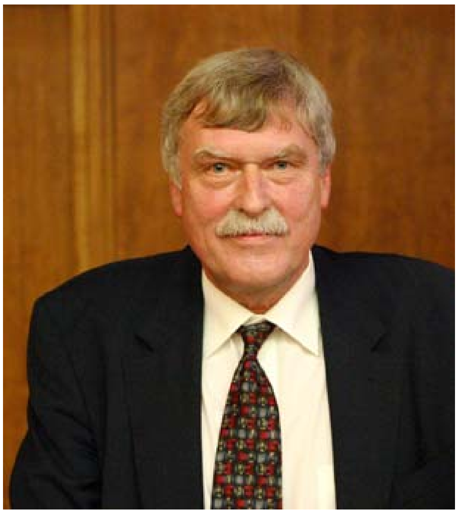
25th Annual Ralph Melville Memorial Lecture delivered at the TAA Annual General Meeting held at the Royal Over-Seas League on 28th November 2007

Securing crop diversity - assuring the future



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Abstract

While the loss of biodiversity receives a lot of publicity, one of its most important components is disappearing almost unheralded: the genetic diversity of the crops on which our current and future food security depends. Such diversity will become ever more important as climates change and new pests and diseases threaten production. Diversity is disappearing from fields throughout the world as changing lifestyles and the globalization of trade have resulted in the abandonment of many traditional crops, and agricultural intensification has resulted in fewer varieties being grown over ever larger areas. Furthermore, many populations of crop wild relatives are under threat from the loss of habitats, and all this is occurring at a time when advances in molecular genetics are making such gene sources more valuable than ever before. Efforts to redress the situation have included the negotiation of the International Treaty on Plant Genetic Resources for Food and Agriculture which came into force in 2004. Large collecting efforts, especially in the 1970s and 1980s, and initiatives to conserve agriculturally important habitats have helped stem the loss, but many germplasm collections are themselves under threat, largely from a lack of reliable funding. Recognizing this situation, the Global Crop Diversity Trust was recently established to provide a stable, long-term source of funding for the world's most important genetic resource collections and a back-up seed repository, the Svalbard Global Seed Vault, has been built in the permafrost, deep within the Arctic Circle, to provide additional security for one of humanity's most important resources.

Introduction

Unprecedented demands will be placed on agriculture over the coming years as the human population expands towards nine billion, increasing urbanization results in changing food habits, an energy hungry world adds biofuels to the list of outputs it demands of its farmers and as pressures grow for the provision of a greater range of ecosystem services. Furthermore, agriculture will almost certainly have to meet these new demands in the face of changing climates, a greater frequency of extreme weather events and an accelerated rate of change in pest and disease spectra. One of the most important resources available to humanity to help meet these challenges is the genetic diversity of crops and their wild relatives. It underpins the ability of farmers and plant breeders to develop new varieties adapted to these changing needs and circumstances. This paper aims to explain the origins and importance of this diversity, threats to its continued existence, strategies for conserving it and some recent policy and institutional initiatives that aim to ensure that it is not only conserved but made readily available to those who need to use it.

Levels of biodiversity

The Convention on Biological Diversity recognizes three levels at which biological diversity is important: diversity among ecosystems, diversity among species and diversity within species. While there are some 250,000 different species of flowering plants only about 7,000 have been used in agriculture. Of these only 150 enter world trade to any significant degree and as few as 20-30 can be regarded as being of major world importance. Fully 50% of humanity's dietary calories come from just three species: rice, wheat and maize. Thus in the context of biodiversity it is not so much the diversity among species that is important for agriculture but rather the diversity that is to be found within species. It is the genetic diversity within crop genepools that underpins the ability of plant breeders to produce new varieties through combining different traits in new combinations to meet new needs and circumstances.

Some idea of the extent of genetic diversity within crop genepools can be gained from the number of samples to be found in some of the world's major collections (see Table 1). Thus, for example, there are almost 100,000 different samples of wheat in the CIMMYT genebank and, duplicates aside, each one is different in some way or another from all the rest.

