintenance of genetic integrity, and systematic description (Chang, 1976; Kuckuck, 1970; Frankel & Soule, 1981). The materials need to be properly described to identify distinct genotypes in the collections and subject them to further evaluation through screening for tolerance or resistance to diseases and pests as well as other physico-chemical properties. In these respects, the PGRC should be supported to develop and strengthen its capabilities beyond morpho-agronomic characterization and use molecular approaches for germplasm characterization.

The wild species and the weed races represent the highest level of genetic heterozygosity and heterogeneity among the different classes of germplasm. They generally have high rates of natural outcrossing than the domesticates. *Oryza longistaminata* A. Chev. et Roehr., a perennial wild rice of Africa, for example, is even self-incompatible (Chang, 1985). The genetic variability provided by the wild species and weed races is a source of the following:

1. resistance to diseases and pests, controlled by major genes;

2. tolerance to extreme environments such as salinity, desiccation, waterlogging, and frost;
3. high vegetative vigour in sugar cane and potatoes;
4. high protein content in cassava and oats;
5. greater fibre strength in cotton;
6. greater oil content in oil palm; and
7. cytoplasmic male sterility and restorer systems in many crops.

Summaries of these findings may be found in Harlan (1976), Hawkes (1977), Frankel & Soule (1981), Prescott-Allen & Prescott-Allen (1981, 1982, and Frey (1983).

For most crops, the wild species and weed races are either poorly collected, inadequately maintained or both. In the face of the continuing environmental degradation world-wide, there is an urgent need to collect these important sources of genetic diversity from the centres of origin of the crops. These missions would require sufficient fundings to provide the appropriate logistics to enable collectors to comb the remote and difficult terrain to collect these invaluable genetic resources.

#### Targets for conservation

The primary goal in conservation is to conserve as many representative samples of germplasm as human resources and logistics permit. Priority should be given to those being threatened by extinction or displacement, and in areas where construction activities (roads, buildings, dams, etc.) pose a threat to the flora and fauna. These efforts should aim at collecting the maximum diversity in the minimum amount of samples. The size of a germplasm collection can limit its accessibility, and thus hinder its use and management. Large sizes of germplasm can pose problems such as the following:

1. Difficulty in getting an overview of the collection, to decide what should be added or could be removed.
2. Difficulty in choosing material because there is so much material to choose from.

3. Difficulty in focusing; knowing very much about a relatively few accessions can be better than knowing relatively little about very many.

To improve this situation, the current practice in many genetic resources centres is to select a limited set of the accessions from a collection with as much genetic diversity as possible: a **core collection**. Frankel (1984) introduced this concept and defined it as 'a limited set of accessions which represents, with a minimum repetitiveness, the genetic diversity of a crop species and its wild relatives'. This idea was picked up and applied by the genebank community as a method of overcoming the difficulties in handling large collections. A germplasm collection is often the result of historical events and arbitrary decisions; collecting missions and specific research programmes often resulted in over-representation of certain material whereas other types of material can be under-represented. Core collection tries to increase the balance between the types of material in a relatively small selection of accessions. Once the core has been defined for conservation, there will also be a need for setting up a duplicate collection of the core germplasm at another location, as an insurance against environmental hazards such as bushfires, earthquakes, and sudden mechanical/electrical failures in the storage facility.

#### **The PGR programme at Bunso**

To enable the PGRC to handle her germplasm effectively to the benefit of users, and with the intention of minimizing the cost of genetic conservation, while ensuring long-term conservation of maximum genetic variation, it is the PGRC's vision to create core collections for all the crops it holds under conservation.

One of the PGRC's targets in the short term is to gather the diversity of those food crops, which it describes as 'minor crops' or under-utilized plants. These include the African yam bean (*Sphenostylis stenocarpa* Harms), Kerstings groundnuts (*Kerstingiella geocarpa* Harms, now called

*Macrotyloma geocarpa*), Frafra potato (*Solenostemon rotundifolius*), Bambara groundnut (*Vigna subterranea* (L.) Thou.), Velvet beans (*Mucuna pruriens* DC var. *utilis* Wall.), and Pigeon peas (*Cajanus cajan* (L.) Millsp.). These minor staple food crops need to be safeguarded in the face of rapid spread of improved varieties of the major staples. These 'orphan' crops which appear versatile in our agro-ecosystems and which have been tolerant to long-term neglect in research support, will be the ones that farmers will fall on if drought or disease break out in the major food crops. The inherent potentials of these under-utilized crops will be known when they are brought into mainstream research.

Our future collecting missions will incorporate ethnobotanical studies to tap traditional knowledge on conservation and uses of these crops. This knowledge is considered to be the best starting-point for effective conservation. The role of women in genetic resources activities in Ghana has been described by Bennett-Lartey & Akromah (1996), but there is still more to learn on the status of plant populations, on the extent and nature of plant use by local communities, and on the capacity of the resource base to support different economic activities. Indigenous knowledge can be used to evaluate the cultural, biological, and economic importance of biodiversity. It is also useful in creating awareness of the importance of biodiversity, as it is generally easier for the general public to relate to than the results of scientific trials.

The use and benefits derived from conserved germplasm is the sole criterion for assessing a genetic conservation programme. The land races being conserved at Bunso hardly enter breeding programmes in our research institutions. Most breeders tend to prefer breeding materials that already have the desired agronomic background for the following reasons:

1. Crossing a commercial variety with a primitive land race or wild species would introduce many undesirable genes into the

breeding programme and retard the progress of conventional breeding.

2. Seed scarcity and lack of evaluation data on the exotic germplasm, which appear to have no immediate usefulness, are another barrier to using the land races and wild species.
3. Crossability between two distinct species often poses technical difficulties in combining the desired traits, e.g. infertility of hybrids.

Not all land races and wild species carry undesirable gene-complexes. The Turkish, Kenyan and Australian semidwarfs, for example, have greatly improved US wheat production (Reitz & Craddock, 1969; Vogel, Allen & Peterson, 1963; Burgess, 1971). Wild species of *Avena* have greatly enhanced yield levels by contributing greater vegetative growth rates (Helsel & Frey, 1983). A strain of *Oryza nivara* collected from the Uttar Pradesh State of India has provided tropical Asia with the sole source of resistance to the grassy stunt virus (Chang *et al.*, 1975). Varieties developed by IRRI beginning with IR28 carried the *Gs* gene (Khush, 1977).

To prepare exotic germplasm for greater use by plant breeders, it is often necessary to break up the tight linkage between the desired genes and undesirable alleles. This may require an artificially directed backcrossing programme to package the desired genes into the agronomic backgrounds. These preparatory measures, which are known as conversion or germplasm enhancement or pre-breeding, must constitute an important component of the PGRC's programme to make them become more attractive to breeders and enhance their use in breeding programmes.

The other aspect of the PGR programme at Bunso, which requires immediate support and redress, is the documentation system. Documentation is such an essential component of genetic conservation that it is needed in every facet of the programme. Full documentation of conserved material and free exchange of the information would stimulate exchange, evaluation, and use. This process will also help in preserving

valuable germplasm at duplicate sites. Unfortunately, PGRC's documentation of useful information has lagged behind the other facets and become so fragmented and unavailable to interested researchers that it is becoming a bottleneck in its germplasm conservation system. Rogers, Snoad & Seidewitz (1975) have illustrated the functions of a documentation system serving a genetic resources centre. The requisite computer hardware and software must be provided to ensure an efficient documentation system that will serve the full spectrum of conservationists and users. Beside the use of data files for information gathering (passport, characterization, evaluation, etc.), there should be computer programmes for storage, retrieval, statistical analyses, and collation.

It is apparent that these components of the genetic resources programme can no longer be overlooked if our conservation policy is to serve the needs and aspirations of present and future generations. Hence, to effectively execute these programmes, an Information Technologist and a Biostatistician would be required to augment the current research personnel comprising Genetic Resources Conservationists, Plant Breeder, Agronomists, Plant Pathologist and Entomologist.

There will be a need to expand the seed storage facilities, as the current equipment will soon become inadequate for future collections. The Centre requires additional deep freezers, ovens for drying seeds, a low humidity-controlled drying room where seeds will be processed for storage, and a large capacity stand-by generator to keep the facility running during power cuts. Finally, for the Centre to stay abreast with current trends in genetic conservation world-wide and to derive maximum benefit from seed exchange and technology, it has to foster collaboration and strong linkages with international seed storage centres and make every effort to provide in-service training for all categories of the PGR personnel.

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