Centres of origin and diversity

How did this vast diversity originate? When farmers began domesticating wild species and growing them as crops, they selected those types best adapted to their local environment and most suited to their immediate needs. As

Table 1. Number of samples in some collections of major food crops maintained by Centres of the CGIAR *(Source: CGIAR Systemwide Information Network on Genetic Resources, SINGER, http://singer.cgiar.org/)*

Crop	*Institute*	*No. of samples*
Banana	Bioversity International, Italy	1,240
Barley	International Centre for Agricultural Research in the Dry Areas, ICARDA, Syria	26,795
Bean	Centro International de Agricultura Tropical CIAT, Colombia	35,254
Cowpea	International Institute of Tropical Agriculture, IITA, Nigeria	15,004
Lentil	International Centre for Agricultural Research in the Dry Areas, ICARDA, Syria	10,099
Maize	Centro International de Mejoramiento de Maiz y Trigo, CIMMYT, Mexico	25,951
Potato	Centro Internacional de la Papa, CIP, Peru	7,544
Rice	International Rice Research Institute, IRRI, Philippines	108,272
Sorghum	International Crops Research Institute for the Semi Arid Tropics	36,774
Wheat	Centro International de Mejoramiento de Maiz y Trigo, CIMMYT, Mexico	94,576

they migrated to new areas and as their needs changed, so a combination of human and natural selection gave rise to new and different forms adapted to the new circumstances. Still further types were developed as these crops expanded into ever more environments through seed exchange or sale among farmers, or even through theft or pillage. Domestication and the creation of crop diversity, however, did not happen uniformly around the world, but occurred preferentially in certain regions. The Russian geneticist, Nikolai Vavilov, working in the1920s and 1930s was the first to recognize this and he identified a number of Centres of Origin or Centres of Diversity in which a large percentage of the world's crops were domesticated and where still today significant genetic diversity can be found on farmers' fields. The majority of these Centres lie in developing regions of the world. For example, the area known as the Fertile Crescent, extending from the Mediterranean through northern Syria and Iraq, southern Turkey and into western Iran, gave rise to such crops as wheat, barley, lentil, chickpea, pea, olive, fig, onion and flax. Sorghum, pearl millet and cowpea originated in the African Sahel; beans, maize and tomatoes were domesticated in meso-America; rice, banana, coconut and mung bean originated in south and southeast Asia; and the Chinese Centre of origin in east Asia gave rise to soya bean and several species of citrus fruits.

Wild relatives

It is not only the genetic diversity within crop genepools that is important for crop improvement, the diversity within a crop's wild relatives is also increasingly recognized as an invaluable resource for breeding. When in the process of domestication farmers selected the seed from a small number of superior plants for planting the following season, this created a genetic bottleneck which had the effect of limiting the size of the domesticated crop genepool to only a fraction of that of the progenitor. Many potentially useful genes never made it into the domesticated genepool. However, with the development of modern biological techniques it is becoming ever easier to transfer genes from wild relatives into crops. In the case of rice, for example, many modern varieties of *Oryza sativa* include a gene conferring resistance to the grassy stunt virus from the related species *Oryza nivara*. A gene for hairy stems and leaves has been transferred from *Solanum berthaltii* to the potato, thereby conferring resistance to insects, and scientists are broadening the genetic base of bread wheat, *Triticum aestivum*, through reconstituting the species from its three progenitors: *Triticum uratu*, *Aegilops speltoides* and *Triticum tauschii*.

In vitro cassava germplasm collection (CIAT)

While modern biotechnology has made it possible to transfer genes across species, genera, families and even kingdoms, the genepool of a crop and its close relatives remains a highly important source of useful genes for crop improvement. The value of crop genepools is continually increasing as knowledge about them grows and as modern molecular techniques make it ever easier to identify potentially useful genes – and their variants known as alleles – within them.

Threats to diversity

In spite of its importance, crop genetic diversity is under threat in many parts of the world. Diversity is lost as farmers switch to new crops in response to changing demands, abandoning their old ones. Genetic diversity is also lost when farmers replace obsolete varieties with ones that better meet their immediate needs and circumstances. The problem became particularly acute in the late 1960s and throughout the 1970s and 1980s as the Green Revolution took hold, especially in Asia. While dramatic production increases ensued, one undesirable side effect was the replacement of thousands of traditional local farmer varieties and landraces with a small handful of closely related, high yielding semi-dwarf wheat and rice varieties.

While the number of varieties under production in a given area provides only an approximate indicator of genetic diversity (the genetic relatedness among the varieties, for example, must also be taken into account) some of the statistics tell a compelling story: in Sri Lanka approximately 2,000 varieties of rice were grown in 1959 compared with just 5 major varieties today and in India where it was estimated that more than 30,000 rice varieties were once being grown, today 75% of the production comes form less than 10 varieties. In the USA 50% of the wheat crop comes from just 9 varieties and 75% of the potatoes come from just 4 varieties. A U.S. Department of Agriculture inventory of seeds that were available from catalogues in 1984 showed that only 3 per cent of the seeds listed in a similar USDA inventory conducted in 1903 were still available commercially. Of the 7,000 apple varieties available in the U.S. in 1900, over 5,000 had been lost and the remaining number was steadily declining

Ochoa (1975)[1] reported that on the Chilean island of Chiloé collectors had found approximately 200 primitive potato varieties in 1928 and 1938 but not much more than half that number in 1948, even fewer in 1958, and only 35-40 in 1969. Similar results were reported in northern Peru where collecting in one village yielded 25 native samples in 1955 and none in 1970.

The problem is also serious for the wild relatives of many crops. It has been estimated[2] that within the *Poaceae*, the family to which the world's major cereal crops belong, some 476 species, or approximately 6% of the total, are threatened and of these 88 are classified as endangered. Within the pea and bean family (*Leguminosae*), 2205 species, representing 22% of the family, are threatened and of these some 400 are endangered and 22-36 have recently become extinct. In the *Solanaceae*, the family to which potato, tomato and peppers belong, 13% (220 species) are considered threatened, with 41 endangered and 2 believed to have recently become extinct. With every population or species lost, we lose options for the future.

Conservation strategies

What can we do about these threats to genetic diversity? There are a number of conservation options. Wild relatives of crops are generally best maintained under *in situ* conditions, in national parks, nature reserves or in other specially protected and managed areas. A recent joint report by WWF, Equilibrium and the University of Birmingham[3] calls attention to the need for much greater efforts to conserve wild relatives of crops through the use of protected areas.

Traditional farmer varieties can be conserved through maintaining them on farmers' fields, so-called 'on-farm conservation'. The development and promotion of new products and marketing opportunities for traditional varieties can increase their value and production can become profitable again. The expanding demand for greater diversity and novelty in diets, a growing emphasis on the importance of more 'natural' products, and an increasing recognition of the cultural – and often nutritional – value of traditional foods all favour the continued production of traditional crops and varieties. Niche marketing and agrotourism provide mechanisms for capturing these benefits as does the entry of supermarket chains into this field. The recent rise of the heirloom variety movement for fruits and vegetables – particularly in richer nations - is also having a very positive effect on the conservation of traditional varieties by farmers, smallholders and gardeners. However, if on farm conservation is to be successful, any measures put in place to promote it must be sustainable. Conservation based on short-term fads, payments to farmers for growing obsolete varieties or measures put in place pending the development of new, improved varieties do not offer realistic conservation options for the longer term.

Whatever action is taken to conserve wild relatives and traditional crop varieties under *in situ* conditions or on farmers' fields, in many circumstances there is no option but to conserve materials *ex situ*. Crops that produce orthodox seeds (i.e. seeds that can be dried and cooled), such as most cereals and pulses, can be stored at low temperatures in seed genebanks. Seeds held at -18°C in a cold store, or even a domestic deep-freezer can be conserved for decades without losing significant viability. Crops that are vegetatively propagated such as potato, that do not produce orthodox seeds such as many tropical fruits, or that are sterile and do not produce seed at all such as the banana, are all best maintained as living plants or tissues. They can be conserved as collections of plants growing in specially managed field genebanks, or as plantlets or tissues in test tubes maintained *in vitro* in facilities where temperature, light and the growth medium are all carefully controlled. Increasingly it is possible to cryo-preserve plant tissues and conserve them for decades in liquid nitrogen at -196°C. In addition, plant genetic resources can be conserved as pollen or even in the form of DNA – physically or as sequence data.

Status of *ex situ* conservation

While recognizing the importance of conserving and managing crop genetic diversity under *in situ* conditions and on farmers' fields, it is nevertheless arguable that *ex situ* conservation remains the most vital conservation system for the future of agriculture. Plant germplasm collections greatly facilitate access to genetic resources for crop improvement and they are a resource that increases in value over time as more information and knowledge is built up about the material within them. It would be impossibly complicated and expensive if new materials had to be freshly collected from the wild or from farmers' fields every time a plant breeder needed new genetic diversity.

Although considerable plant collecting was carried out over the period from the 1960s to 1980s in the wake of the Green Revolution, growing concerns during the 1980s and 1990s about the ownership of genetic resources and access rights to them led to a slowdown in collecting and exchange, and to fewer resources being allocated for the upkeep of genebanks. The situation was exacerbated by the growing influence of the environmental movement, which strongly favoured *in situ* over *ex situ* conservation, making it ever more difficult to secure funding for the latter in spite of its importance to agriculture.

According to FAO[4], in a report prepared for the 4th International Technical Conference on Plant Genetic Resources held in Leipzig in 1996, in 1970 there were less than 10 genebanks throughout the world. As a result of the collecting efforts of the 1970s and 1980s, by 1995 there were almost 1500 genebanks located in 150 countries. Approximately 400 of these, in 75 countries, had some medium and/or long-term storage capability but only 35 genebanks met international standards for long-term storage. In 1995 more than 6 million samples were maintained in genebanks worldwide, but only 1-2 million of these were considered "unique", i.e. there was a very high level of duplication of the same samples among different genebanks. Most of the samples were in the form of seeds with less than 10% maintained as plants growing in field genebanks and only about 38,000 were held within *in vitro* facilities, indicating that species that do not produce orthodox seeds, including many fruits and vegetables, were under-represented in collections. Up to 1 million samples were judged to be in urgent need of regeneration and there were adequate passport data on only about 50% of samples in national collections.

In 2002, a report by Imperial College Wye[5] stated that over the 5-year period (1996 - 2000) following the publication of the original FAO report, there were few major changes in the size and distribution of collections, although they had increased slightly in 77% of countries. However, in spite of the pledges made by governments at Leipzig to give more attention to plant genetic resources, approximately 7% of the 98 countries surveyed had lost portions of their collections, budgets had remained static or declined in 65% of countries and regeneration backlogs had increased in 66% of developing countries. Overall, the situation was considerably worse in developing than in developed countries. The report concluded that there was an urgent need for long-term, stable and sustained funding.

International policies for the conservation and use of PGRFA

Plant genetic resources have been the subject of political controversy and social tension for centuries - probably since crops were first domesticated. Disputes over who owns them, who has the right to control access to them and who should benefit from their use have been long and contentious. Until the late 1980s and early 1990s a dominant view was that plant genetic resources for food and agriculture (PGRFA) are an international public good. This view was enshrined in the International Undertaking on Plant Genetic Resources, an agreement that was adopted in 1983 and adhered to by 118 countries[6]. It states in its preamble that: *"This Undertaking is based on the universally accepted principle that plant genetic resources are a heritage of mankind and consequently should be available without restriction."*

Throughout the 1980s and 1990s there was growing concern, especially among many developing countries and NGOs, that while the landraces produced by the activities and intellectual endeavors of generations of farmers and indigenous communities were considered a public good, increasingly the varieties developed from them through the action and intellectual endeavors of scientists and plant breeders were becoming protected. At first such protection was largely afforded through the rather mild protection of Plant Breeders Rights, but concerns grew with the increasingly use of the much stronger protection afforded by patents. Accusations of biopiracy were rife and pressures mounted for an international agreement that would recognize the rights of all countries to control access to the genetic resources found within their borders and that would ensure a fair and equitable sharing of the benefits arising from their use.

An international agreement that attempted to address such issues, the Convention on Biological Diversity (CBD)[7], came into force in late 1993. However, it arose largely from the environment movement and had only little, and late input from agriculturalists. The Convention recognizes the right of each country to negotiate the terms by which access would be granted to the biological diversity that originated within its borders – an approach that has been widely interpreted as promoting bilateralism. While it might be argued that such bilateralism is relevant for genetic resources for industrial or pharmaceutical use, it is certainly less appropriate in most agricultural situations. It is hard, if not impossible to determine the county of origin of most crop genetic resources; they have crossed national borders and even continents freely for centuries. Furthermore there is a very high degree of inter-dependence among all countries with respect to PGRFA, and a modern crop variety might well include parents originating from more than a dozen countries in its pedigree. In part because of this complexity and in part because of the difficulty of setting up the systems and mechanisms necessary for implementing the CBD, the years following its coming into force saw a significant downturn in the amount of collecting and international exchange of PGRFA.

Recognizing this situation, FAO convened negotiations for a new international agreement tailored specifically for crop genetic resources. The agreement, known as the International Treaty on Plant Genetic Resources for Food and Agriculture[8], came into force in 2004 and has to date been ratified by 116 countries. The centrepiece of the treaty is the creation of a multilateral system for access and benefit sharing. The system covers 35 of the world's most important food crops as well as 30 forage genera. These are to be shared under the terms of a standard material transfer agreement that lays out a uniform set of procedures and benefit sharing mechanisms to which all parties must adhere. While there are still some final details remaining to be negotiated, the coming into force of the International Treaty is a landmark in the history of plant genetic resources. For the first time there is an internationally agreed and legally binding set of rules and procedures governing access to PGRFA and the sharing of any benefits that arise from its use for food and agriculture.

Some recent institutional developments

As was pointed out earlier, many collections of crop diversity are in great need of additional financial support. Recognizing this, in 2004 FAO and the International Plant Genetic Resources Institute (IPGRI, now Bioversity International), acting on behalf of the Consultative Group on International Agricultural Research (CGIAR), established the Global Crop Diversity Trust as an independent foundation under international law[9]. The Trust seeks to fund the world's most important germplasm collections through grants for upgrading and capacity building as well as for their long-term maintenance. The ability to provide sustainable funding for collections over the long term is being sought through the creation of an endowment fund which has the target of raising US$260 million. To date the Trust has raised almost US$150 million with over US$100 million of this for the endowment fund.

In another recent development, the government of Norway has constructed a seed storage facility within the permafrost deep inside a mountain on the island of Spitsbergen in the Svalbard archipelago, some 800 miles from the North Pole. The facility, known as the Svalbard Global Seed Vault, has been built to house up to 6 million samples of plant germplasm and maintain them at -18°C under what are probably the most secure conditions to be found anywhere on the planet. The operational expenses of the Vault will be covered by the Global Crop Diversity Trust and the facility is being offered to genebanks throughout the world for them to house duplicate sets of their collections for additional security. The facility will be officially opened on 26th February, 2008 and it is expected that on that day more than a quarter of a million samples will be deposited in the Vault for safekeeping.

Conclusions

Crop diversity is arguably one of humanity's most important resources in the fight against poverty and malnutrition and for facing the challenges of the future. However, these resources have suffered from many years of comparative neglect and many important collections are in urgent need of financial support. In the words of the World Bank's 2008 World Development Report[10]:

> ***"Conserving the world's rich heritage of crop and animal genetic diversity is essential to future global food security. Gene banks and in situ resources that provide fair access to all countries and equitably share the benefits are a global public good that requires global collective action."***

Some recent developments give cause for optimism. These include the new International Treaty on Plant Genetic Resources for Food and Agriculture that came into force in 2004, the establishment of the Global Crop Diversity Trust in the same year and the opening in 2008 of the Svalbard Global Seed Vault, a facility that will provide additional security for the world's most important collections.

Entrance to the Svalbard Global Seed Vault *(Mari Tefre/Global Crop Diversity Trust)*

Seed boxes on shelves in the Svalbard Global Seed Vault *(Mari Tefre/Global Crop Diversity Trust)*

Notes:

1 Ochoa, C. 1975. Potato Collecting Expeditions in Chile, Bolivia and Peru, and the Genetic Erosion of Indigenous Cultivars. In: H. Frankel and J.G. Hawkes, eds. *Crop Genetic Resources for Today and Tomorrow*. International Biological Programme 2. pp. 167-173. Cambridge University Press, Cambridge

2 Walter, K.S. and H.J. Gillett. 1998. 1997 IUCN *Red List of Threatened Plants*. The World Conservation Union

3 Stolton, S., N. Maxted, B. Ford-Lloyd, S. Kell and N. Dudley. 2006. *Food Stores: Using Protected Areas to Secure Crop Genetic Diversity*. A research report by WWF, Equilibrium and the University of Birmingham, UK. WWF – World Wildlife Fund for Nature.

4 FAO, 1996. *State of the World's Plant Genetic Resources for Food and Agriculture*. FAO, Rome, Italy.

5 Imperial College Wye, 2002. *Crop Diversity at Risk: the Case for Sustaining Crop Collections*. Imperial College Wye, UK.

6 For the text of the International Undertaking see: http://www.fao.org/AG/CGRFA/iu.htm

7 For the text of the Convention on Biological Diversity see: http://www.cbd.int/

8 For the text of the International Treaty on Plant Genetic resources for Food and Agriculture see: http://www.planttreaty.org/

9 For further information on the Global Crop Diversity trust see: http://www.croptrust.org/

10 World Bank, 2007. *World Development Report 2008: Agriculture for Development*. World Bank, Washington, DC, USA.